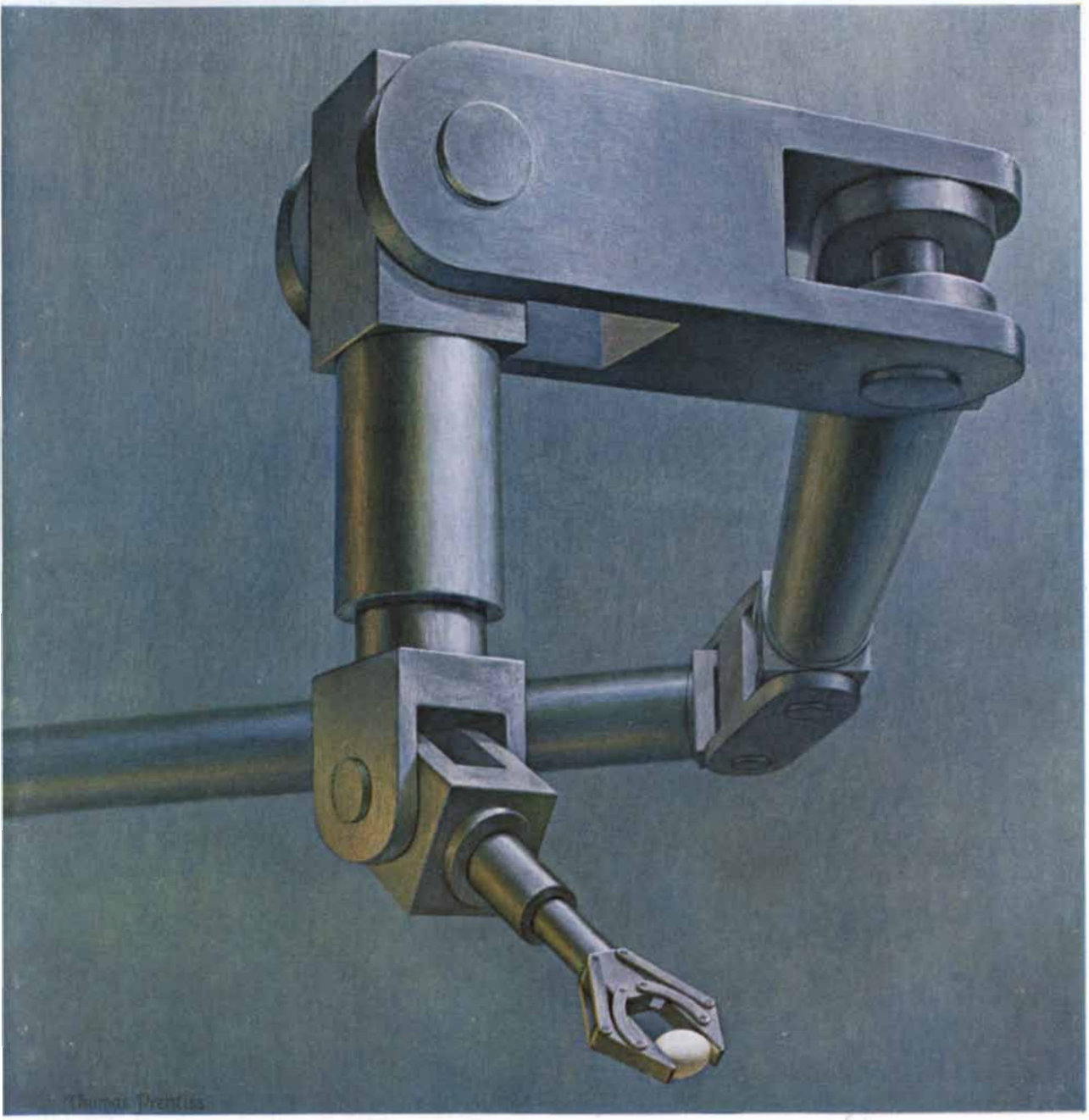
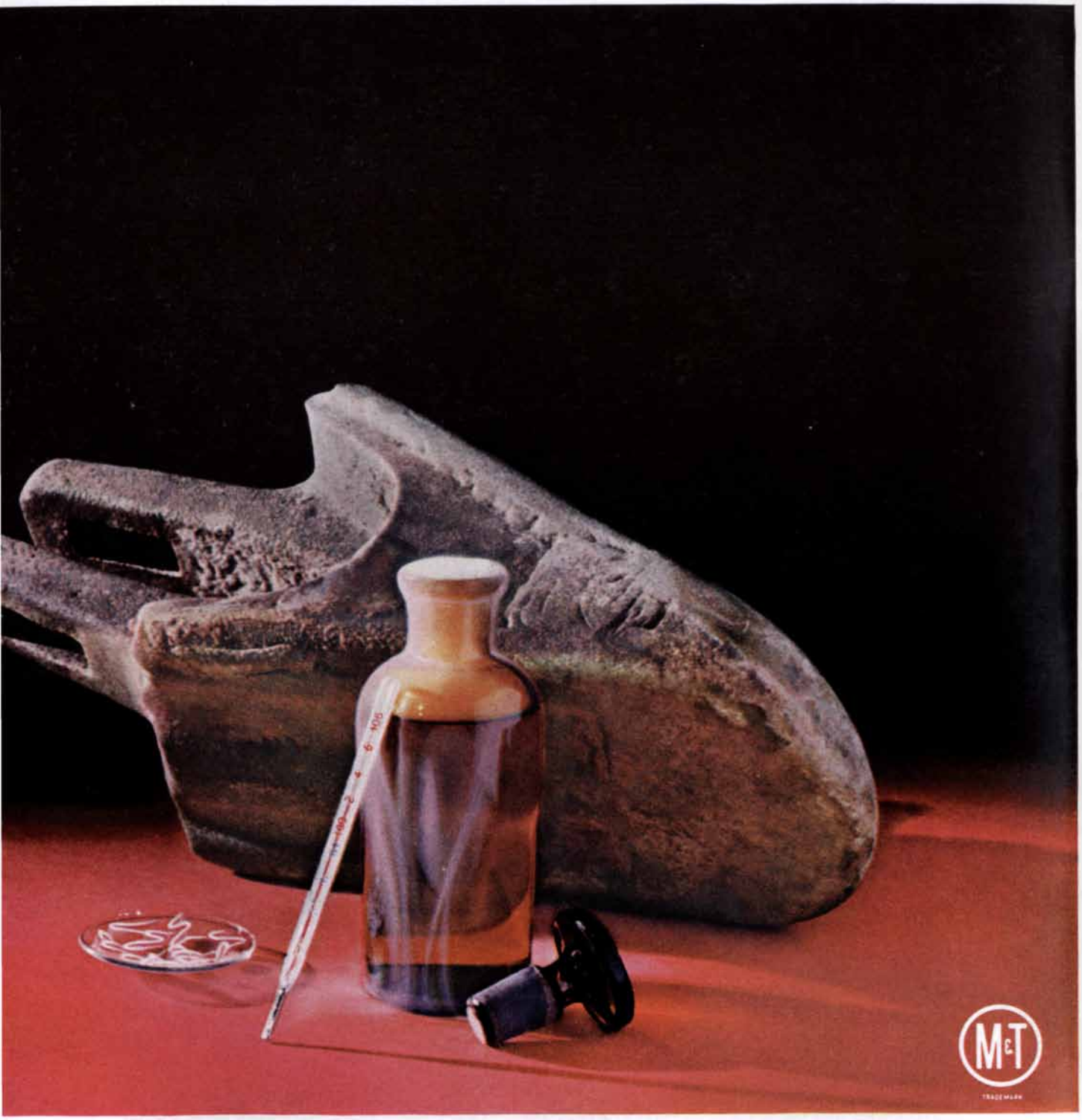
# SCIENTIFIC AMERICAN



INDUSTRIAL MANIPULATORS

SIXTY CENTS

October 1964



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

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

Four examples:

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

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

Acids can eat through strong steels. Yet a thin porcelain enamel containing M&T Sodium Antimonate stops them; M&T Vinyl Plastisol linings also resist them effectively.

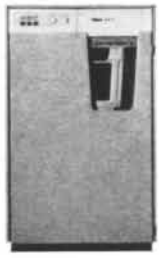
Even though they're the toughest of steels, power shovel teeth blunt their bite on rock and dirt. Not nearly so soon when a layer welded with M&T Murex* Hard-Surfacing Electrodes takes the abrasion.

There are many more ways that M&T's work protects man and his materials. To see what we may have for your problem, write or phone M&T Chemicals Inc., General Offices, Rahway, N. J.... or M&T Products of Canada Ltd., Hamilton, Ont.

**M&T Chemicals Inc.**

*Trademark of M&T Chemicals Inc.

# Why use one CRAM unit for linear programming?



## (Four or five magnetic tape files will do the job almost as well.)

It's true. There are other general-purpose computers which can solve both your business and scientific problems. But the NCR 315 can meet your Linear Programming needs with just one magnetic card file (CRAM). Other systems can require as many as five magnetic tape files to equal CRAM'S speed in coping with linear program parameters. (300 constraints; up to 1500 variables)

Why? Because CRAM's random access capabilities enable the programmer to bring variables into main memory instantly – without the many lengthy tape searches required with conventional tape-drives.

Whatever your primary need for a computer, check the advantages of NCR Linear Programming. It has solved such diverse management problems as cut and trim in paper box construction, the most economical blend for sausage, and the most efficient route for ships carrying cargo from port to port. For a general-purpose computer to handle both your business and scientific problems, you'll like the NCR 315 with CRAM.

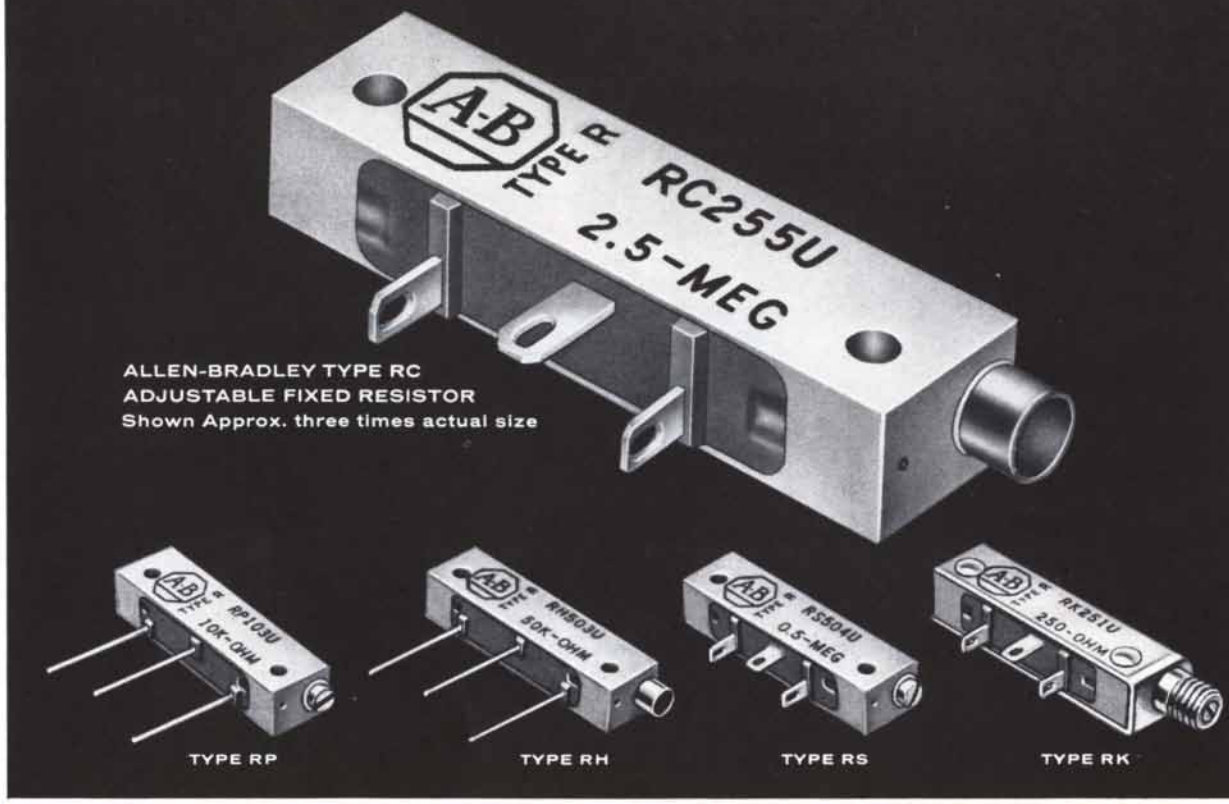
You can obtain complete details from your local NCR representative. Or write to NCR, Dayton, Ohio 45409.

NCR

BE SURE TO VISIT THE NCR PAVILION AT THE NEW YORK WORLD'S FAIR.

THE NATIONAL CASH REGISTER COMPANY ®

# Allen-Bradley hot molding gives precise, stable control in severe environments




■ You can be certain of "Quality" in performance when you use Allen-Bradley hot molded, adjustable resistors. Their solid resistance and collector tracks—made by A-B's exclusive hot molding process—provide such smooth control that it approaches infinite resolution. The discrete steps from turn to turn of wire-wound units, as well as transients during operation are eliminated. Settings remain fixed under severe shock and vibration. You'll find Type R controls ideal for use at high frequencies—where conventional wire-wound controls are entirely unsatisfactory—they have low distributed capacity and are relatively noninductive. The molded enclosure of the Type R unit is both dustproof and watertight, permitting encapsulation.

Allen-Bradley Type R resistors are suitable for use from −55°C to +125°C and are rated ¼ watt at 70°C, 300 volts max. RMS. Available in total resistance values from 100 ohms to 2.5 megohms with tolerances of ±10% or ±20%. For more complete details on the Type R control, please send for Technical Bulletin B5205: Allen-Bradley Co., 1204 South Third Street, Milwaukee, Wisconsin 53204.

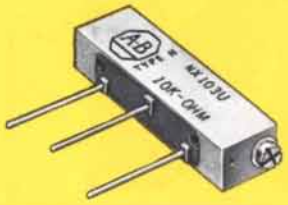
In Canada: Allen-Bradley Canada Ltd., Galt, Ontario.

## NEW TYPE N HOT MOLDED PERFORMANCE FOR LESS CRITICAL ENVIRONMENTS

**Here's an addition to the Allen-Bradley line of quality adjustable fixed resistors. It features the same solid hot molded resistance and collector tracks . . . the same stepless adjustment . . . stability . . . and high frequency characteristics.**

**The molded enclosure is splashproof and dust-tight, and using proper measures, it can be encapsulated. The adjusting screw has a handy new cross slot. It accepts conventional flat blade or Phillips type screwdriver which eliminates screwdriver dropout during adjustment.**

**The new Type N control is rated 1/3 watt at 50°C, 300 volts max., and derates to zero power at 100°C. Available in total resistance values from 100 ohms to 2.5 megohms. Please write for complete specifications.**




A-B QUALITY

**ALLEN-BRADLEY**

QUALITY ELECTRONIC COMPONENTS

Established 1845 **SCIENTIFIC AMERICAN** October 1964 Volume 211 Number 4

ARTICLES



DEPARTMENTS





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## THE COVER

The painting on the cover is an idealized representation of a manipulator, a device for extending the reach and power of the human hand (see "Industrial Manipulators," page 88). These devices have already been developed for such specialized purposes as manipulating radioactive components inside a nuclear reactor and performing operations in a "hot chemistry" laboratory. They are also being investigated for their potential usefulness in more commonplace tasks, including the automatic performance of repeated manipulative operations in industrial processes. A key principle in the development of such machines is the use of feedback to enable the human operator to "feel" the pressure exerted by the grasp of the machine. The success of the application of this principle is symbolized in the painting by the fact that the object that is shown being manipulated is an egg.

## THE ILLUSTRATIONS

Cover painting by Thomas Prentiss

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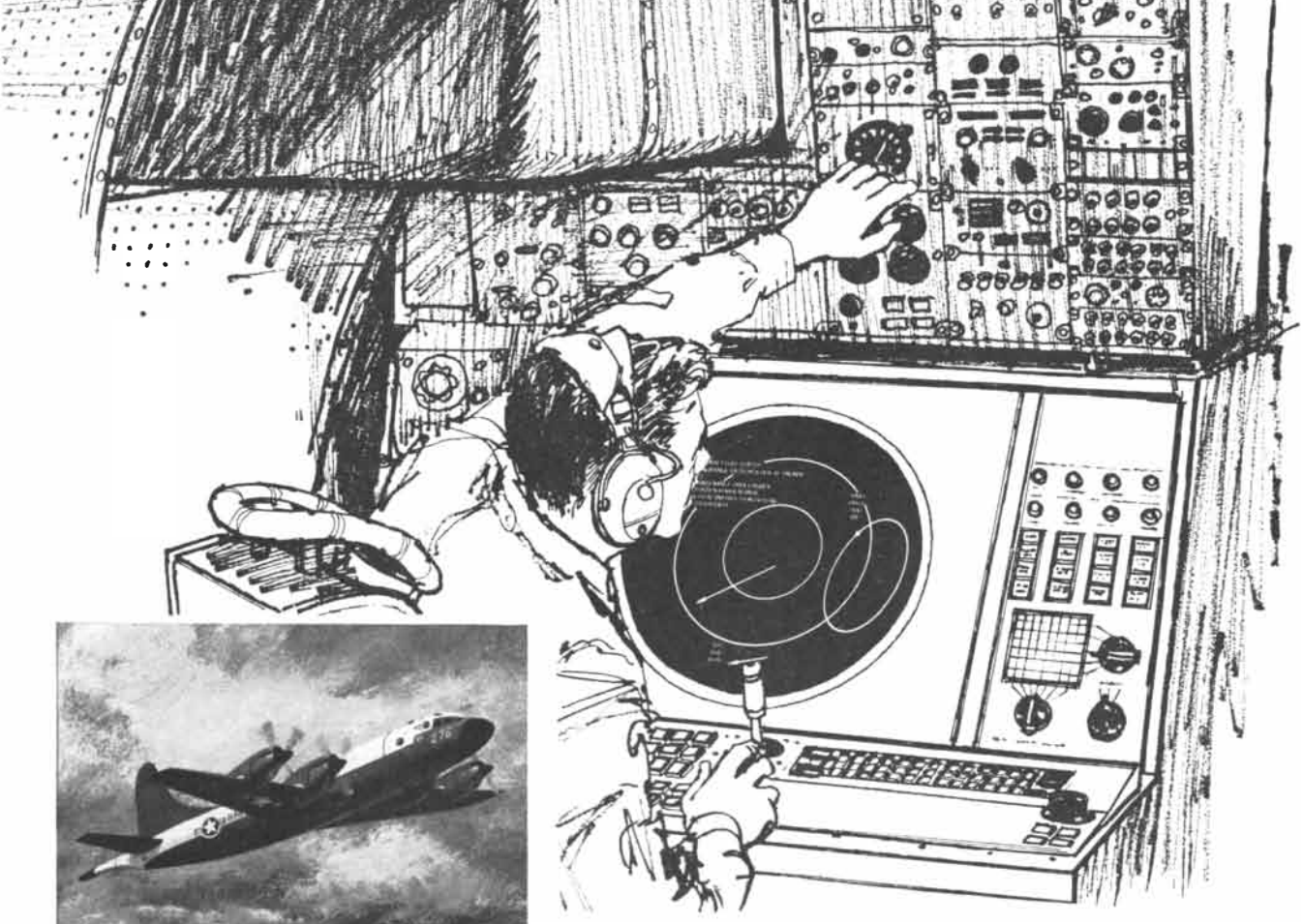


# New airborne computer display allows immediate analysis of tactical situations

The most comprehensive situation display ever provided a pilot and crew of an aircraft has been developed for the U.S. Navy's A-New program, a project of the Naval Air Development Center, Johnsville, Pa. General Dynamics developed the airborne display console which operates with the Navy's new airborne digital computer system being developed for anti-submarine warfare. The display takes commands from the computer which considers all data received from the electronic sub-hunting equipment, communications links and other sources.

Information which may be visually presented to the airborne tactical coordinator includes text and tabular data on such factors as tactical and navigational problems. Situation maps showing locations of possible targets and other ships and planes in the area may be presented.

Using the CHARACTRON® Shaped Beam Tube, the versatile display presents high resolution alphanumerics by extruding an electron beam through a matrix etched with characters and symbols. Vectors are drawn with a spot writing mode. This data may be mixed with information recorded on a scan converter tube or other electrical storage device. Externally generated figures may be displayed using the electron beam on a time shared basis. Advanced versions will be able to combine live TV and radar data with alphanumerics and vectors generated by the computer.

Initial display equipment is a compact rugged version of the S-C 1090 standard display console which is capable of operating in the high vibration environment of an aircraft flying either at high altitude or close to the water. To adapt the console to airborne use, a special CHARACTRON display tube was developed which is only 27½ inches long, compared to a standard 42 inches. Innovations in tube design reduce the length and create remarkably high resolution for display applications where space is at a premium.

Present system developments include seven displays in varying sizes for presentation of data to various ASW aircraft crew members. Several of these displays will be portable and interchangeable. These displays are another *operating* example of Stromberg-Carlson's capability to supply reliable answers to display problems.

For more information on advanced displays, write Stromberg-Carlson–San Diego, Dept. E-44, P. O. Box 127, San Diego, Calif. 92112.

**STROMBERG-CARLSON**

A DIVISION OF **GENERAL DYNAMICS**

# At SDS we believe in 100¢ dollars, 60,000,000 μsec minutes, and SDS computers.

**SDS 92** – $29,000 with 2048 words of memory, Control Console, Buffered I/O Channel and Model 35 Teletype Printer.

Basic core memory of 2048 words, expandable to 32,768 words, all directly addressable. Memory "Scratch Pad" for immediate access to operands, addresses, and temporary storage. Hardware Index Register; indexing requires no additional time. One standard and any number of optional buffered I/O channels with rates to 572,000 words per second. Up to 256 levels of priority interrupt.

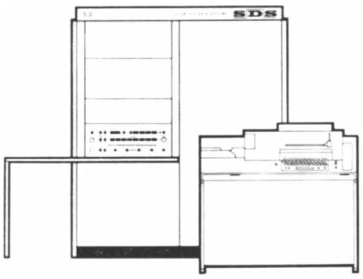
Memory cycle time: 1.75 μsec

Execution times, including all accesses and indexing:

**Fixed Point**

(12 bits plus a parity bit)

| | |
|---|---|
| 3.5 μsec | Add |
| 7.0 μsec (optional) | Multiply |



**SDS 910** – $45,000 with 2048 words of memory, Control Console, Buffered I/O Channel and Model 35 Teletype Printer with Paper Tape Reader and Punch.

Basic core memory of 2048 words, expandable to 16,384 words, all directly addressable. One standard and one optional buffered I/O channel with rates to 62,500 words per second. Up to 1024 levels of priority interrupt.

Memory cycle time: 8.0 μsec

Execution times, including all accesses and indexing:

**Fixed Point**

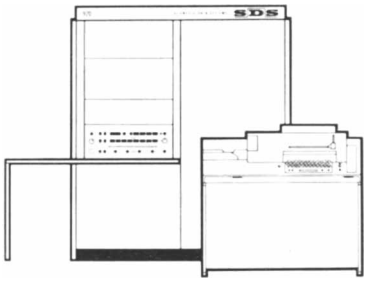
(24 bits plus a parity bit)

| | |
|---|---|
| 16.0 μsec | Add |
| 248.0 μsec | Multiply |

**Floating Point**

(24-bit frac., 9-bit exp. 39-bit frac., 9-bit exp.)

| | | |
|---|---|---|
| 432.0 μsec | Add | 896.0 μsec |
| 464.0 μsec | Multiply | 1696.0 μsec |



**SDS 920** – $65,000 with 4096 words of memory, Control Console, Buffered I/O Channel and Model 35 Teletype Printer with Paper Tape Reader and Punch. Up to 1024 levels of priority interrupt.

Basic core memory of 4096 words, expandable to 16,384 words, all directly addressable. One standard and one optional buffered I/O channel with rates to 62,500 words per second.

Memory cycle time: 8.0 μsec

Execution times, including all accesses and indexing:

**Fixed Point**

(24 bits plus a parity bit)

| | |
|---|---|
| 16.0 μsec | Add |
| 32.0 μsec | Multiply |

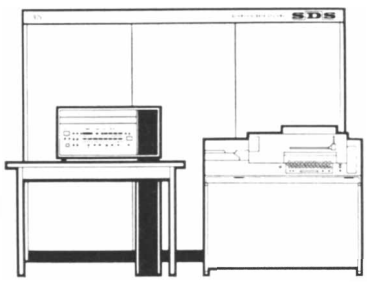
**Floating Point**

(24-bit frac., 9-bit exp. 39-bit frac., 9-bit exp.)

| | | |
|---|---|---|
| 352.0 μsec | Add | 384.0 μsec |
| 248.0 μsec | Multiply | 656.0 μsec |

When you buy an SDS computer, you get a full measure of value, speed, reliability, programming and systems support. Designed for engineering and scientific applications and real-time systems integration, SDS computers are the fastest and most powerful machines you can get for the money. High internal computing speeds, powerful instructions and efficient input/output systems ensure maximum speed and flexibility for a wide variety of applications. The continually growing program library contains FORTRAN II and IV, ALGOL, symbolic assemblers and meta-assemblers, executive routines and standard mathematical calculations. Rugged mechanical design, exclusive use of silicon semiconductors, high noise tolerance, and well-planned circuitry mean error-free operation even in less than favorable environments. With SDS computers you get more answers faster at lower cost and with greater reliability than with any other general purpose digital computers on the market today.

If you believe in 100¢ dollars and 60,000,000 μsec minutes and if you would like to know more about SDS computers, just send the coupon on the following page to Scientific Data Systems, 1649 Seventeenth Street, Santa Monica, California.



**SDS 925** – $82,500 with 4096 words of memory, Control Console, Time Multiplexed Communication Channel and Model 35 Teletype Printer with Paper Tape Reader and Punch.

Basic core memory of 4096 words, expandable to 16,384 words, all directly addressable. One standard and any number of optional buffered I/O channels with rates to 572,000 words per second. Up to 1024 levels of priority interrupt.

Memory cycle time: 1.75 $\mu$sec

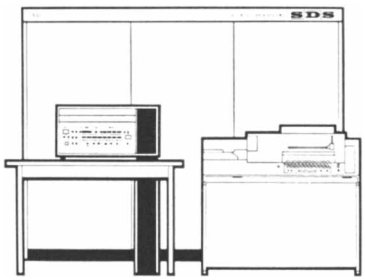
Execution times, including all accesses and indexing:

**Fixed Point**
(24 bits plus a parity bit)

| | |
|---|---|
| 3.5 $\mu$sec | Add |
| 54.25 $\mu$sec | Multiply |

**Floating Point**
(24-bit frac., 9-bit exp. 39-bit frac., 9-bit exp.)

| | | |
|---|---|---|
| 95.5 $\mu$sec | Add | 196.0 $\mu$sec |
| 101.5 $\mu$sec | Multiply | 371.0 $\mu$sec |



**SDS 930** – $96,500 with 4096 words of memory, Control Console, Time Multiplexed Communication Channel and Model 35 Teletype Printer with Paper Tape Reader and Punch.

Basic core memory of 4096 words, expandable to 32,768 words, all directly addressable. One standard and any number of optional buffered I/O channels with rates to 572,000 words per second. Input/output simultaneous with computation. Up to 1024 levels of priority interrupt.

Memory cycle time: 1.75 $\mu$sec

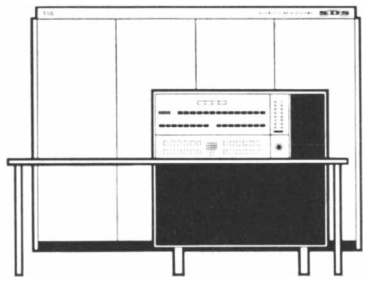
Execution times, including all accesses and indexing:

**Fixed Point**
(24 bits plus a parity bit)

| | |
|---|---|
| 3.5 $\mu$sec | Add |
| 7.0 $\mu$sec | Multiply |

**Floating Point**
(24-bit frac., 9-bit exp. 39-bit frac., 9-bit exp.)

| | | |
|---|---|---|
| 74.0 $\mu$sec | Add | 83.0 $\mu$sec |
| 54.0 $\mu$sec | Multiply | 138.0 $\mu$sec |



**SDS 9300** – $150,000 with 4096 words of memory, Control Console and Time Multiplexed Communication Channel.

Basic core memory of 4096 words, expandable to 32,768 words, all directly addressable. One standard and any number of optional buffered input/output channels with rates to 572,000 words per second. Input/output simultaneous with computation up to 1024 levels of priority interrupt.

Memory cycle time: 1.75 $\mu$sec

Execution times, including all accesses and indexing:

**Fixed Point**
(24 bits plus a parity bit)

| | |
|---|---|
| 1.75 $\mu$sec | Add |
| 3.5 $\mu$sec | Double Precision Add |
| 7.0 $\mu$sec | Multiply |
| 5.25 $\mu$sec | Shift (24 positions) |

**Floating Point** (with optional hardware)
(39-bit frac., 9-bit exp.)

| | |
|---|---|
| 14.0 $\mu$sec | Add |
| 12.25 $\mu$sec | Multiply |

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1649 Seventeenth Street, Santa Monica, Calif.

Sales offices in New York, Boston, Washington, Philadelphia, Pittsburgh, Huntsville, Orlando, Chicago, Houston, Albuquerque, San Francisco. Foreign representatives: Instronics, Ltd., Stittsville, Ontario, CECIS, Paris; F. Kanematsu, Tokyo; RACAL, Sydney.

Please send me literature on the following SDS computers:

☐ SDS 92 ☐ SDS 910 ☐ SDS 920
☐ SDS 925 ☐ SDS 930 ☐ SDS 9300

Name _____
Company _____
Address _____
City _____ State _____

# At SDS your 100¢ dollar buys you 60,000,000 μsec minutes, SDS computers and...

## LARGE PROGRAM LIBRARY

With the purchase or lease of an SDS computer, you automatically receive programs from the large SDS program library. The continually growing library includes compilers, assemblers, FORTRAN, ALGOL, and a wide variety of mathematical and utility subroutines. A few of the automatic programs are:

**SYMBOL** – This two-pass assembly program provides for input of symbolic programs from typewriter, paper tape, cards or magnetic tape. SYMBOL also recognizes a variety of generative and non-generative directives that aid the small-computer user in coding and checking out his programs.

**META-SYMBOL** – A superset of SYMBOL, this advanced symbolic processor brings compiler-level capability to the machine-language programmer. META-SYMBOL has function and procedure capability permitting the programmer to code in a high-level, machine-independent language.

**FORTRAN II** and **IV** – SDS FORTRAN II combines high speed, flexibility and efficient object code, even in systems with only 4096 words of memory. SDS FORTRAN IV is an extended version of FORTRAN systems including SDS FORTRAN II, IBM FORTRAN IV and ASA FORTRAN IV.

**REAL-TIME FORTRAN II** – This expanded version of SDS FORTRAN II enables SDS computers to operate efficiently in real-time environments.

**MONARCH** – This monitor is a batch-oriented operating system providing large-scale processing power for SDS digital computers. MONARCH operates under typewriter or card control and allows batched assemblies, compilations and executions.

**HELP** – The HELP utility programming system aids the small-machine user in the checkout and operation of machine language programs. HELP is completely modular so the programmer needs to load only applicable parts.

**ALGOL – SDS ALGOL** represents the most comprehensive implementation of ALGOL 60. It is available in two systems: a one-pass basic system and a two-pass expanded system. An input/output facility similar to that of FORTRAN is incorporated into the language.

Programs and programming information are exchanged among members of the SDS Users Group at regularly scheduled meetings. In addition to their influence on SDS programming packages, the SDS Users Group is a major factor in determining hardware developments and new products.

## FLEXIBLE PERIPHERAL EQUIPMENT

A wide range of compatible peripheral equipment is available for all SDS computers: card readers and punches, paper tape I/O units, line printers, magnetic tape units, digital plotters, magnetic drums and discs, oscilloscopes and other displays. Peripheral devices can be used interchangeably with all SDS computer systems.

**MAGPAK,** a special SDS low cost magnetic tape system, brings the operating efficiency of large-scale computer systems to the small computer user. Every Magpak unit contains two independent drives, each of which provides two independent data channels with a transfer rate of 1,500 characters per second. Storage capacity is approximately six million 6-bit characters. Programs written for Magpak and SDS standard IBM-compatible magnetic tape units are exactly alike.

## FIELD SERVICE

SDS field service engineers in numerous cities across the country give your SDS computer equipment the kind of preventive maintenance that means trouble-free operation. Parts depots in strategic locations ensure quick equipment replacement and repair.

## DATA COMMUNICATIONS

SDS Data Communications Equipment provides all SDS computers with multi-channel communication through common carrier or privately owned transmission facilities and terminal equipment. SDS computers may be used in applications and systems such as time-sharing systems in which the computer's capacity is time-shared among several users located in remote areas; inquiry-answer systems in which the computer maintains centralized files, processes inquiries, and presents answers in fields such as reservations, inventory, production control, and management reporting; message switching systems in which written message communications of all types are automatically accepted, stored, and dispatched to their proper destinations; remote data processing systems in which a centralized computing facility accepts data from remote locations, processes the data (possibly incorporating it into centralized files) and transmits resulting reports to the proper remote sites; and inter-computer communication systems in which data is transmitted at relatively high speeds between two remotely located data processing systems.

## SDS LOGIC MODULES & SYSTEM COMPONENTS

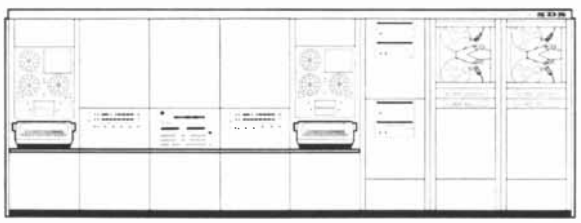
SDS provides a wide range of all-silicon circuit modules that are completely compatible with the circuitry used in SDS computers and peripheral equipment. These logic modules can also be used independently. SDS circuit modules feature high speed, exceptional reliability, and an extremely high level of noise rejection.

In addition to circuit modules, SDS manufactures a complete line of A/D Converters, Multiplexers, D/A Converters and Amplifiers. These units operate directly with SDS computers with no additional interface. For maximum reliability, integrated circuits are used extensively in SDS components.

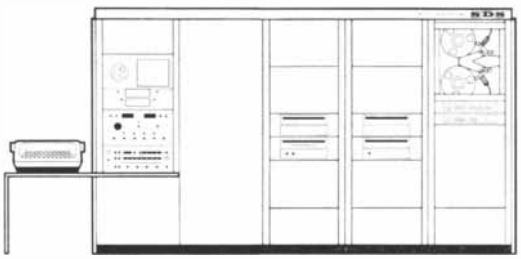
# FREE SYSTEMS ENGINEERING

SDS systems engineers will help you integrate SDS equipment into your existing computer installation. Or they will design, engineer and check out, without charge, a new digital system if it contains 80% SDS equipment. You get a complete, fully checked out, computer controlled data system with diagnostic programs – custom engineered to your specific application – for only the total cost of the components. The wide line of SDS equipment available allows most requirements to be met with standard off-the-shelf hardware. That means you can save up to 25% of the total cost of your digital system with SDS engineering and equipment.

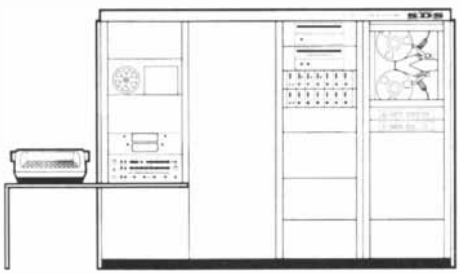
Typical SDS-built systems include:



JPL's digital instrumentation systems are based on two multiplexed SDS computers. They read telemetry data, convert it to digital, process and record the data on magnetic tape at tracking stations around the world.



Dow Chemical Company combines an SDS 910 and a general purpose analog computer for chemical process simulation. The SDS system provides analog outputs and accepts analog inputs for hybrid operation of the computers.



Edwards Air Force Base uses a system built around the SDS 910 for rocket engine testing. The system receives test data, analyzes it and stores the results on magnetic tape.

To learn what kind of computers your 100¢ dollar buys you at SDS, turn back one page. To learn more about SDS computers systems and services, send the coupon below to Scientific Data Systems, 1649 Seventeenth Street, Santa Monica, California.

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Sales offices in New York, Boston, Washington, Philadelphia, Pittsburgh, Huntsville, Orlando, Chicago, Houston, Albuquerque, San Francisco. Foreign representatives: Instronics, Ltd., Stittsville, Ontario; CECIS, Paris, F. Kanematsu, Tokyo; RACAL, Sydney.

Please send me literature on the following SDS equipment:

☐ SDS 92 ☐ SDS 910 ☐ SDS 920
☐ SDS 925 ☐ SDS 930 ☐ SDS 9300
☐ Systems Engineering ☐ Magpak ☐ Data Communications

Name _____
Company _____
Address _____
City _____ State _____

# LETTERS

Sirs:

In his article "Magnetothermoelectricity" [SCIENTIFIC AMERICAN, June] Raymond Wolfe generously acknowledges that the first published suggestion that the Ettingshausen effect could be used for thermomagnetic refrigeration was made by C. S. Wallace and me in 1958. However, he throws into sharp contrast the "tiny amount of cooling" we achieved, namely .25 degree centigrade, and the 54 degrees C. achieved several years later by a Lockheed group. It appears to me that this is an excellent example of the contrast between "pure" and "applied" research, and I wish to justify why Wallace and I stoutly resisted any "better mousetrap" approach.

We actually did the work in 1955 and 1956 as students with Dr. K. Landecker and Professor Harry Messel. We had just shown (*Journal of Applied Physics*, Vol. 27, page 820; 1956) that a cascaded thermoelectric refrigerator could be built, and we were fascinated by the interrelation of "charge carriers" and "heat carriers." So we naïvely said if these two types of carrier are one and the same and one pushes the charge carriers through a material (i.e., sends a current through it) in a direction at right angles to a magnetic field, then the charge carriers will be subjected to a force at right angles to both the current and the magnetic field, and hence one side should get hot and the other cold. So we took a slab of bismuth, a car battery, a thermocouple and a galvanometer from the freshman laboratory and acquired a horseshoe magnet from somewhere, carried out the experiment and obtained .25 degree C. cooling, with the parabolic dependence on current we predicted and so on. By analogy with the thermoelectric cascade, we predicted that a tapered block would give optimum cooling, and I was gratified to find that the Lincoln Laboratory had used "this simple trick" to achieve 101 degrees C. cooling.

It cost us about 18 cents to do our experiment and we obtained .25 degree C. cooling, verified several of our theoretical calculations and also predicted that the tapered block would optimize the effect. In subsequent years groups at Lockheed and the Lincoln Laboratory achieved 101 degrees C. cooling, but I suspect the cost cannot be prorated to $72!

BRIAN J. O'BRIEN

Professor of Space Science
Rice University
Houston, Tex.

Sirs:

In the August issue of *Scientific American*, in the column "50 and 100 Years Ago," an item dated August, 1864, was quoted from *Lancet* dealing with regeneration of previously severed and surgically sutured nerves. Professor Laugier of the Hotel Dieu was reported to have united a severed median nerve surgically and to have noted, "almost immediately after," signs of return of sensation. Complete recovery was reported in a few days. This alleged feat supposedly overthrew the then existing opinion that weeks and months were required for regeneration under the circumstances. The implication that Professor Laugier's report represents the true facts must certainly be gained by anyone not familiar with peripheral nerve injuries and their surgical treatment. The regrowth of nerve fibers in a sutured nerve actually takes weeks and months. Until this regrowth occurs there would be no return of function.

STANLEY STELLAR, M.D.

Professor of Clinical Neurosurgery
New York University Medical Center
New York, N.Y.


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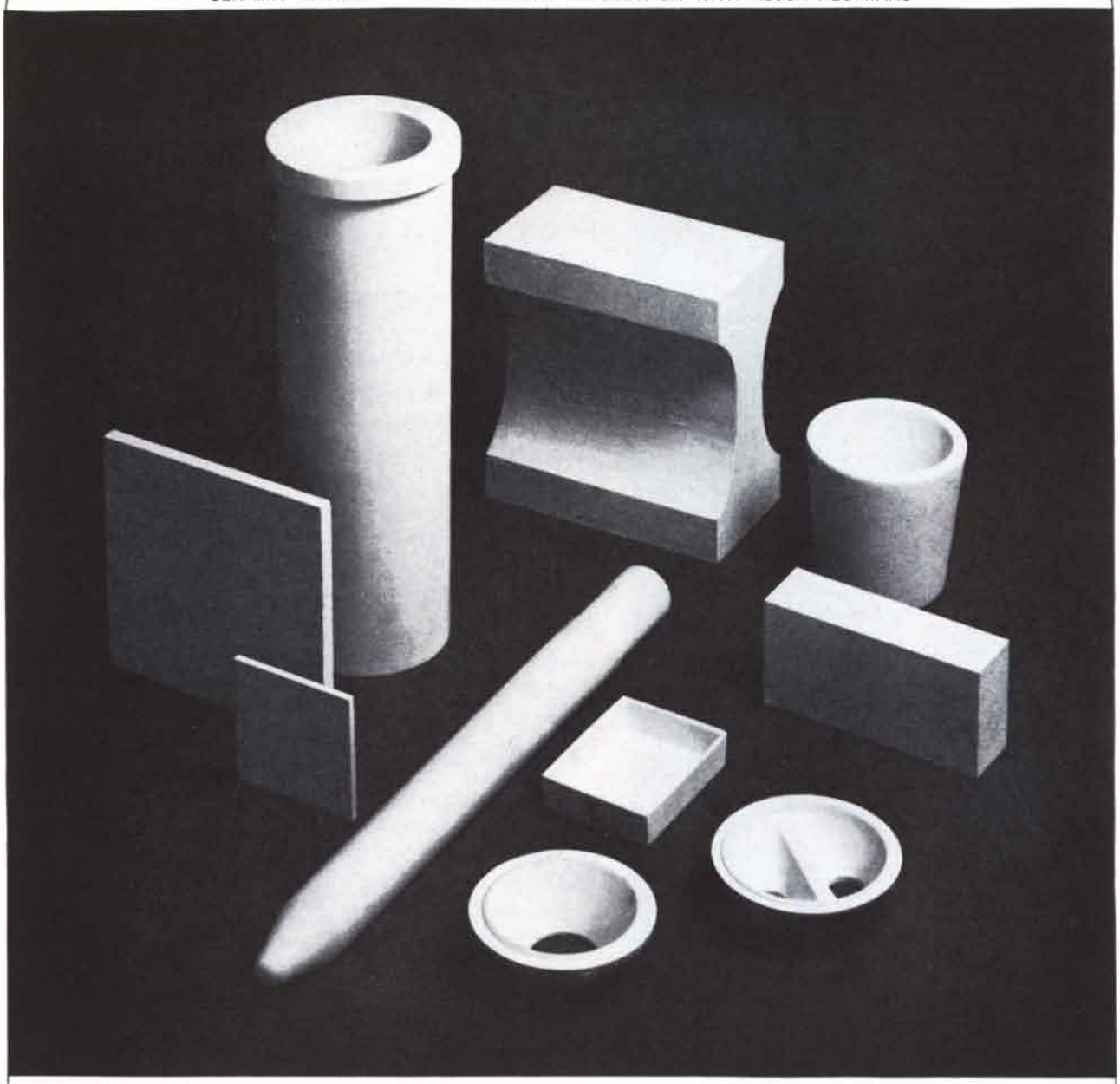
CERAMIC ENGINEERS AT TAYLOR MIX IMAGINATION WITH ALCOA ALUMINAS



## This is ZIRMUL—challenging new alumina-zirconia-silica refractory for glass-melting furnaces

Developed by The Chas. Taylor Sons Co., using Alcoa® Alumina, ZIRMUL* is demonstrating notable versatility throughout the glass and ceramic industries. It is essentially an alumina refractory bonded with a zirconia-mullite matrix and containing a minimum of glassy phase.

Ideal as refractory materials for melting soda-lime and lead glasses, alumina and zirconia are generally considered the most chemically stable of the reasonably priced noncoloring oxides suitable for these applications.

ZIRMUL can be termed an all-purpose refractory. It combines structural stability, uniform density, relatively low thermal conductivity and excellent resistance to corrosion and spalling.

In kiln furniture applications, users report superior resistance to sag, thermal shock and ware reaction. It is used as contact material against nickel and barium ferrites in air or inert atmosphere. It is nonreactive and has good thermal stability in hydrogen brazing of alumina ceramics. It is not subject to oxidation growth or "spit outs."

Alcoa does not make refractories, but we do supply the high-grade aluminas that make modern refractory performance possible. For more information, please write Aluminum Company of America, 840-K Alcoa Building, Pittsburgh, Pa. 15219.

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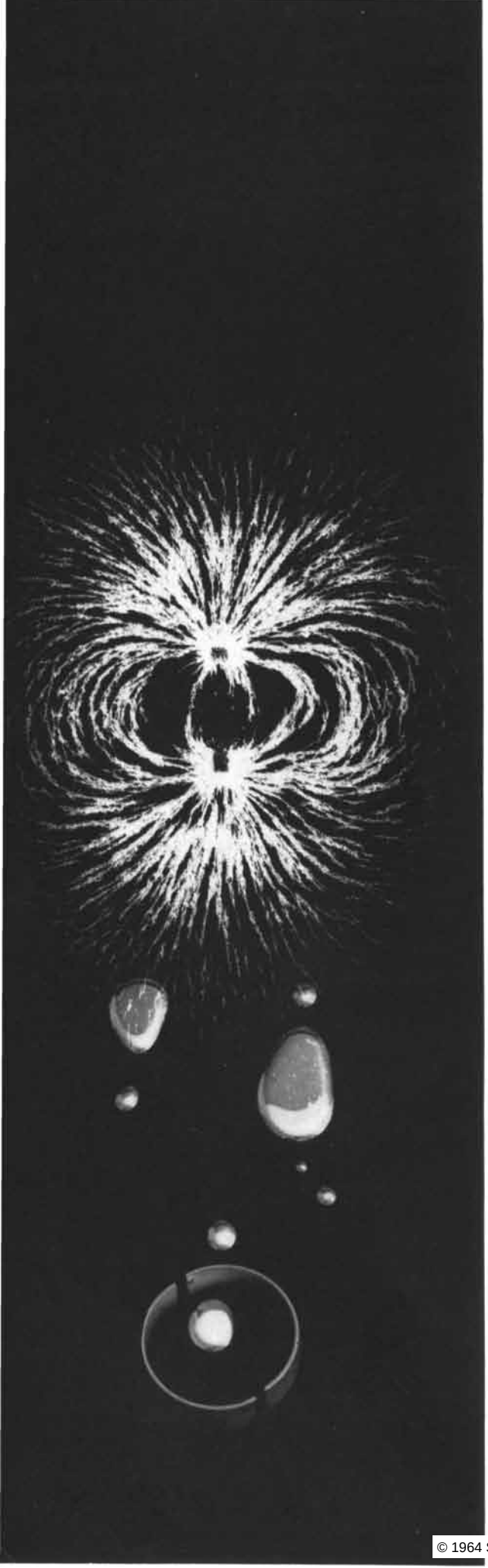


*One of a series briefly describing GM's research in depth*

# The Magnetic Personality of MHD Bearings

We've been analyzing it at the Research Laboratories.

Frankly, we don't know what the practical applications of our MHD analysis will be. Not yet, anyway.

But we're nevertheless pleased that our engineers were the first to successfully demonstrate the much-investigated MHD bearing.

Recently, with the help of the University of Chicago's 32.5-inch cyclotron magnet, they proved experimentally a theory that has been described only by mathematical analysis; that is, when electrically conducting liquid metals are used as bearing lubricants, load carrying capacity can be dramatically increased by subjecting them to a magnetic field. The more powerful the magnetic field, the more viscous becomes the liquid-metal lubricant . . . and the greater the load the MHD bearing will support.

Even more important, our engineers found excellent agreement between their mathematical predictions and the measured performance of the experimental MHD bearing.

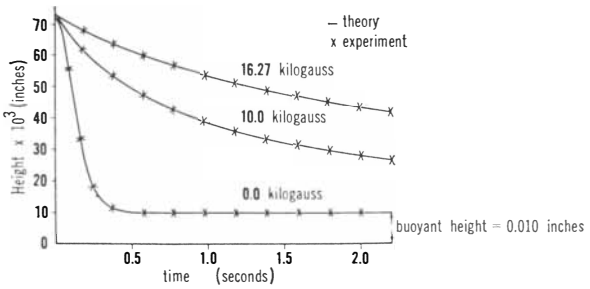
GM bearing designers are intrigued.

Consider the operating characteristics of the magnetohydrodynamic bearing: the possibility of zero frictional torque . . . high thermal conductivity . . . the ability to withstand high temperatures and nuclear radiations . . . and automatic electrical adjustment to compensate for transient loads.

From theoretical analysis through confirming experiment, the successful demonstration of the first experimental MHD bearing is typical of the full-circle research philosophy of General Motors.

## General Motors Research Laboratories

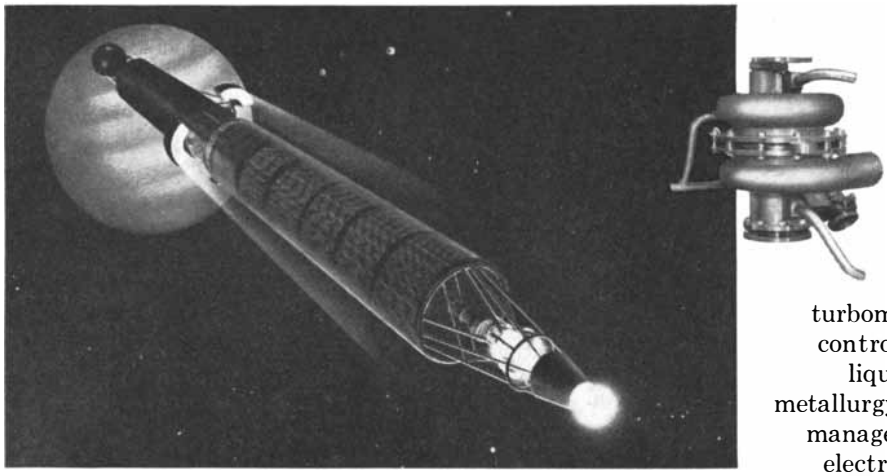
Warren, Michigan




Predicted rate at which a film of mercury is squeezed from between two flat circular plates agrees closely with measured values.

Symbolized elements of MHD bearing.

# It's possible that some people have never heard of a project called SNAP-50/SPUR. But they will.



Chances are this nation has never had a more challenging space project than this attempt to supply man-in-space with electrical power.

And that means enough electricity to provide a mission with *all* the power needed for space communications, propulsion, research, weapons and life support.

This is SNAP-50/SPUR.

It is a brilliant answer to some demanding questions:

How do you build a power station that must be a giant in output, but small in size and weight?

How do you invent a space power station that furnishes reliable, continuous power for more than a year?

The solution staggers the imagination.

Yet, such a system, designated SNAP-50/SPUR, is now being developed under the sponsorship of the Atomic Energy Commission and United States Air Force.

SNAP-50/SPUR will employ a nuclear reactor as a heat source to operate turbines that will drive electrical generators. Heat rejection and cooling is accomplished by a cylindrical radiator.

Working temperatures in the system are near that of molten iron. Here, conversion and rejection of heat demands the most advanced technologies.

Closed loop power conversion systems necessary for this kind of power production are being designed and tested by Garrett-AiResearch.

Garrett-AiResearch, with 25 years of experience in research and production of heat transfer, turbomachinery, control systems, liquid metals, metallurgy, thermal management and electrical power management has already developed much of the technology to be used in SNAP-50/SPUR power conversion equipment.

Today, in Garrett labs, turbines and heat exchangers are being operated with alkali metals at high temperatures.

Major components will be tested this year in Garrett's Phoenix facilities. Turbodynamic bearing tests (picture at left) are already in operation.

SNAP-50/SPUR is a rewarding assignment – actually the forerunner of future space power plants. Certainly, it demands unique capabilities. That's why Garrett is playing such an important role. Because . . .

## Garrett *is* experience

GARRETT AIRESEARCH

*Los Angeles • Phoenix*

# 50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

OCTOBER, 1914: "There is no doubt whatsoever that Germany's remarkable rush across Belgium and northeastern France to within a short distance from the walls of Paris was due to two things: a first-class mobilization plan and an equipment in motor vehicles second to none in the world. When the history of the present war comes to be written in later years, it will be found that the motor car, the motor truck, the tractor, motor-drawn cannon and motor-driven aerial fleet have far exceeded the wildest hopes of their advocates."

"The astounding ease with which the fortifications of Liège, Namur and now Antwerp have been reduced by the attack of modern siege artillery has brought home the conviction to military men that the day of the defense of frontiers by great forts, such as those which line the French frontier, has passed, probably never to return. There will be division of opinion on this subject; but the comment of one of our Army engineers, when he saw the photographs of the wreck of the Belgian forts in this issue of SCIENTIFIC AMERICAN ('That means that there is nothing left but the mobile field army') seems to us to be very much to the point."

"Although the German destroyers have so far conducted no attack in force against the blockading fleet, it is certain that from the very declaration of war their submarines have been cruising at will in the North Sea; and they have at last scored a success in the sinking of three British armored cruisers of 12,000 tons displacement, which must be recorded as the most brilliant naval success thus far achieved in the present war and which establishes, at a stroke, the deadly efficiency of this, the latest form of naval warfare."

"The Sikorsky biplane is significant of future developments. Hitherto the pilot, while steering and controlling the aeroplane, has also at the same time controlled the motor. But it is obvious that with a multiple power plant this is no longer possible, and accordingly on the Sikorsky the pilot operates the aeroplane controls proper, while an engineer is in charge of the motor controls, receiving his orders from the pilot. The growing necessity for some such division of labor has long been apparent in these days, when the length of flight has been increasing so rapidly and the pilot, in addition to his other arduous duties, has had to undertake those of navigator. In time to come and for long journeys the control of the giant machines of the future will no doubt be further subdivided. The pilot will confine his attention purely to the flying and steering of the aeroplane; an engineer will be in charge of the motors; while a navigating officer will map out the course and, if necessary, take the required observations."

"Surely one of the most appalling things about the present war is the fact that some of the most brilliant young men in Europe, men who cannot be replaced, have been ruthlessly butchered. These men belong to wider issues. Science is more important than the preservation of any one country's independence. An effective remedy for cancer is worth a colony. It is merely a question of economics. As a matter of probability, the loss of these lives entails an inconceivably greater loss than any gain their presence in the fighting line is likely to bestow."

Scientific American.

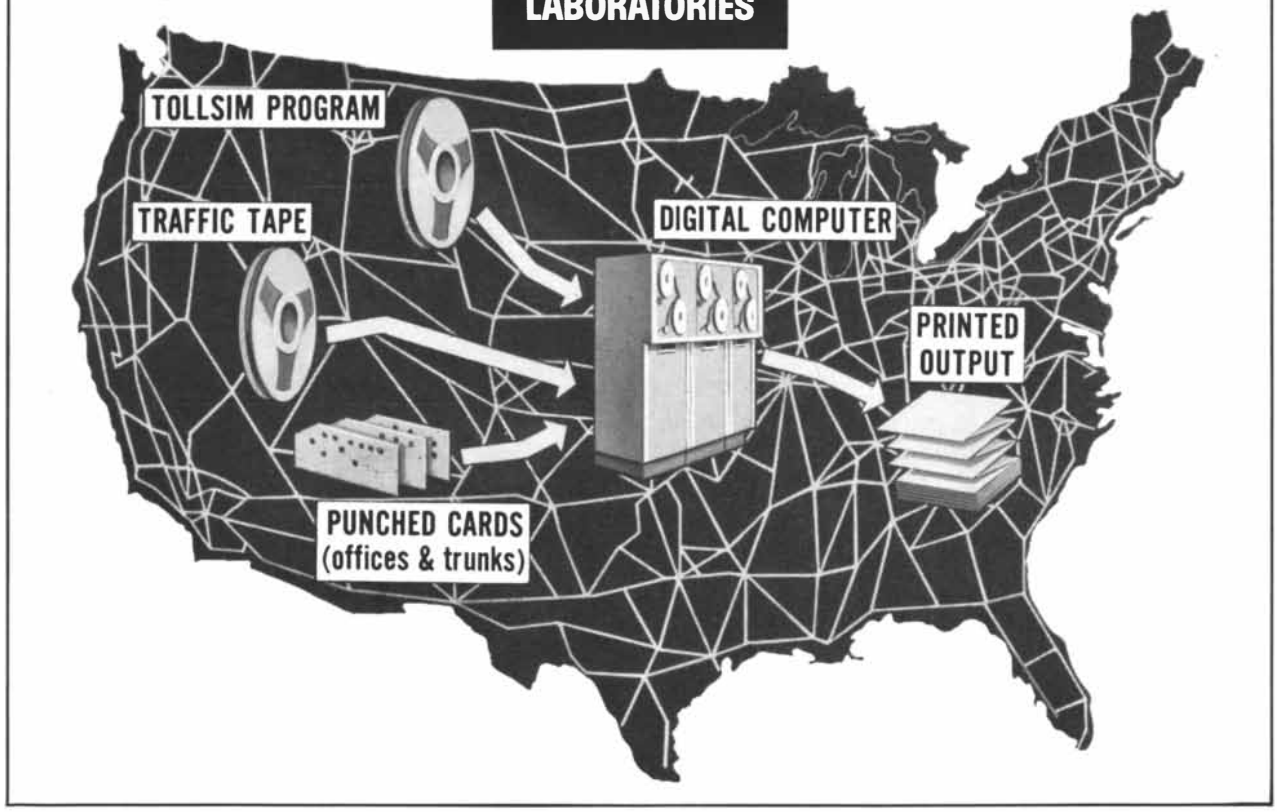
OCTOBER, 1864: "England's iron-clad fleet already afloat includes 19 vessels, the largest of which carries 40 guns and the smallest four guns, the aggregate being 409 guns, with a tunnage of 71,958 and horse-power of 14,762. She has 39 other iron-clad ships afloat, having from one to 16 guns, and 12 powerful ships under construction, which will carry in all 255 guns, are of 43,160 tuns burthen and 9,527 horse-power. Some of those vessels have cost as much as £381,000, or nearly two millions of dollars. England has expended $23,000,000 during the past year in building her iron-clad navy, a sum almost as large as it has cost our Government to build all the monitors, we being at war and England at peace."

"At the present time the world of science is absorbed in investigations along the earliest boundary of the archæologic period, where it fades away into the domains of geology. Until within a few years it was supposed that the crude stone implements which are the oldest legacies from our ancestors and which reveal to modern intelligence the state of the human race in its infancy, were not found in any formations older than those which the geologists call recent, which have been formed since the earth was inhabited by the existing species of animals. But within a few years stone implements, manifestly of human construction, and even bones of men have been found associated with the remains of animals belonging to an earlier age and which have long since perished from the face of the earth. Since the first of these discoveries was announced their progress has been rapid, and the last number of *Silliman's Journal* has an account of seven which have been published within a few months."

"A correspondent who has been down in the submarine vessel recently invented and manufactured by S. S. Merriam and just tested by himself and the Government near New York sends us the following account of his experiences: —'Entering the singular vessel from the top, the door was closed and the order "Men, to your places" given to the little crew, who promptly obeyed. When everything was ready, Mr. Merriam turned some valves and the compressed air came hissing in, producing an unpleasant sensation upon the drum of the ear, of which one was at once relieved by inspiring and swallowing. The vessel seemed perfectly under control, for we stopped when half down to the bottom and raised the door on the bottom of the boat, but the air inside of course prevented any water from coming in, even enough to wet the soles of our feet. One of the crew improved the opportunity to dive out and come up on the surface of the water, much to the astonishment of the spectators on the bank. He afterwards returned and entered the vessel from the bottom. When the door was closed, another and heavier rush of compressed air came in and we were on the bottom of the river, 20-odd feet under water. To return to the rest of the world only a few strokes of the pumps were necessary; the air rushed out of the bottom and the boat was quickly on the surface of the water. We moved with a propeller easily under as well as upon the water, and in all respects the vessel worked so completely that its success is undoubted.' "

Report from

**BELL LABORATORIES**




Many functions of the Bell System communications toll network are simulated by a digital computer using the TOLLSIM program along with a traffic tape and punched cards. The traffic tape, which may be used for a number of traffic studies, specifies times, originating and terminating points, numbers, and durations of simulated telephone calls. The punched cards specify characteristics of real or theoretical offices and trunks. The printed output, by recording and summarizing reattempts, abandoned calls, and other "real life" traffic data, both for the entire network and for its component parts, enables engineers to judge performance under various operating conditions. Many variations are possible. The effect of rearranging switching equipment in an office, for example, can be studied by using a different punched card for that office.

# TRAFFIC ANALYSIS

*Mathematics for good telephone service*

At Bell Laboratories simulated telephone calls are placed through a computer programmed to represent the Bell System nationwide Direct Distance Dialing network. The computer program, known as TOLLSIM for "Toll Network Simulator," is one of many tools used by traffic specialists in studying how well traffic is handled by the network and how certain design changes might improve telephone service.

For example, a long-standing problem within the telephone industry is that of coping with heavy overload conditions during relatively short periods. These overloads can occur because of storms or other disasters that result in unusually heavy telephone calling. Such conditions also occur during the Christmas season and on Mother's Day.

In conjunction with earlier theoretical work, a TOLLSIM simulation indicated that, during overload conditions, a greater number of customers could be served if the pattern of automatic alternate routing of telephone calls were changed. The change involved making fewer attempts to route the calls over long, roundabout alternate routes when shorter direct trunks were busy. The results were then confirmed by field tests performed during the 1963 Christmas period.

This work is an example of the way Bell Laboratories people advance traffic theory and practical applications. The goal: to tailor facilities closely to the needs of telephone customers.

**BELL TELEPHONE LABORATORIES** ... Research and Development Unit of the Bell System.


# World's first fuel-cell operated submarine!

**July, 1964, Groton, Conn.: Star I — a one-man test and research submarine — was successfully operated both submerged and on the surface. An Allis-Chalmers 36-volt fuel cell produced 750 watts to power the vessel's electric drive motors, communications, navigation, life support and lighting equipment.**

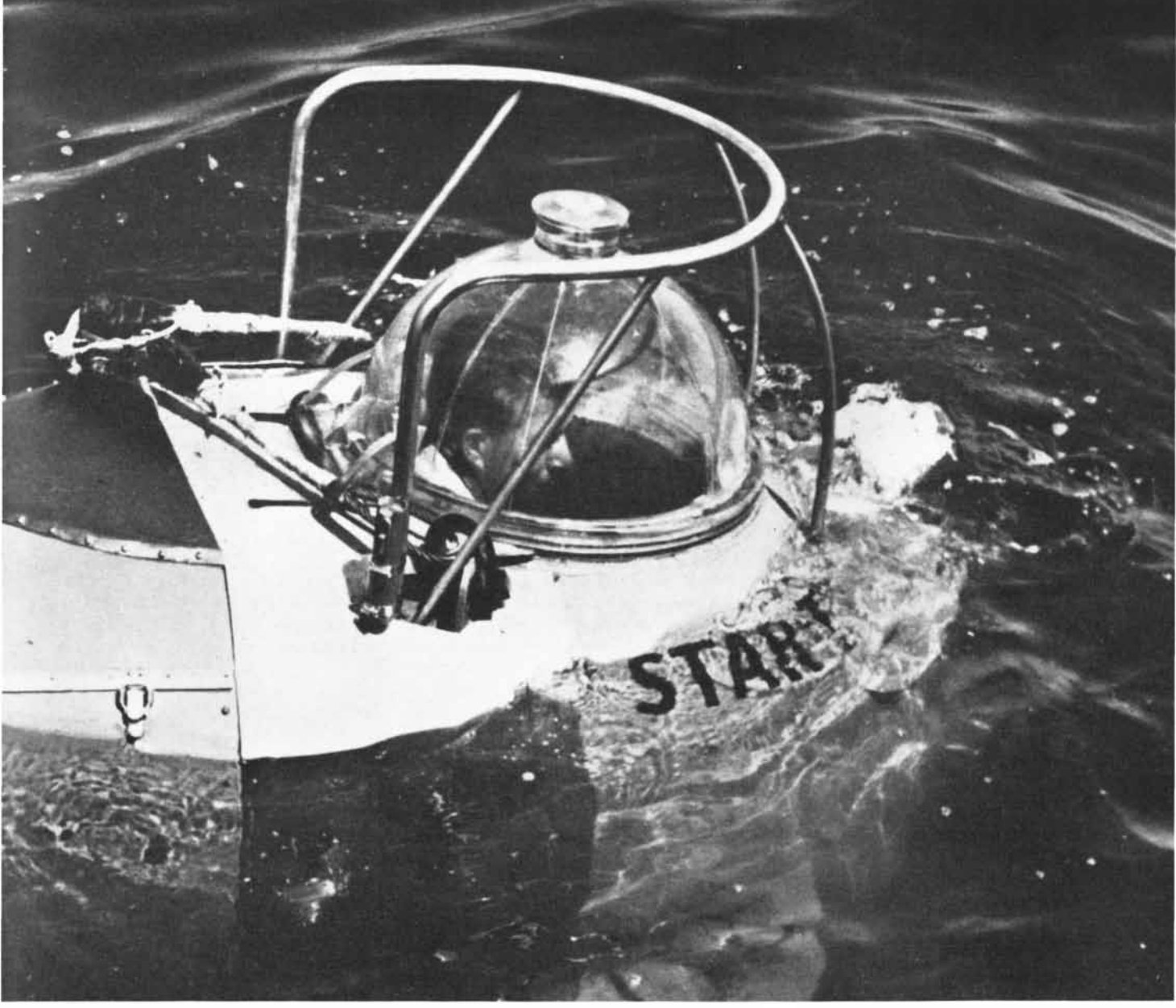
Star I — owned and operated by General Dynamics/Electric Boat Division — was powered by an Allis-Chalmers fuel cell system. It is a nine-foot-long, teardrop shaped 2,500 lb. submarine. A-C and Electric Boat Research engineers teamed up to successfully adapt fuel cell power to the submarine. Purpose: **to extend the vessel's capabilities beyond those of conventional storage battery power.**

In effect what the fuel cell has demonstrated was to double the Star I's endurance time. Previously batteries lasted up to 4 hours and required 8 hours to recharge. In the fuel cell, endurance is measured by the quantity of fuel and oxidant aboard and only five to ten minutes are sufficient to change to a fresh supply of hydrazine (the fuel) and oxygen (the oxidizer).

And this new Allis-Chalmers fuel cell application follows on the heels of A-C's 14 lb. hydrogen-oxygen fuel cell developed for the Air Force. This cell qualified for orbiting. It's scheduled to produce electrical power for systems aboard aerospace vehicles.

May we discuss your aerospace or defense fuel cell application? TELEPHONE AREA CODE 414-774-3600, EXT. 491, ALLIS-CHALMERS, Box 512, Milwaukee, Wis. 53201. A-1939

**ALLIS-CHALMERS**




The compact Allis-Chalmers fuel cell is ready for lowering into the non-pressurized glass fiber fairing behind the STAR I's four-foot spherical pressure hull.


In July, 1964, the 9-foot long STAR I, powered by A-C fuel cells, operated successfully both submerged and on the surface.

## Quick summary:
## ALLIS-CHALMERS FUEL CELL FIRSTS

**FIRST**
. . . in a land vehicle, a 15-kw tractor . . . . . 1959

**FIRST**
. . . to successfully pass zero gravity tests, Wright Patterson AFB . . . . . 1961

**FIRST**
. . . "qualified for space" fuel cells for the Air Force. . . . March, 1964

**FIRST**
. . . to power an underwater vehicle . . . . . July, 1964

**FUEL-CELL** design for Aerospace and Hydrospace applications is but one of the opportunities open today for qualified scientists and engineers at Allis-Chalmers. For information concerning employment write to: Manager of Professional Placement, Allis-Chalmers, Milwaukee, Wisconsin 53201.

# THE AUTHORS

JEROME B. WIESNER and HERBERT F. YORK ("National Security and the Nuclear-Test Ban") have been engaged for most of their professional lifetimes in consultation on this country's military policy and in active development of the weapons. Wiesner, now dean of science at the Massachusetts Institute of Technology, was chairman of the President's Science Advisory Committee and special assistant to the President for science and technology during the Kennedy Administration. York, now chancellor of the University of California at San Diego, was the first director of the Livermore Laboratory, organized in 1952 when the Truman Administration decided to proceed with the development of thermonuclear weapons. Wiesner received a B.S. in 1937 from the University of Michigan and was proceeding with his graduate education there when the outbreak of war called him into service at the Radiation Laboratory of the Massachusetts Institute of Technology. In 1945 he joined the staff of the Los Alamos Scientific Laboratory. Returning to M.I.T. in 1946 as a member of the department of electrical engineering, he completed his doctoral work, the degree being conferred by the University of Michigan in 1950, and was promoted to professorial rank that year. At M.I.T. he also served as director of the Research Laboratory of Electronics and continued his work in military technology as a member of the Army Science Advisory Committee. York's graduate education was similarly interrupted by war service. A graduate of the University of Rochester in 1942, he went to work under the late Ernest O. Lawrence at the Radiation Laboratory of the University of California at Berkeley. He received a Ph.D. there in 1949 and continued as a member of the staff until he assumed responsibility for the new Livermore Laboratory. In 1958, under the Eisenhower Administration, he was called to Washington as chief scientist of the Advanced Research Projects Agency of the Department of Defense and director of defense research and engineering in the office of the Secretary of Defense. Wiesner and York continue their Government service as members of the President's Science Advisory Committee.

WILLIAM B. FOWLER and NICHOLAS P. SAMIOS ("The Omega-Minus Experiment") are physicists at the Brookhaven National Laboratory. Their article is a report on the work of a large group of physicists, engineers and technicians, of which they are members. Fowler obtained a B.S. at the University of Kentucky in 1947 and a Ph.D. at Washington University in 1951. He has been at Brookhaven since then, except for the years 1955 to 1958, when he was with the Lawrence Radiation Laboratory of the University of California. Samios took his degrees at Columbia University, receiving a Ph.D. in 1957.

HEINZ FRAENKEL-CONRAT ("The Genetic Code of a Virus") is professor of molecular biology at the University of California at Berkeley. Born in Breslau, Germany, he obtained an M.D. there in 1933 and a Ph.D. in biochemistry at the University of Edinburgh in 1936. He then came to the U.S., working at the Rockefeller Institute for Medical Research. He also did research at the Institute Butantan in São Paulo before going to Berkeley in 1938. After four years there he spent eight years at the Western Regional Laboratory of the U.S. Department of Agriculture and a year abroad. He joined the Virus Laboratory at Berkeley in 1952. His investigations have been concerned with enzymes, snake venoms, hormones, egg proteins and viruses.

SIR GRAHAM SUTTON ("Micrometeorology") has been director-general of the Meteorological Office, the official British weather service, since 1953. He is a graduate of the universities of Wales and Oxford, where he mainly studied pure mathematics. In 1928, he reports, a chance encounter with Sir David Brunt, a leading meteorologist, led to his leaving university teaching for the Meteorological Office and a change in interest to mathematical physics. Until 1939 he was engaged in research in micrometeorology, but during the war he headed research first in chemical warfare, then in tank armaments and finally in radar development for the British army. In 1947 he resumed academic life as professor of mathematical physics at the Royal Military College of Science, and later he became dean of the college. In 1949 he was elected a Fellow of the Royal Society. He was knighted in 1955.

STELLA Y. BOTELHO ("Tears and the Lacrimal Gland") is associate professor of physiology at the Graduate School of Medicine of the University of Pennsylvania. Born in Japan, she was

REQUEST AND AUTHORIZATION FOR MILITARY PERSONNEL TDY TRAVEL
AND CIVILIAN PERSONNEL TDY AND PCS TRAVEL
*(AR 310-10 and CPR T-3)*

1. TYPE OF TRAVEL ORDERS
[X] TDY, UCMR PROPER STA. [ ] PCS *(Civilian only)* [ ] CONFIRMATORY ORDERS

2. NAME OF REQUESTING OFFICE: Army Tank Automotive Center
3. TELEPHONE EXT
4. DATE: 23 June 1964

| 5. FIRST NAME - MIDDLE INITIAL - LAST NAME | GRADE | SERVICE NUMBER | ARM OR SERVICE (Military) POSITION OR TITLE (Civilian) | SECURITY CLEARANCE |
|---|---|---|---|---|
| The Goer | 8-ton tactical support vehicle | 19748 | U. S. Army | |

6. ORGANIZATION AND STATION: 7th Army
7. TO PROCEED O/A
8. APPROXIMATE NUMBER OF DAYS
9. ITINERARY [ ] CIPAP: Via Kenosha, Wisc.; St. Lawrence Seaway; Le Havre, France; Frankfurt, Germany

10. PURPOSE OF TEMPORARY DUTY: Test and Evaluation

11. TRANSPORTATION AUTHORIZED
[ ] COMMON CARRIER: [ ] AIR [ ] SURFACE [ ] WATER [ ] AS DETERMINED BY TRANSPORTATION OFF. *(Military only)*
[ ] GOVERNMENT OWNED [ ] VEHICLE [ ] AIRCRAFT [X] VESSEL
[ ] PRIVATELY-OWNED VEHICLE AT RATE OF _____ CENTS PER MILE [ ] TPA TMDAG
[ ] REIMBURSEMENT LIMITED TO COST TO GOVT OF TRAVEL BY USUAL MODE OF TRANSPORTATION, INCLUDING PER DIEM. *(Civilian only)*

12. PER DIEM AUTHORIZED *(Civilian Personnel only)*
[ ] MAXIMUM AUTHORIZED BY CPR T-3 [ ] OTHER ... PER DIEM *(Specify)*

13. TRANSPORTATION OF DEPENDENTS *(Civilian Personnel only)*
[ ] EMPLOYEE REQUESTS TRANSPORTATION OF DEPENDENTS ... AT GOVERNMENT EXPENSE
UNDER REMARKS
[ ] TRANSPORTATION AUTHORIZED BY GOVERNMENT [ ] VEHICLE [ ] AIRCRAFT
[ ] TRANSPORTATION AUTHORIZED BY COMMON CARRIER *(Commercial Air, Rail, Bus, Vessel)*
[ ] TRANSPORTATION AUTHORIZED BY PRIVATELY-OWNED CONVEYANCE

14. SHIPMENT OF HOUSEHOLD GOODS *(Civilian personnel only)*
[ ] EMPLOYEE HAS DEPENDENTS AND IS AUTHORIZED MOVEMENT OF HOUSEHOLD GOODS NOT IN EXCESS OF 7000 POUNDS NET WEIGHT
[ ] EMPLOYEE DOES NOT HAVE DEPENDENTS ... AUTHORIZED MOVEMENT OF HOUSEHOLD GOODS NOT IN EXCESS OF 2500 POUNDS NET WEIGHT

15. REMARKS *(Use this space for special requirements, delay, authority for issuance, names of dependents, designation as courier, supervision accompanied tone, excess baggage, etc.)*

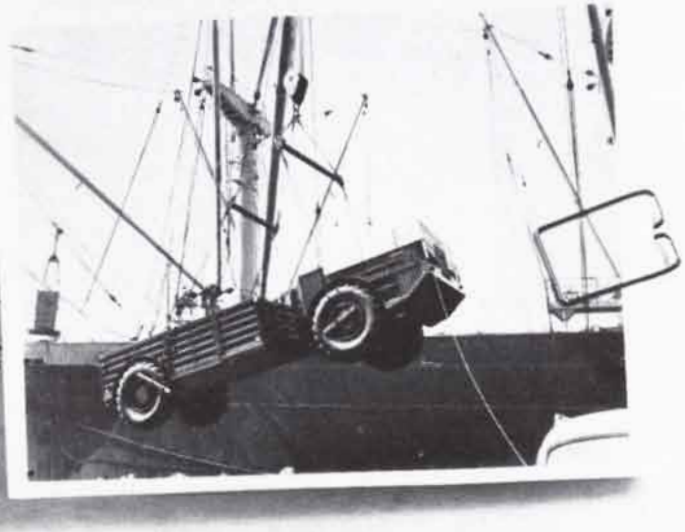
Goers are scheduled for a full-scale troop test program. These units -- designed with ATAC by Caterpillar's Defense Products Department -- will participate in full field maneuvers as well as individual test operations.

16. ADMINISTRATIVE APPROVAL
Lt. L. Circuse
Training, Ordnance
*(Name, grade or title)*

17. FISCAL APPROVAL *(Chargeable to)*
Public Accountant
Fin. Sec., Ordnance
NAME, GRADE OR TITLE

DA FORM 662 1 OCT 63 PREVIOUS

TOP PRIORITY



CATERPILLAR
Reg. U. S. Pat. Off.

brought to this country as a child. She received an A.B. at the University of Pennsylvania in 1940 and an M.D. at the Woman's Medical College in 1949. In that year she joined the faculty of the Pennsylvania Graduate School of Medicine as an instructor in physiology and pharmacology. Among other appointments, she has been visiting professor of physiology at the University of Cambridge, a clinical neurophysiologist at the Philadelphia General Hospital and is now chief of the section of applied physiology at that hospital.

RALPH S. MOSHER ("Industrial Manipulators") holds the position of project engineer in control systems and machine design at the Advanced Technology Laboratories of the General Electric Company in Schenectady, N.Y. After serving as a navigator in the Air Force during World War II he obtained a B.S. in mechanical engineering at the University of New Hampshire. He has been with General Electric ever since. His work in manipulators grew out of the need for special remote-handling equipment for use in the now discontinued Atomic Nuclear Propulsion program of the Air Force.

PAUL A. KOLERS ("The Illusion of Movement") is a research associate in the Research Laboratory of Electronics and the department of electrical engineering at the Massachusetts Institute of Technology. He received a Ph.D. in experimental psychology at New York University in 1957. From 1956 to 1958 he held a research fellowship in experimental and physiological psychology at the Veterans Administration Hospital in West Haven, Conn. Then he worked as a research psychologist for the Air Force and, later, for the Navy. In 1962 he joined the Center for Cognitive Studies at Harvard University, remaining there until early this year.

STANLEY C. WECKER ("Habitat Selection") is an instructor in the department of biology at the City College of the City University of New York. After receiving a B.S. from City College in 1955, he studied at the University of Michigan, obtaining an M.S. in 1957 and a Ph.D. in 1962. His primary interest is vertebrate ecology, with some overlap into the field of animal behavior.

A. E. MIRSKY, who in this issue reviews Sir Julian Huxley's *Essays of a Humanist,* is a leading biochemist and a member of the Rockefeller Institute, where he has worked since 1927.

# UNITED BRINGS YOU RED, WHITE & BLUE

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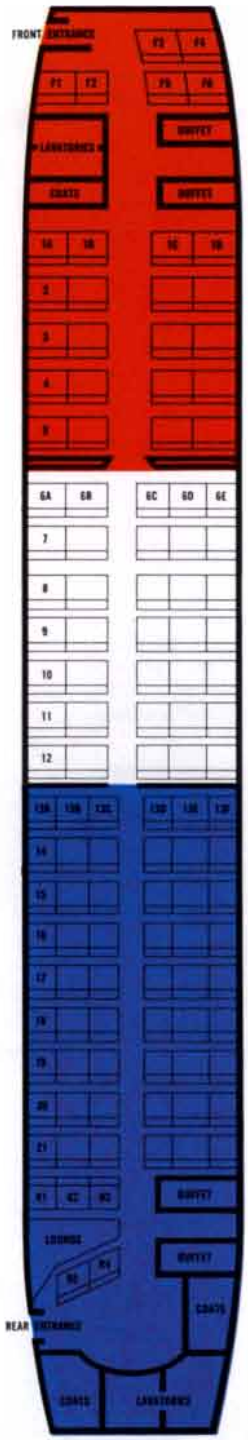

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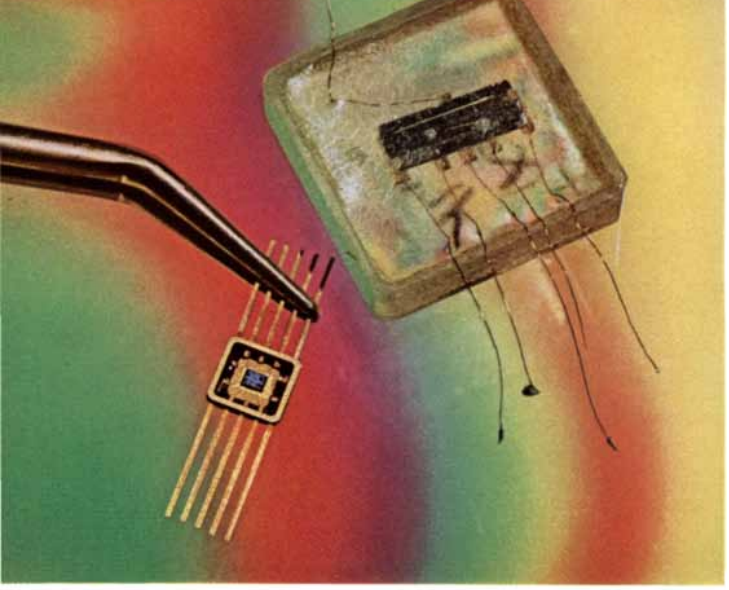

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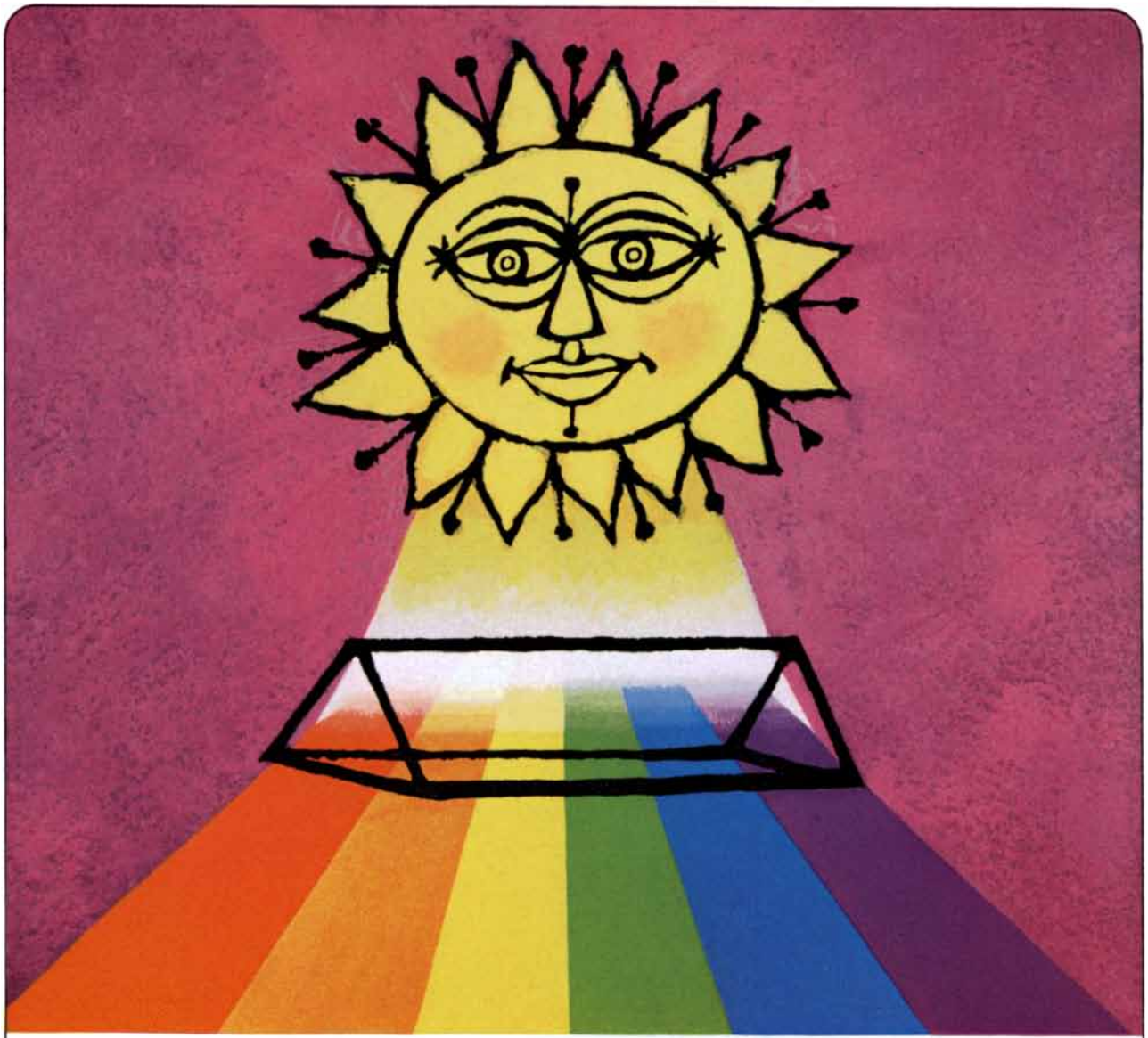

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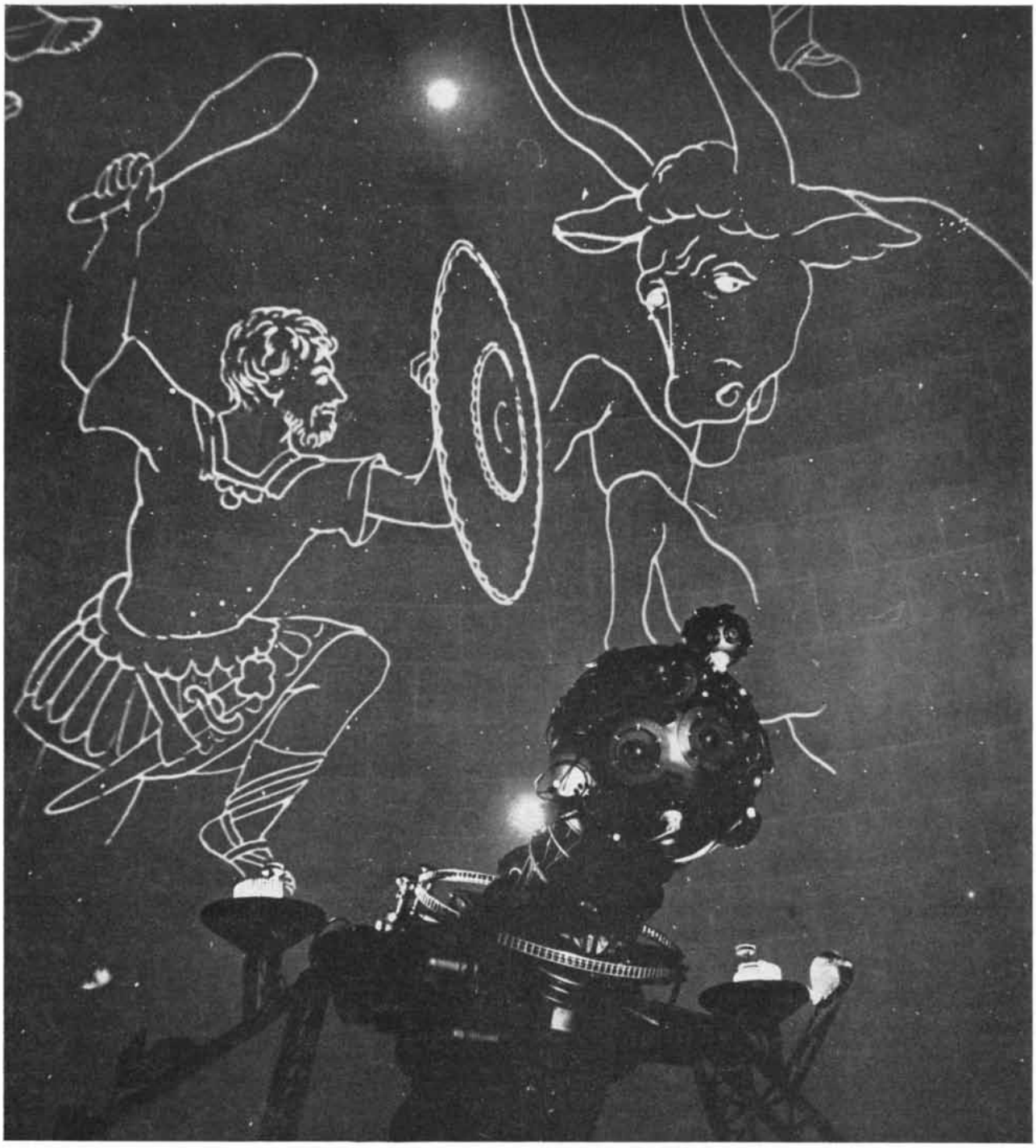

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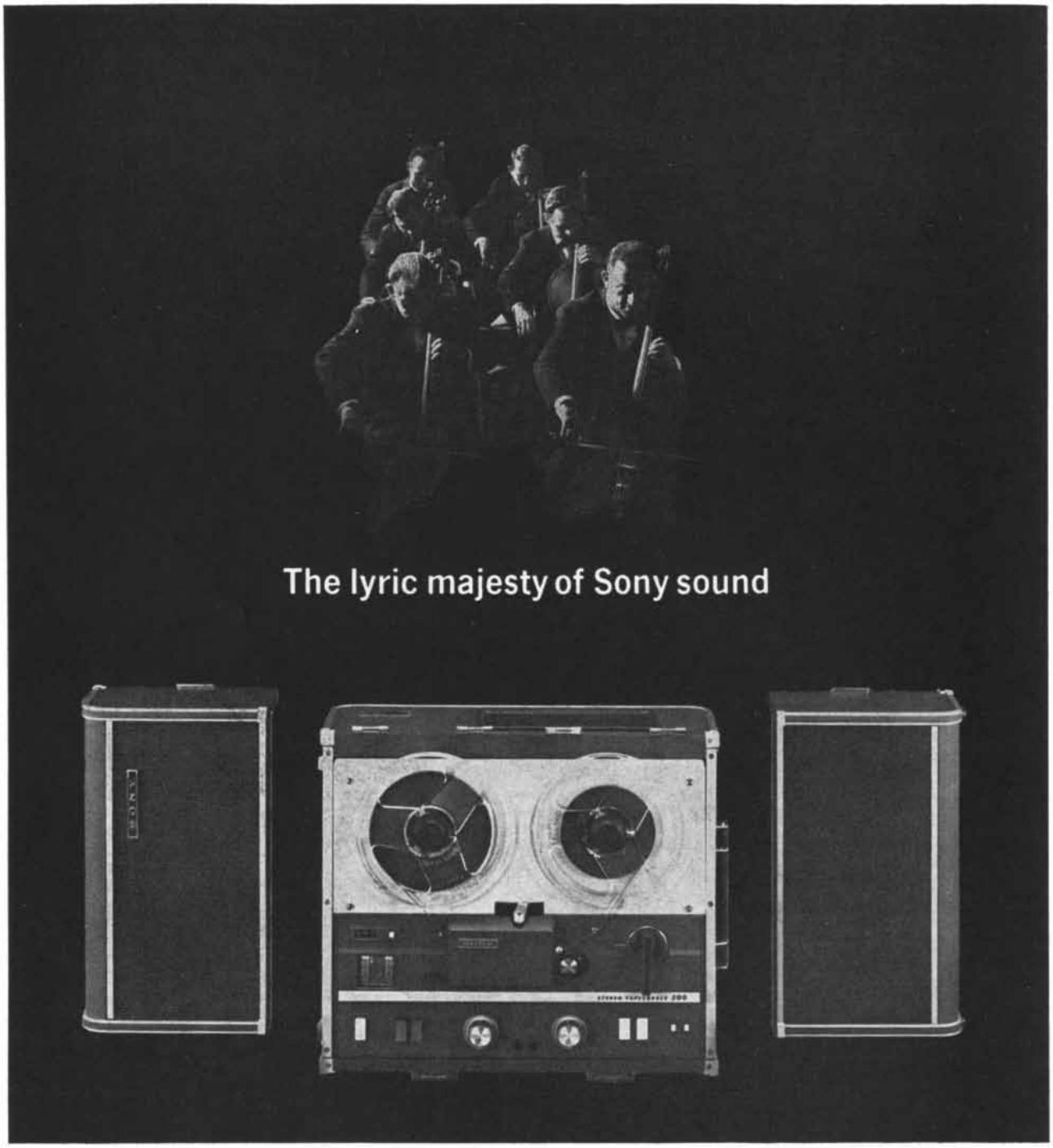


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# National Security and the Nuclear-Test Ban

*Two scientific advisers to the Eisenhower and Kennedy administrations present the reasons why further nuclear tests are unnecessary and why there can be no technical solution to the problem of national security*

by Jerome B. Wiesner and Herbert F. York

The partial nuclear-test ban—the international treaty that prohibits nuclear explosions in the atmosphere, in the oceans and in outer space—has been in effect for a little more than a year. From July, 1945, when the first atomic bomb was set off in New Mexico, until August, 1963, when the U.S. completed its last series of atmospheric bomb tests in the Pacific, the accumulated tonnage of nuclear explosions had been doubling every three years [*see top illustration on page 29*]. Contamination of the atmosphere by fission products and by the secondary products of irradiation (notably the long-lived carbon 14) was approaching a level (nearly 10 percent of the natural background radiation) that alarmed many biologists. A chart plotting the accumulation of radioactive products can also be read as a chart of the acceleration in the arms race.

Now, for a year, the curve has flattened out. From the objective record it can be said that the improvement of both the physical and the political atmosphere of the world has fulfilled at least the short-range expectations of those who advocated and worked for the test ban. In and of itself the treaty does no more than moderate the continuing arms race. It is nonetheless, as President Kennedy said, "an important first step—a step toward peace, a step toward reason, a step away from war."

The passage of a year also makes it possible to place in perspective and evaluate certain misgivings that have been expressed about the effect on U.S. national security of the suspension of the testing of nuclear weapons in the atmosphere. These misgivings principally involve the technology of nuclear armament. National security, of course, involves moral questions and human values—political, social, economic and psychological questions as well as technological ones. Since no one is an expert in all the disciplines of knowledge concerned, it is necessary to consider one class of such questions at a time, always with the caution that such consideration is incomplete. As scientists who have been engaged for most of our professional lifetimes in consultation on this country's military policy and in the active development of the weapons themselves, we shall devote the present discussion primarily to the technological questions.

The discussion will necessarily rest on unclassified information. It is unfortunate that so many of the facts concerning this most important problem are classified, but that is the situation at this time. Since we have access to classified information, however, we can assure the reader that we would not have to modify any of the arguments we present here if we were able to cite such information. Nor do we know of any military considerations excluded from open discussion by military secrecy that would weaken any of our conclusions. We shall discuss the matter from the point of view of our country's national interest. We believe, however, that a Soviet military technologist, writing from the point of view of the U.S.S.R., could write an almost identical paper.

Today as never before national security involves technical questions. The past two decades have seen a historic revolution in the technology of war. From the blockbuster of World War II to the thermonuclear bomb the violence of military explosives has been scaled upward a million times. The time required for the interhemispheric transport of weapons of mass destruction has shrunk from 20 hours for the 300-mile-per-hour B-29 to the 30-minute flight time of the ballistic missile. Moreover, the installation of the computer in command and control systems has increased their information-processing capacity by as much as six orders of magnitude compared with organizations manned at corresponding points by human nervous systems.

It has been suggested by some that technological surprise presents the primary danger to national security. Yet

recognition of the facts of the present state of military technology must lead to the opposite conclusion. Intercontinental delivery time cannot be reduced to secure any significant improvement in the effectiveness of the attack. Improvement by another order of magnitude in the information-processing capacity of the defending system will not make nearly as large a difference in its operational effectiveness.

The point is well illustrated by the 100-megaton nuclear bomb. Whether or not it is necessary, in the interests of national security, to test and deploy a bomb with a yield in the range of 100 megatons was much discussed during the test-ban debates. The bomb was frequently referred to as the "big" bomb, as if the bombs now in the U.S. arsenal were somehow not big. The absurdity of this notion is almost enough by itself to settle the argument. A one-megaton bomb is already about 50 times bigger than the bomb that produced 100,000 casualties at Hiroshima, and 10 megatons is of the same order of magnitude as the grand total of all high explosives used in all wars to date. Other technical considerations that surround this question are nonetheless illuminating and worth exploring.

There is, first of all, the "tactics" of the missile race. The purpose of a missile system is to be able to destroy or, perhaps more accurately, able to threaten to destroy enemy targets. No matter what the statesmen, military men and moralists on each side may think of the national characteristics, capabilities and morality of the other side, no matter what arguments may be made about who is aggressive and who is not or who is rational and who is not, the military planners on each side must reckon with the possibility that the other side will attack first. This means that above all else the planner must assure the survival of a sufficient proportion of his own force, following the heaviest surprise attack the other side might mount, to launch a retaliatory attack. Moreover, if the force is to be effective as a deterrent to a first strike, its capacity to survive and wreak revenge and even win, whatever that may mean, must be apparent to the other side.

Several approaches, in fact, can be taken to assure the survival of a sufficient missile force after a first attack on it. The most practical of these are: (1) "hardening," that is, direct protection against physical damage; (2) concealment, including subterfuge and, as in the case of the Polaris submarine missiles, mobility, and (3) numbers, that is, presenting more targets than the attacker can possibly cope with. The most straightforward and certain of these is the last: numbers. For the wealthier adversary it is also the easiest, because he can attain absolute superiority in numbers. A large number of weapons is also a good tactic for the poorer adversary, because numbers even in the absence of absolute superiority can hopelessly frustrate efforts to locate all targets.

There is an unavoidable trade-off, however, between the number and the size of weapons. The cost of a missile depends on many factors, one of the most important being gross size or weight. Unless one stretches "the state of the art" too far in the direction of sophistication and miniaturization, the cost of a missile turns out to be roughly proportional to its weight, if otherwise identical design criteria are used. The protective structures needed for hardening or the capacity of submarines needed to carry the missile also have a cost roughly proportional to the volume of the missile. Some of the ancillary equipment has a cost proportional to the size of the missile and some does not; some operational expenditures vary directly with size or weight and some do not. The cost of the warhead generally does not, although the more powerful warhead requires the larger missile. It is not possible to put all these factors together in precise bookkeeping form, but it is correct to say that the cost of a missile, complete and ready for firing, increases somewhat more slowly than linearly with its size.

On the other hand—considering "hard" targets only—the effectiveness of a missile increases more slowly than cost as the size of the missile goes up. The reason is that the radius of blast damage, which is the primary effect employed against a hard target, increases only as the cube root of the yield and because yield has a more or less direct relation to weight. Against "soft" targets, meaning population centers and conventional military bases, even "small" bombs are completely effective, and nothing is gained by increasing yield. Given finite resources, even in the wealthiest economy, it would seem prudent to accept smaller size in order to get larger numbers. On any scale of investment, in fact, the combination of larger numbers and smaller size results in greater effectiveness for the missile system as a whole, as contrasted to the effectiveness of a single missile.

This line of reasoning has, for some years, formed the basis of U.S. missile policy. The administration of President Eisenhower, when faced with the choice of bigger missiles (the liquid-fueled Atlas and Titan rockets) as against smaller missiles (the solid-fueled Minuteman and Polaris rockets), decided to produce many more of the smaller missiles. The administration of President Kennedy independently confirmed this decision and increased the ratio of smaller to larger missiles in the nation's armament. During the test-ban hearings it was revealed that the U.S. nuclear armament included bombs of 23-megaton yield and higher, carried by bombers. Recently Cyrus R. Vance, Under Secretary of Defense, indicated that the Air Force has been retiring these large bombs in favor of smaller ones. There are presumably no targets that call for the use of such enormous explosions.

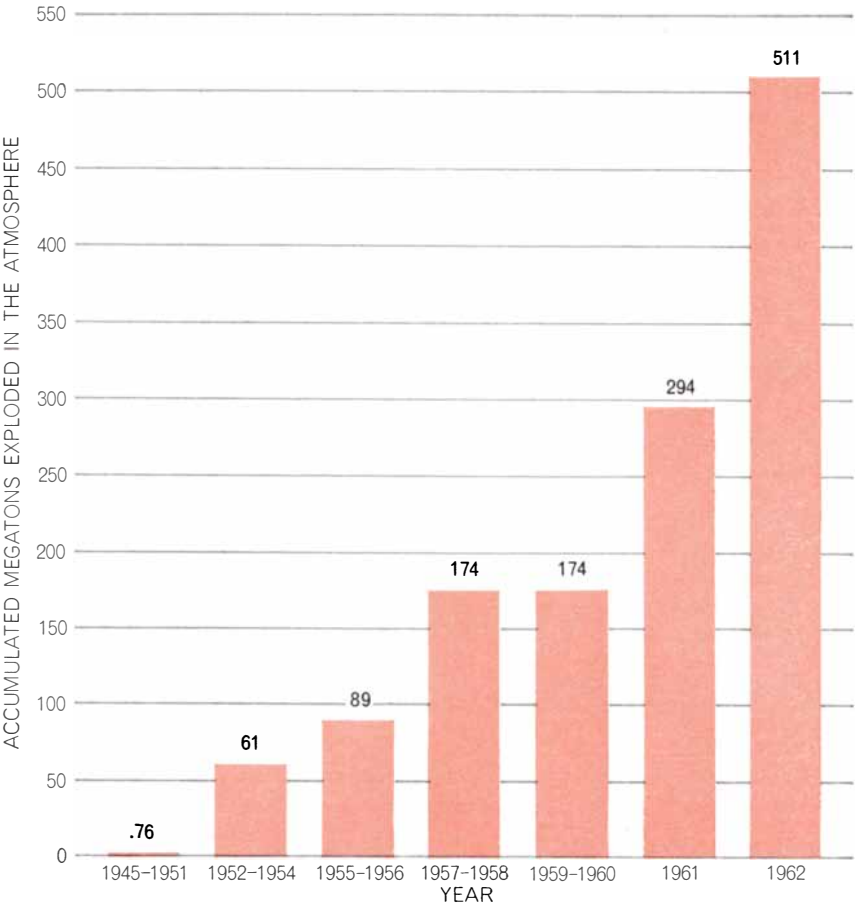
The argument that says it is now critical for U.S. national security to build very big bombs and missiles fails completely when it is examined in terms of the strictly technical factors that determine the effectiveness of a missile attack. In addition to explosive yield the principal factors are the number of missiles, the overall reliability of each missile and the accuracy with which it can be delivered to its target. The effectiveness of the attack—the likelihood that a given target will be destroyed—can be described by a number called the "kill probability" ($P_k$). This number depends on the number of missiles ($N$) launched at the target, the reliability ($r$) of each missile and the ratio of the radius of damage ($R_k$) effected by each missile to the accuracy with which the missiles are delivered to the target (CEP). The term "CEP," which stands for "circular error probable," implies that the distribution of a large number of hits around a given target will follow a standard error curve; actually, for a variety of reasons (which include the presence of systematic errors, coupling between certain causes of error and the sporadic nature of the larger error factors) the distribution does not really follow a standard error curve. The term "CEP" is still useful, however, and can be defined simply as the circle within which half of a large number of identical missiles would fall.

Now, in the case of a soft target, $R_k$ is very large for the present range of warhead yields in the U.S. arsenal. The reason is that soft targets are so highly vulnerable to all the "prompt" effects (particularly the incendiary effects) of thermonuclear weapons. The range of these effects, modified by various attenu-

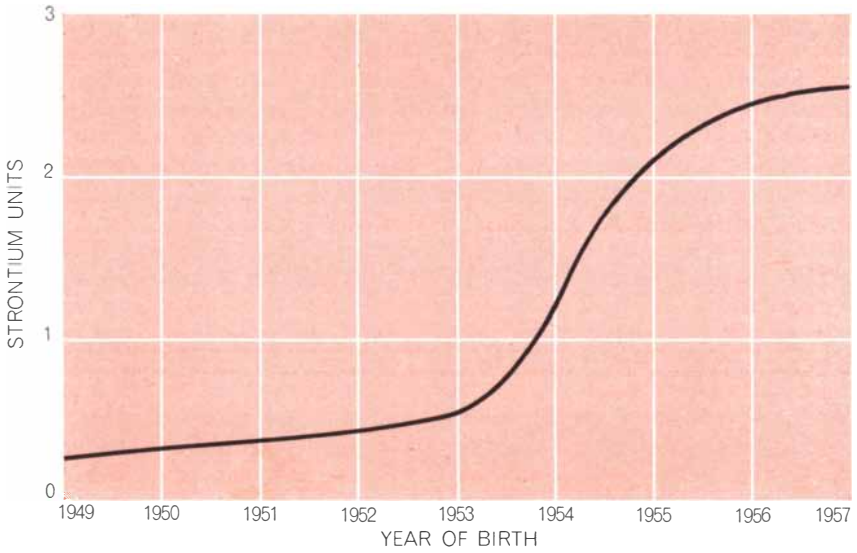
ation factors, increases approximately as the square root or the cube root of the yield at large distances. Under these circumstances, given the accuracy of existing fire-control systems, the ratio $R_k$/CEP is large and the likelihood that the target will be destroyed becomes practically independent of this ratio. Instead $P_k$ depends primarily on $r$, the reliability of the missile. If $r$ is near unity, then a single missile ($N = 1$) will do the job; if $r$ is not near unity, then success in the attack calls for an offsetting increase in the number of missiles [$P_k = 1 - (1 - r)^N$]. In either case changes in $R_k$ make little difference. That is to say, a "big" bomb cannot destroy a soft target any more surely than a "small" one can.

When it comes to hard targets, the ratio $R_k$/CEP becomes much smaller even for bombs of high yield. The blast effects—including the ground rupture, deformation and shock surrounding the crater of a surface burst—have comparatively small radii at intensities sufficient to overcome hardening. Moreover, as mentioned above, the radii of these effects increase only as the cube root of the yield. This rule of thumb is modified somewhat in both directions by the duration of the blast pulse, local variations in geology and other factors, but it is sustained by a voluminous record from weapons tests. Since the radius of blast damage is of the same order of size as the circular error probable, or smaller, the ratio $R_k$/CEP must be reckoned with in an attack on a hard target. Yet even in this situation the cube root of a given increase in yield would contribute much less to success than a comparable investment in numbers, reliability or accuracy.

Yield is of course a product of the yield-to-weight ratio of the nuclear explosive employed in the warhead multiplied by the weight of the warhead. In order to gain significant increases in the first of these two quantities further nuclear tests would be necessary. Increase in the weight of the warhead, on the other hand, calls for bigger and more efficient missiles. In the present state of the art, efforts to improve CEP and reliability as well as weight-carrying capacity hold out more promise than efforts to improve the yield-to-weight ratio. The reason is that missile design and control involve less mature and less fully exploited technologies than the technology of nuclear warheads. Finally, an increase in the number of missiles, although not necessarily cheap, promises more straightforward and assured




**NUCLEAR EXPLOSIONS IN THE ATMOSPHERE from 1945 to 1962, the last full year in which the U.S. and the U.S.S.R. set off such explosions, are presented on the basis of accumulated megatons. The bars of equal height for the periods 1957–1958 and 1959–1960 reflect the informal moratorium on testing. The overall increase in megatons has doubled every three years. The data for this chart are from *Federal Radiation Council Report No. 4.***




**STRONTIUM 90 IN THE TEETH OF INFANTS between 1949 and 1957 was measured in a cooperative project of the Committee for Nuclear Information and the Washington University and St. Louis University schools of dentistry. This curve shows the strontium-90 activity in the deciduous teeth of bottle-fed infants. Because such teeth can be collected only some six years after the birth of the child, the curve does not come up to the present. The sharp rise in strontium-90 activity coincides with the period of extensive nuclear testing beginning in 1953. In the course of the project 110,000 teeth were collected.**

results than a fractional increase in yield-to-weight ratio. Of all the various possible technical approaches to improving the military effectiveness of an offensive missile force, therefore, the only one that calls for testing (whether underground or in the atmosphere) is the one that offers the smallest prospect of return.

Suppose, however, a new analysis, based on information not previously considered, should show that it is in fact necessary to incorporate the 100-megaton bomb in the U.S. arsenal. Can this be done without further weapons tests? The answer is yes. Because the U.S.S.R. has pushed development in this yield range and the U.S. has not, the U.S. 100-megaton bomb might not be as elegant as the Soviet model. It would perhaps weigh somewhat more or at the same weight would produce a somewhat lower yield. It could be made, however, and the basic techniques for making it have been known since the late 1950's. The warhead for such a bomb would require a big missile, but not so big as some being developed by the National Aeronautics and Space Administration for the U.S. space-exploration program. Such a weapon would be expensive, particularly on a per-unit basis; under any imaginable circumstances it would be of limited use and not many of its kind would be built.

The extensive series of weapons tests carried out by the U.S.—involving the detonation of several hundred nuclear bombs and devices—have yielded two important bodies of information. They have shown how to bring the country's nuclear striking force to its present state of high effectiveness. And they have demonstrated the effects of nuclear weapons over a wide range of yields. Among the many questions that call for soundly based knowledge of weapons effects perhaps none is more important in a discussion of the technical aspects of national security than: What would be the result of a surprise attack by missiles on the country's own missile forces? Obviously if the huge U.S. investment in its nuclear armament is to succeed in deterring an attacker, that armament must be capable of surviving a first strike.

A reliable knowledge of weapons effects is crucial to the making of rational decisions about the number of missiles needed, the hardening of missile emplacements, the degree of dispersal, the proportion that should be made mobile and so on. The military planner must bear in mind, however, that such decisions take time—years—to carry out and require large investments of finite physical and human resources. The inertia of the systems is such that the design engineer at work today must be concerned not with the surprise attack that might be launched today but rather with the kind and size of forces that might be launched against them years in the future. In addition to blast, shock and other physical effects, therefore, the planner must contend with a vast range of other considerations. These include the yields of the various bombs the attacker would use against each target; the reliability and accuracy of his missiles; the number and kind of weapons systems he would have available for attack; the tactics of the attacker, meaning the number of missiles he would commit to a first strike, the fractions he would allocate to military as against civilian targets and the relative importance he would assign to various kinds of military targets, the effects of chaos on the defender's capacity to respond, and so on. In all cases the planner must project his thinking forward to some hypothetical future time, making what he can of the available intelligence about the prospective attacker's present capabilities and intentions. Plainly all these "other considerations" involve inherently greater uncertainties than the knowledge of weapons effects.

The extensive classified and unclassified literature accumulated in two decades of weapons tests and available to U.S. military planners contains at least some observations on all important effects for weapons with a large range of yields. These observations are more or less well understood in terms of physical theories; they can be expressed in numerical or algebraic form, and they can be extrapolated into areas not fully explored in the weapons tests conducted by the U.S., for example into the 100-megaton range. As one departs from the precise circumstances of past experiments, of course, extrapolation becomes less and less reliable. Nonetheless, some sort of estimate can be made about what the prompt and direct effects will be under any conceivable set of circumstances.

Consider, in contrast, the degree of uncertainty implicit in predicting the number and kind of weapons systems that might be available to the prospective attacker. Such an uncertainty manifested itself in the famous "missile gap" controversy. The remarkable difference between the dire predictions made in the late 1950's—based as they were on the best available intelligence—and the actual situation that developed in the early 1960's can be taken as indicating the magnitude of the uncertainties that surround the variables other than weapons effects with which the military planner must contend. Moreover, these factors, as they concern a future attack, are uncertain not only to the defender; they are almost as uncertain to the attacker.

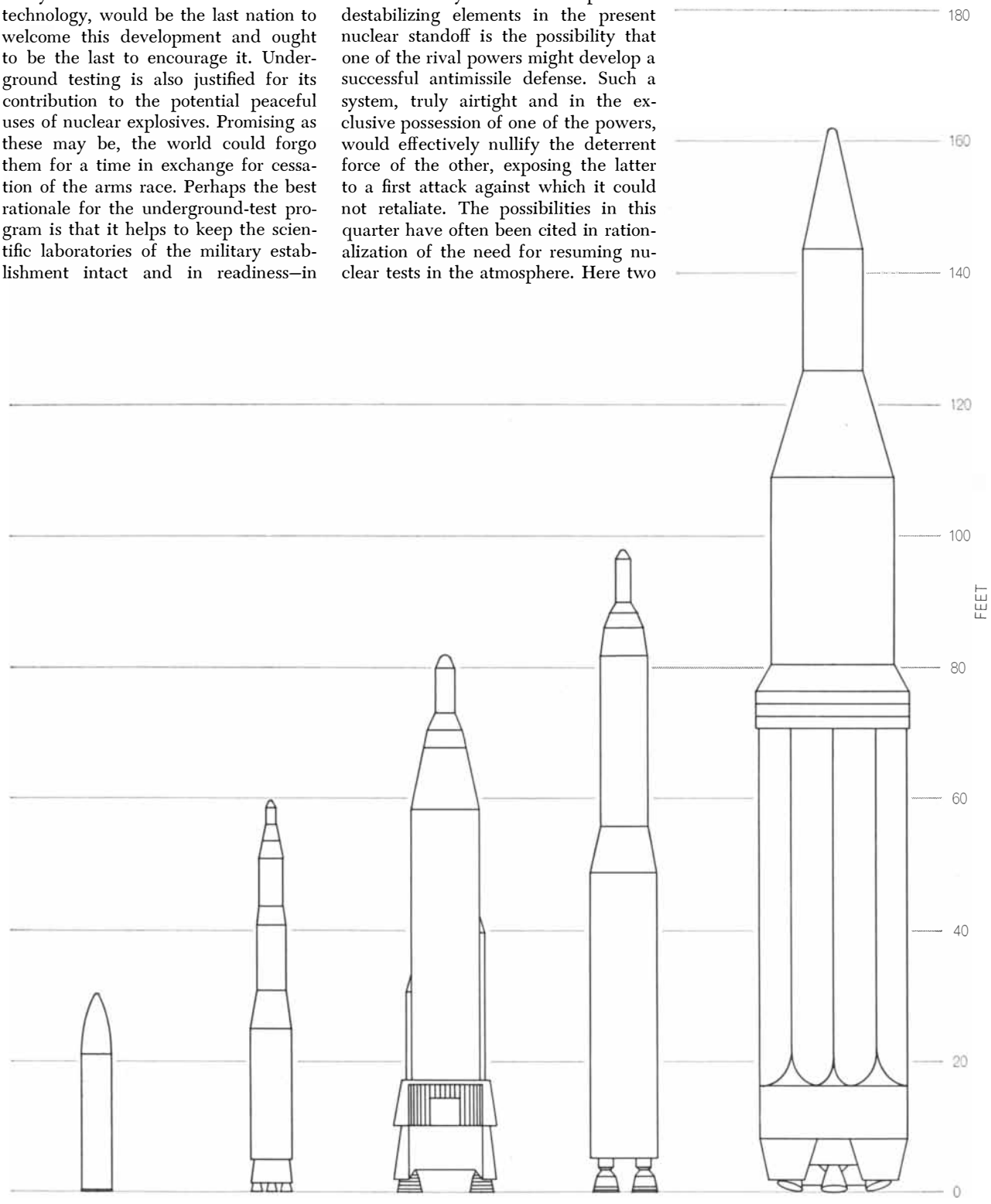
Uncertainties of this order and kind defy reduction to mathematical expression. A human activity as complex as modern war cannot be computed with the precision possible in manipulation of the data that concern weapons effects. What is more, the uncertainties about this single aspect of the total problem are not, as is sometimes assumed, multiplicative in estimation of the overall uncertainty. Most, but not all, of the uncertainties are independent of one another. The total uncertainty is therefore, crudely speaking, the square root of the sum of the squares of the individual uncertainties.

In our view further refinement of the remaining uncertainties in the data concerning prompt direct physical effects can contribute virtually nothing more to management of the real military and political problems, even though it would produce neater graphs. Furthermore, if new effects should be discovered either experimentally or theoretically in the future, or if, in certain peculiar environments, some of the now known effects should be excessively uncertain, it will be almost certainly possible to "overdesign" the protection against them. Thus, although renewed atmospheric testing would contribute some refinement to the data on weapons effects, the information would be, at best, of marginal value.

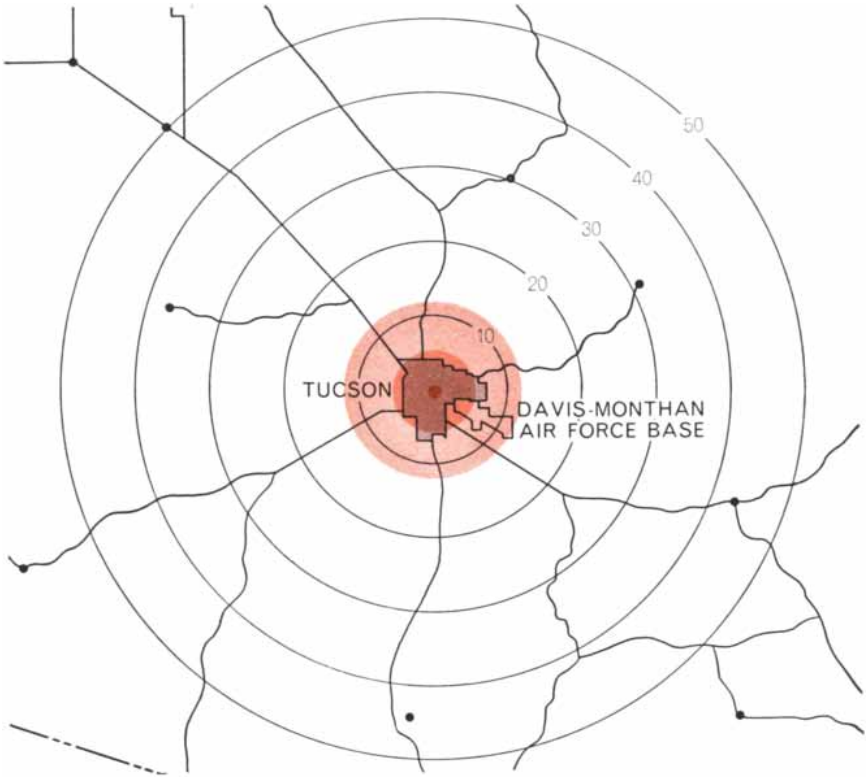
Such refinements continue to be sought in the underground tests that are countenanced under the partial test ban. From this work may also come some reductions in the cost of weapons, modest improvements in yield-to-weight ratios, devices to fill in the spectrum of tactical nuclear weapons and so on. There is little else to justify the effort and expenditure. The program is said by some to be necessary, for example, to the development of a pure fusion bomb, sometimes referred to as the "neutron bomb." It is fortunate that this theoretically possible (stars are pure fusion systems) device has turned out to be so highly difficult to create; if it were relatively simple, its development might open the way to thermonuclear arma-

ment for the smallest and poorest powers in the world. The U.S., with its heavy investment in fission-to-fusion technology, would be the last nation to welcome this development and ought to be the last to encourage it. Underground testing is also justified for its contribution to the potential peaceful uses of nuclear explosives. Promising as these may be, the world could forgo them for a time in exchange for cessation of the arms race. Perhaps the best rationale for the underground-test program is that it helps to keep the scientific laboratories of the military establishment intact and in readiness—in readiness, however, for a full-scale resumption of the arms race.

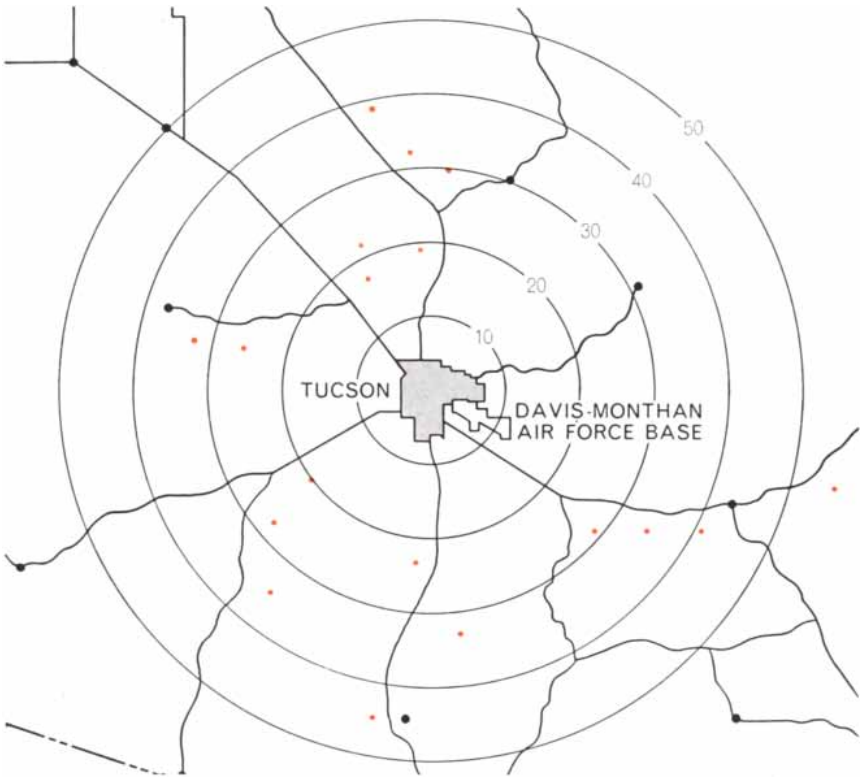
Paradoxically one of the potential destabilizing elements in the present nuclear standoff is the possibility that one of the rival powers might develop a successful antimissile defense. Such a system, truly airtight and in the exclusive possession of one of the powers, would effectively nullify the deterrent force of the other, exposing the latter to a first attack against which it could not retaliate. The possibilities in this quarter have often been cited in rationalization of the need for resuming nuclear tests in the atmosphere. Here two




**PAYLOAD OF EXISTING ROCKETS sets a limit on the size of nuclear weapons that can be used in a rocket attack. The five U.S. rockets shown here are drawn to scale. At left is the Polaris Type A-3, designed for launching from submarines; it weighs 30,000 pounds, has a range of 2,500 nautical miles and can carry a nuclear warhead of about one megaton. Second from left is Minuteman II; it weighs 65,000 pounds, has a range of 6,300 nautical miles and can carry a warhead of about one megaton. Third is Atlas; it weighs 269,000 pounds, has a range of 9,000 nautical miles and can carry a warhead of about five megatons. Fourth is Titan II; it weighs 303,000 pounds, has a range of 6,300 nautical miles and can carry a warhead of about 20 megatons. To lift a larger warhead would require a rocket such as Saturn I (*right*), which weighs 1,138,000 pounds. Data are from the journal *Missiles and Rockets.***




**"SOFT" TARGET is here represented by Tucson, Ariz. This drawing outlines the effects of a one-megaton bomb set off at 11,000 feet. The fireball (*dark red*) would have a radius of .7 mile. At a distance of 4.32 miles from "ground zero" (*lighter red*) the overpressure would be five pounds per square inch, enough to destroy houses of ordinary construction. At a distance of 12 miles (*lightest red*) virtually all flammable materials would be ignited.**




**"HARD" TARGETS are represented by the 18 Titan II emplacements that according to published reports are located around Tucson (*red dots*). Each missile is protected in a silo designed to withstand an overpressure of 300 pounds per square inch. To knock out such an emplacement a one-megaton weapon would have to hit the ground within .38 mile.**

questions must be examined. One must first ask if it is possible to develop a successful antimissile defense system. It then becomes appropriate to consider whether or not nuclear weapons tests can make a significant contribution to such a development.

Any nation that commits itself to large-scale defense of its civilian population in the thermonuclear age must necessarily reckon with passive modes of defense (shelters) as well as active ones (antimissile missiles). It is in the active mode, however, that the hazard of technological surprise most often lurks. The hazard invites consideration if only for the deeper insight it provides into the contemporary revolution in the technology of war.

The primary strategic result of that revolution has been to overbalance the scales in favor of the attacker rather than the defender. During World War II interception of no more than 10 percent of the attacking force gave victory to the defending force in the Battle of Britain. Attrition of this magnitude was enough to halt the German attack because it meant that a given weapons-delivery system (bomber and crew) could deliver on the average only 10 payloads of high explosive; such a delivery rate was not sufficient to produce backbreaking damage. In warfare by thermonuclear missiles the situation is quantitatively and qualitatively different. It is easily possible for the offense to have in its possession and ready to launch a number of missiles that exceeds the number of important industrial targets to be attacked by, let us say, a factor of 10. Yet the successful delivery of only one warhead against each such target would result in what most people would consider an effective attack. Thus where an attrition rate of only 10 percent formerly crowned the defense with success, a penetration rate of only 10 percent (corresponding to an attrition rate of 90 percent) would give complete success to the offense. The ratio of these two ratios is 100 to one; in this sense the task of defense can be said to have become two orders of magnitude more difficult.

Beyond this summary statement of the situation there are many general reasons for believing that defense against thermonuclear attack is impossible. On the eve of attack the offense can take time to get ready and to "point up" its forces; the defense, meanwhile, must stay on the alert over periods of years, perpetually ready and able to fire within the very few minutes

available after the first early warning. The attacker can pick its targets and can choose to concentrate its forces on some and ignore others; the defense must be prepared to defend all possible important targets. The offense may attack the defense itself; then, as soon as one weapon gets through, the rest have a free ride.

The hopelessness of the task of defense is apparent even now in the stalemate of the arms race. A considerable inertia drags against the movement of modern, large-scale, unitary weapons systems from the stage of research and development to operational deployment. The duration and magnitude of these enterprises, whether defensive or offensive, practically assure that no system can reach full deployment under the mantle of secrecy. The designer of the defensive system, however, cannot begin until he has learned something about the properties and capabilities of the offensive system. Inevitably the defense must start the race a lap behind. In recent years, it seems, the offense has even gained somewhat in the speed with which it can put into operation stratagems and devices that nullify the most extraordinary achievements in the technology of defense. These general observations are expensively illustrated in the development and obsolescence of two major U.S. defense systems.

Early in the 1950's the U.S. set out to erect an impenetrable defense against a thermonuclear attack by bombers. The North American continent was to be ringed with a system of detectors that would flash information back through the communications network to a number of computers. The computers were to figure out from this data what was going on and what ought to be done about it and then flash a series of commands to the various interceptor systems. In addition to piloted aircraft, these included the Bomarc (a guided airborne missile) and the Nike-Hercules (a ballistic rocket). By the early 1960's this "Sage" system was to be ready to detect, intercept and destroy the heaviest attack that could be launched against it.

The early 1960's have come and yet nothing like the capability planned in the 1950's has been attained. Why not? Time scales stretched out, subsystems failed to attain their planned capabilities and costs increased. Most important, the offense against which the system was designed is not the offense that actually exists in the early 1960's. Today the offensive system on both sides is a mixture of missiles and bombers. The Sage system has a relatively small number of soft but vital organs completely vulnerable to missiles—a successful missile attack on them would give a free ride to the bombers. As early as 1958 the Department of Defense came to realize that this would be the situation, and the original grand plan was steadily cut back. In other words, the Sage system that could have been available, say, in 1963 and that should have remained useful at least through the 1960's would in principle have worked quite well against the offense that existed in the 1950's.

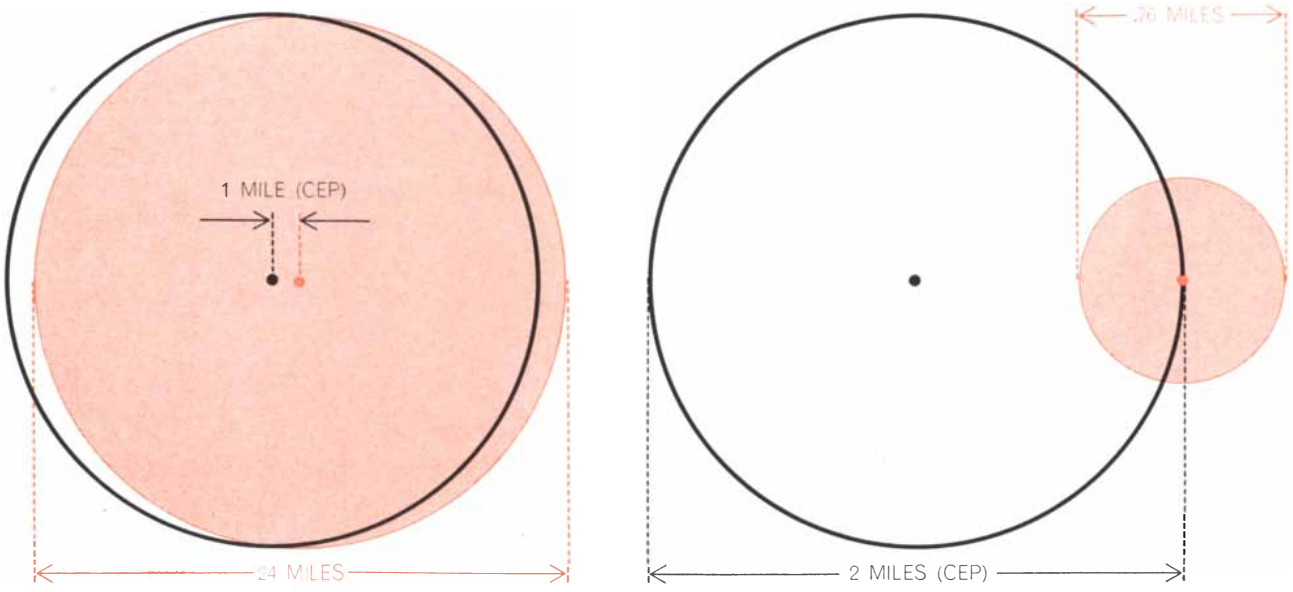
To answer the intercontinental ballistic missile, the Department of Defense launched the development of the Nike-Zeus system. Nike-Zeus was intended to provide not a defense of the continent at its perimeter but a point defense of specific targets. To be sure, the "points" were fairly large—the regions of population concentration around 50 to 70 of the country's biggest cities. The system was to detect incoming warheads, feeding the radar returns directly into its computers, and launch and guide an interceptor missile carrying a nuclear warhead into intersection with the trajectory of each of the incoming warheads.

Nike-Zeus was not designed to defend the 1,000 or so smaller centers outside the metropolitan areas simply because there are too many of these to be covered by the resources available for a system so huge and complicated. Nor was the system designed to defend the retaliatory missiles, the security of these forces being entrusted to the more reliable protection of dispersal, concealment, mobility and number. In principle, the defense of a hardened missile silo would have presented by far the simplest case for proof of the effectiveness of Nike-Zeus as advanced by those who contend that such a system can be made to "work." There would be no ambiguity about the location of the target of the incoming warhead. By the same token Nike-Zeus might have been considered for the defense of a few special defense posts, such as the headquarters of the Air Defense Command of the Strategic Air Command. These special cases are so few in number, however, that it had to be concluded that the attacker would either blast his way through to them by a concentration of firepower or ignore them altogether.

At the time of the conception of the Nike-Zeus system its designers were confronted with a comparatively simple problem, namely that of shooting down the warheads one by one as they presented themselves to the detectors. Even this simple problem had to be regarded as essentially unsolvable, in view of the fact that a 90-percent success in interception constitutes failure in the inverted terms of thermonuclear warfare. At first, therefore, the designers of the offensive system did not take the prospect of an antimissile system seriously. Then the possibility that the problem of missile interception might be solved in principle gave them pause. Thereupon the designers of the offense began to invent a family of "penetration aids," that is, decoys and confusion techniques. The details of these and the plans for their use are classified, but the underlying principles are obvious. They include light decoys that can be provided in large numbers but that soon betray their character as "atmospheric sorting" separates them from the heavier decoys (and actual warheads) that can be provided in smaller numbers to confuse the defending detectors down to the last minute. Single rockets can also eject multiple warheads. Both the decoys and the warheads can be made to present ambiguous cross sections to the radar systems. These devices and stratagems overwhelmed the designed capability of the Nike-Zeus system and compelled its recent abandonment.

If the installation of the system had proceeded according to plan, the first Nike-Zeus units would have been operational within the next year or two. This could have been celebrated as a technical milestone. As a means of defense of a substantial percentage of the population, however, the system would not have reached full operational deployment until the end of the decade. In view of its huge cost the system should then have looked forward to a decade of useful life until, say, the late 1970's. Thus, in inexorable accordance with the phase-lag of the defense, the U.S. population was to be defended a decade too late by a system that might have been effective in principle (although most probably not in practice) against the missiles of the early 1960's.

The race of the tortoise and the hare has now entered the next lap with the development of the Nike-X system as successor to Nike-Zeus. The Advanced Research Projects Agency of the Department of Defense has been spending something on the order of $200 million a year on its so-called Defender Program, exploring on the broadest front the principles and techniques that might




**ACCURACY OF MISSILES has far more relevance for hard targets than for soft. It has been estimated that at maximum range both U.S. and Soviet rockets have a "circular error probable" of about a mile, that is, there is a probability of 50 percent that a rocket will hit within a mile of the target. The radius of fire damage for a one-megaton bomb will not be greatly affected by a near miss (*circles at left*). The radius of kill for a one-megaton bomb aimed at a target hardened to 300 pounds per square inch, however, is so much smaller than the circular error probable (*circles at right*) that a number of weapons would have to be used to assure a hit. The illustrations in this article and the figures on which they are based are not the responsibility of the authors but of the editors.**

prove useful in the attempt to solve the antimissile problem. Although nothing on the horizon suggests that there is a solution, this kind of work must go forward. It not only serves the forlorn hope of developing an active antimissile defense but also promotes the continued development of offensive weapons. The practical fact is that work on defensive systems turns out to be the best way to promote invention of the penetration aids that nullify them.

As the foregoing discussion makes clear, the problems of antimissile development are problems in radar, computer technology, missile propulsion, guidance and control. The nuclear warheads for the antimissile missile have been ready for a long time for delivery to the right place at the right time. Although it is argued that certain refinements in the existing data about weapons effects are needed, the other uncertainties all loom much larger than the marginal uncertainties in these physical effects. The antimissile defense problem, then, is one in which nuclear testing can play no really significant part.

The pursuit of an active defense system demands parallel effort on the passive defense, or shelter, front because the nature of the defense system strongly conditions the tactics of the offense that is likely to be mounted against it. To take a perhaps farfetched example, a Nike-Zeus system that provided protection for the major population centers might invite the attacker to concentrate the weight of his assault in ground bursts on remote military installations and unprotected areas adjacent to cities, relying on massive fallout to imperil the population centers. This example serves also to suggest how heavily the effectiveness of any program for sheltering the civilian population depends on the tactics of the attacker. Fallout shelters by themselves are of no avail if the attacker chooses to assault the population centers directly.

In any speculation about the kind of attack to which this country might be exposed it is useful to note where the military targets are located. Most of the missile bases are, in fact, far from the largest cities. Other key military installations, however, are not so located. Boston, New York, Philadelphia, Seattle, San Francisco, Los Angeles (Long Beach) and San Diego all have important naval bases. Essential command and control centers are located in and near Denver, Omaha and Washington, D.C. The roll call could be extended to include other major cities containing military installations that would almost certainly have to be attacked in any major assault on this country. The list does not stop with these; it is only prudent to suppose still other cities would come under attack, because there is no way to know in advance what the strategy may be.

The only kind of shelter that is being seriously considered these days, for other than certain key military installations, is the fallout shelter. By definition fallout shelters offer protection against nothing but fallout and provide virtually no protection against blast, fire storms and other direct effects. Some people have tried to calculate the percentage of the population that would be saved by fallout shelters in the event of massive attack. Such calculations always involve predictions about the form of the attack, but since the form is unknowable the calculations are nonsensical. Even for the people protected by fallout shelters the big problem is not a problem in the physical theory of gamma-ray attenuation, which can be neatly computed, but rather the sociological problem of the sudden initiation of general chaos, which is not subject to numerical analysis.

Suppose, in spite of all this, the country were to take fallout shelters seriously and build them in every city and town. The people living in metropolitan areas that qualify as targets because they contain essential military installations and the people living in metropolitan areas that might be targeted as a matter of deliberate policy would soon recognize that fallout shelters are inadequate. That conclusion would be reinforced by the inevitable reaction from the other side, whose military planners would be compelled to consider a mas-

sive civilian-shelter program as portending a first strike against them. Certainly the military planners of the U.S. would be remiss if they did not take similar note of a civilian-shelter program in the U.S.S.R. As a step in the escalation of the arms race toward the ultimate outbreak of war, the fallout shelter would lead inevitably to the blast shelter. Even with large numbers of blast shelters built and evenly distributed throughout the metropolitan community, people would soon realize that shelters alone are not enough. Accidental alarms, even in tautly disciplined military installations, have shown that people do not always take early warnings seriously. Even if they did, a 15-minute "early" warning provides less than enough time to seal the population into shelters. Accordingly, the logical next step is the live-in and work-in blast shelter leading to still further disruption and distortion of civilization. There is no logical termination of the line of reasoning that starts with belief in the usefulness of fallout shelters; the logic of this attempt to solve the problem of national security leads to a diverging series of ever more grotesque measures. This is to say, in so many words, that if the arms race continues and resumes its former accelerating tempo, 1984 is more than just a date on the calendar 20 years hence.

Ever since shortly after World War II the military power of the U.S. has been steadily increasing. Throughout this same period the national security of the U.S. has been rapidly and inexorably diminishing. In the early 1950's the U.S.S.R., on the basis of its own unilateral decision and determination to accept the inevitable retaliation, could have launched an attack against the U.S. with bombers carrying fission bombs. Some of these bombers would have penetrated our defenses and the American casualties would have numbered in the millions. In the later 1950's, again on its own sole decision and determination to accept the inevitable massive retaliation, the U.S.S.R. could have launched an attack against the U.S. using more and better bombers, this time carrying thermonuclear bombs. Some of these bombers would have penetrated our defenses and the American casualties could have numbered in the tens of millions.

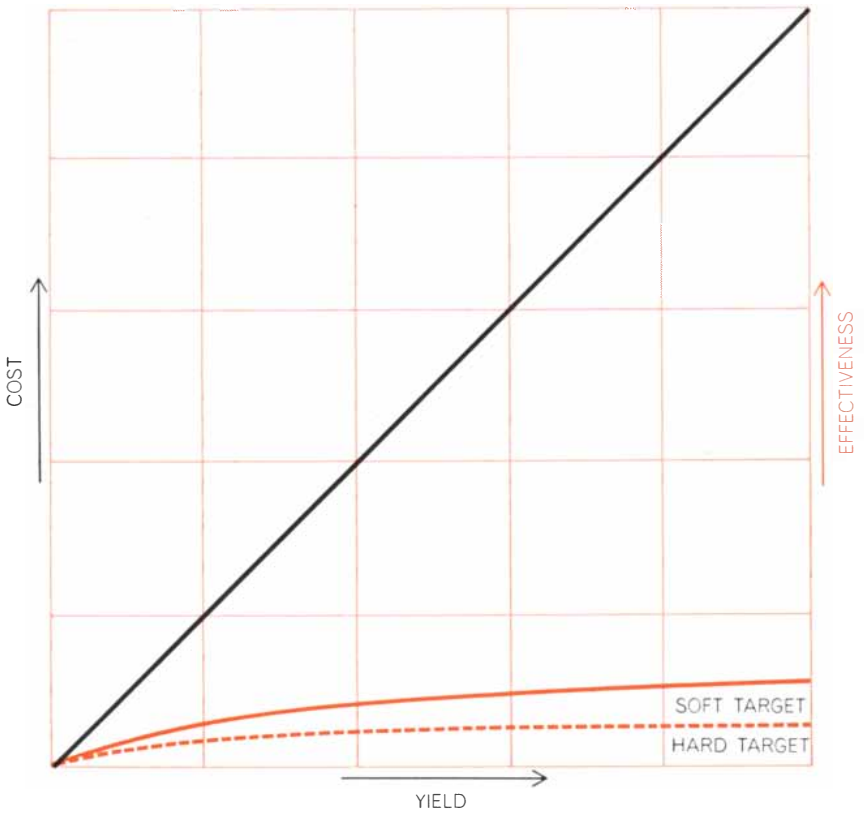
Today the U.S.S.R., again on the basis of its own decision and determination to accept the inevitable retaliation, could launch an attack on the U.S. using intercontinental missiles and bombers carrying thermonuclear weapons. This time the number of American casualties could very well be on the order of 100 million.

The steady decrease in national security did not result from any inaction on the part of responsible U.S. military and civilian authorities. It resulted from the systematic exploitation of the products of modern science and technology by the U.S.S.R. The air defenses deployed by the U.S. during the 1950's would have reduced the number of casualties the country might have otherwise sustained, but their existence did not substantively modify this picture. Nor could it have been altered by any other defense measures that might have been taken but that for one reason or another were not taken.

From the Soviet point of view the picture is similar but much worse. The military power of the U.S.S.R. has been steadily increasing since it became an atomic power in 1949. Soviet national security, however, has been steadily decreasing. Hypothetically the U.S. could unilaterally decide to destroy the U.S.S.R. and the U.S.S.R. would be absolutely powerless to prevent it. That country could only, at best, seek to wreak revenge through whatever retaliatory capability it might then have left.

Both sides in the arms race are thus confronted by the dilemma of steadily increasing military power and steadily decreasing national security. *It is our considered professional judgment that this dilemma has no technical solution.* If the great powers continue to look for solutions in the area of science and technology only, the result will be to worsen the situation. The clearly predictable course of the arms race is a steady open spiral downward into oblivion.

We are optimistic, on the other hand, that there is a solution to this dilemma. The partial nuclear-test ban, we hope and believe, is truly an important first step toward finding a solution in an area where a solution may exist. A next logical step would be the conclusion of a comprehensive test ban such as that on which the great powers came close to agreement more than once during 10 long years of negotiation at Geneva. The policing and inspection procedures so nearly agreed on in those parleys would set significant precedents and lay the foundations of mutual confidence for proceeding thereafter to actual disarmament.




**COST OF NUCLEAR WEAPONS increases almost linearly with their yield (*black curve*). Their effectiveness, however, does not. The radiation effects, particularly heat, of an air burst against a soft target increase only as square root of the yield (*solid colored curve*); of the blast effects of a ground burst against a hard target, as cube root (*broken curve*).**

# The Omega-Minus Experiment

*An account of the experiment, performed with Brookhaven National Laboratory's 33-billion-electron-volt accelerator, that confirmed the existence of a new particle predicted by the "eightfold way"*

by William B. Fowler and Nicholas P. Samios

Among the landmarks of physics in the 20th century are the successful predictions of theoretical physics. The Davisson-Germer experiment showing that electrons behave like waves (predicted by Louis de Broglie), the discovery of the massless neutrino (predicted by Wolfgang Pauli), the discoveries of the positron and other antiparticles (predicted by P. A. M. Dirac) —these are some of the successes of hypotheses that to many seemed hardly more than speculations when they were first proposed. Each was a concept invented by abstract, mathematical reasoning based on earlier experimental results, and each was eventually verified by physical detection of the predicted phenomenon. The latest in this series of remarkable "inventions" is the omega-minus particle, whose existence was predicted only two years ago and has now been confirmed by actual production of the particle.

There are special reasons why the discovery of this particle has aroused the interest of physicists. It supports a theory that shows promise of introducing some kind of order into the puzzling assortment of particles that physicists have detected in their dissection of the atomic nucleus. The theory was proposed in 1961 by Murray Gell-Mann of the California Institute of Technology and independently by Yuval Ne'eman of Tel Aviv University in Israel [see "Strongly Interacting Particles," by Geoffrey F. Chew, Murray Gell-Mann and Arthur H. Rosenfeld; SCIENTIFIC AMERICAN, February]. It groups the particles into families according to their quantum properties. Gell-Mann noted that one of the families apparently was incomplete. Nine members of the family were known; the theory indicated there should be a tenth, and it specified the properties the missing particle must possess.

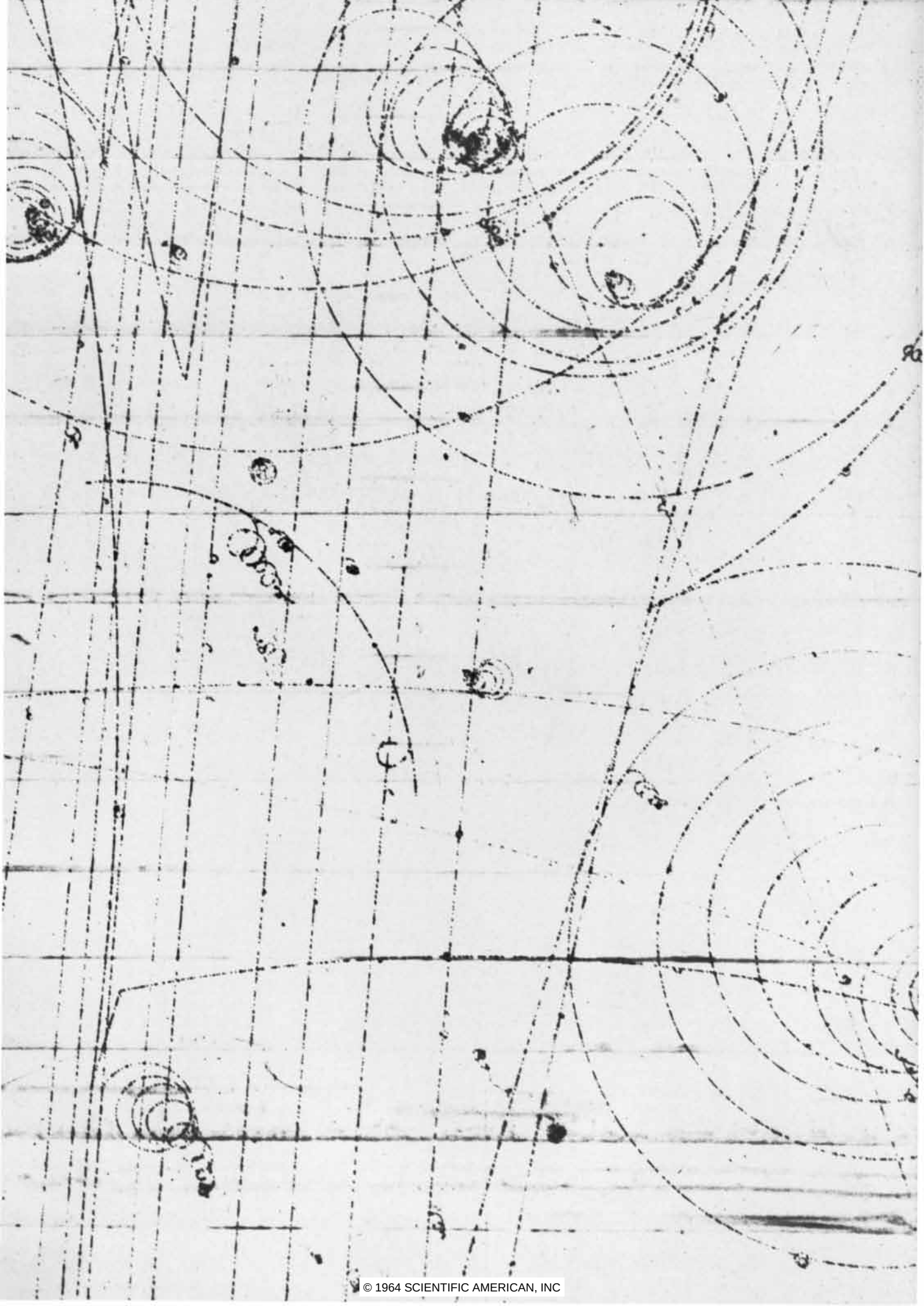
The situation was somewhat like the one presented by Dmitri Mendeleev when he devised the periodic table of the elements in 1869. Mendeleev saw that there were three vacancies at certain positions in his table, and he insisted that elements corresponding to those vacancies, whose properties he described, must exist and would someday be found. They were discovered not long afterward. Similarly, the missing particle described by Gell-Mann, which he named omega-minus, was found when it was searched for, and it proved to have exactly the properties specified by the theory.

This article will relate how the omega-minus was produced and identified. The details of the theory need not concern us here; they were thoroughly discussed in the February issue by Gell-Mann and his coauthors. It classifies nuclear particles (baryons and mesons) by a system based on the branch of mathematics called group theory. The system is known as SU(3) symmetry and has also been named the "eightfold way," because it involves eight mathematical operators related to the quantum numbers of particles.

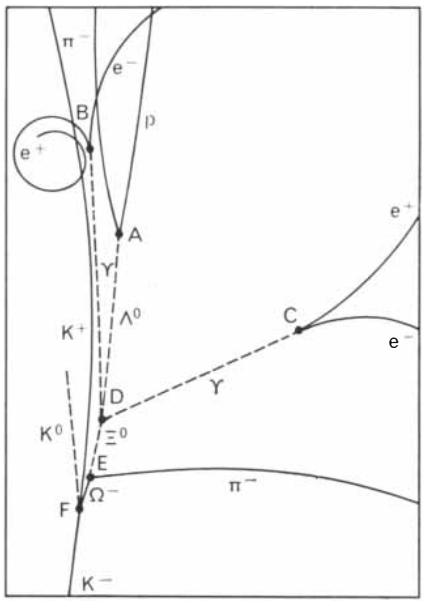
According to this scheme the particles constituting a family must all have the same spin angular momentum (speed of intrinsic spin) and the same parity (left-handedness or right-handedness). They may differ in mass, electric charge and the properties known as "strangeness" and "isotopic spin," but in these quantities they must be related to one another by certain rules.

The family with which we are concerned starts with the baryons called delta particles—delta-minus, delta-zero, delta-plus and delta-double-plus (with two units of positive charge). The members of this quartet have a spin angular momentum of 3/2 units, positive parity and an effective mass of 1,238 million electron volts. (In particle physics mass is now commonly expressed in terms of energy.) Now, if one looks around for other known baryons that may belong to the same family, the sigma particle of mass 1,385 mev (million electron volts) immediately appears to be a likely relative. Like the deltas, the three charge versions of the sigma particle (sigma-minus, sigma-zero and sigma-plus) have a spin angular momentum of 3/2 and positive parity. The quantum number describing the strangeness of the delta particles is zero; that of the sigmas is minus one. The deltas have an isotopic spin of 3/2; the sigmas, an isotopic spin of 1—a half-unit difference. Thus the sigma triplet, at a higher mass level than the delta quartet, begins to form a symmetrical pyramid [*see illustration on page 42*].

**BROOKHAVEN ACCELERATOR with which the omega-minus experiment was performed appears in the aerial photograph on the opposite page. The ring-shaped configuration of ground to the right of the large building at left center is a mound covering the tunnel that houses the magnet ring in which protons are accelerated to 33 billion electron volts. The beam of protons is injected into the ring by a linear accelerator that is housed in the small building at lower right center. The main target area is in the building at left center. The accelerating ring is some 800 feet in diameter. The accelerator, known as an alternating gradient synchrotron, has been in operation since 1960.**



What doublet might constitute the next level of the pyramid? The difference in mass between the delta and the sigma particles, 147 mev, suggested that the mass of the next pair of particles should be about 1,532 mev, 147 mev higher than that of the sigmas. No such particle, bearing the right quantum numbers, had been detected. At the biennial International Conference on High Energy Physics in Geneva in July, 1962, however, experimenters reported the discovery of a pair of xi particles (xi-minus and xi-zero) of mass 1,530 mev. Gell-Mann, who was present at the conference, immediately saw the connection between this almost routine announcement and the eightfold way.




**BUBBLE-CHAMBER PHOTOGRAPH on the opposite page was the first to show the existence of the omega-minus particle. The sequence of events in the production of the particle is given in the map above. The track of a K-minus meson ($K^-$) is seen at bottom of the photograph. The $K^-$ collides with a proton at vertex *F* to yield a K-zero meson ($K^0$), a K-plus meson ($K^+$) and an omega-minus particle ($\Omega^-$). The $K^+$ makes an identifiable track. The $\Omega^-$ disintegrates at vertex *E* to a pi-minus ($\pi^-$) and a xi-zero ($\Xi^0$) particle. The $\Xi^0$ is identified by its decay products, seen emerging from decay vertex *D:* two gamma rays that give rise to positron-electron pairs ($e^+$ and $e^-$) at *C* and *B*, and a lambda zero ($\Lambda^0$) that yields a $\pi^-$ and a proton ($p$) at vertex *A*. Knowledge of the masses and momenta of charged decay products of neutral particles that leave no tracks (*broken lines*) enable physicists to identify them. Thus the third particle branching from vertex *F* is known to be a $K^0$.**

The new xi particles qualified for membership in the family with the delta and sigma particles by their mass (very close to the predicted 1,532 mev). What was more, their strangeness was minus two, further confirming their position in the pyramid, because the strangeness quantum numbers now ran: delta quartet, zero; sigma triplet, minus one; xi doublet, minus two.

It was now possible to predict with reasonable confidence that the pyramid must be crowned by a singlet at the apex—a particle of strangeness minus three, spin 3/2, positive parity, negative charge and mass about 1,676 mev (146 mev higher than that of the xi particles). A determined, full-scale search for this particle, already named omega-minus, was therefore launched almost immediately.

Many of the nearly 100 known nuclear particles had already been placed in families (consisting of eight members each) on the basis of the new theory of classification. They seemed to fit into the theoretical system of organization very satisfactorily. It is one thing, however, to devise a scheme describing a set of known facts and quite another to create a generalization that will bring to light new phenomena previously undreamed of. The test of any grand-scale theory is its ability to predict what was previously unpredictable and to lead to new knowledge. If the eightfold way could produce, out of pure theory, the exact properties of a new particle, it might be an important step toward unraveling the obscurities surrounding the fundamental nature of matter and energy. The quest for this particle was worth a large effort.

It required, first of all, powerful and sophisticated tools, and fortunately tools adequate for the job were already at hand. The very large machines that have been built for nuclear physics in recent years were designed for just such crucial and difficult experiments as this one. The Brookhaven National Laboratory, with its 33-bev (33-billion-electron-volt) accelerator and a new 80-inch liquid-hydrogen bubble chamber, was prepared for the opportunity and welcomed the task of searching for the omega-minus. The situation was an experimentalist's dream: an important theory to be tested, a specific and crucial prediction on which the theory could stand or fall and equipment fully capable of producing and detecting the predicted particle if it existed. In November, 1963, Brookhaven undertook a large-scale omega-minus experiment that was to engage a large number of physicists (including the authors of this article), engineers and technicians.

What interaction might produce the omega particle? There was available a beam of high-energy K mesons, generated as secondary products by the 33-bev alternating-gradient synchrotron. Calculations suggested that sufficiently energetic K-minus particles, on interacting with target protons, would produce the omega-minus baryon and K-plus and K-zero mesons by the following reaction: $K^- + p \rightarrow \Omega^- + K^+ + K^0$. How much energy would the K-minus projectiles need to generate this reaction? The masses of the products (omega-minus, K-plus and K-zero) respectively represented energies of 1,676 mev, 494 mev and 498 mev, or a total of 2,668 mev. Because part of the energy of the projectiles in such a reaction goes into the energy of motion, or momentum, of the products emerging from the reaction, it was calculated that the K-minus mesons would need to hit the target protons with an energy of at least 3,200 mev. To heighten the probability of producing the reaction, it would be desirable to use a K-minus beam with substantially more energy than that minimum. Fortunately the accelerating and beam-separating system was capable of creating such beams with energies up to 5,000 mev.

The experiment was therefore designed as follows. A 5,000-mev beam of K-minus mesons would be shot into the bubble chamber. To avoid producing a confusion of tracks in the chamber the K-minus injections would be limited to bursts of 10 to 20 particles during the exposure time of each picture. It was hoped that an occasional K-minus meson would interact with a proton in the liquid hydrogen and produce an omega-minus particle. The omega-minus would be identified by the products into which it decayed.

The physical system set up for the experiment deserves at least a brief description. If a beam of 33-bev protons from the alternating-gradient synchrotron were directed into a bubble chamber, it would produce such a deluge of tracks that individual events could hardly be picked out of the scramble. When Brookhaven decided to build its 80-inch bubble chamber, one of its staff physicists, Medford S. Webster, undertook to develop a means of producing a pure beam of secondary particles that could be used with the chamber. The

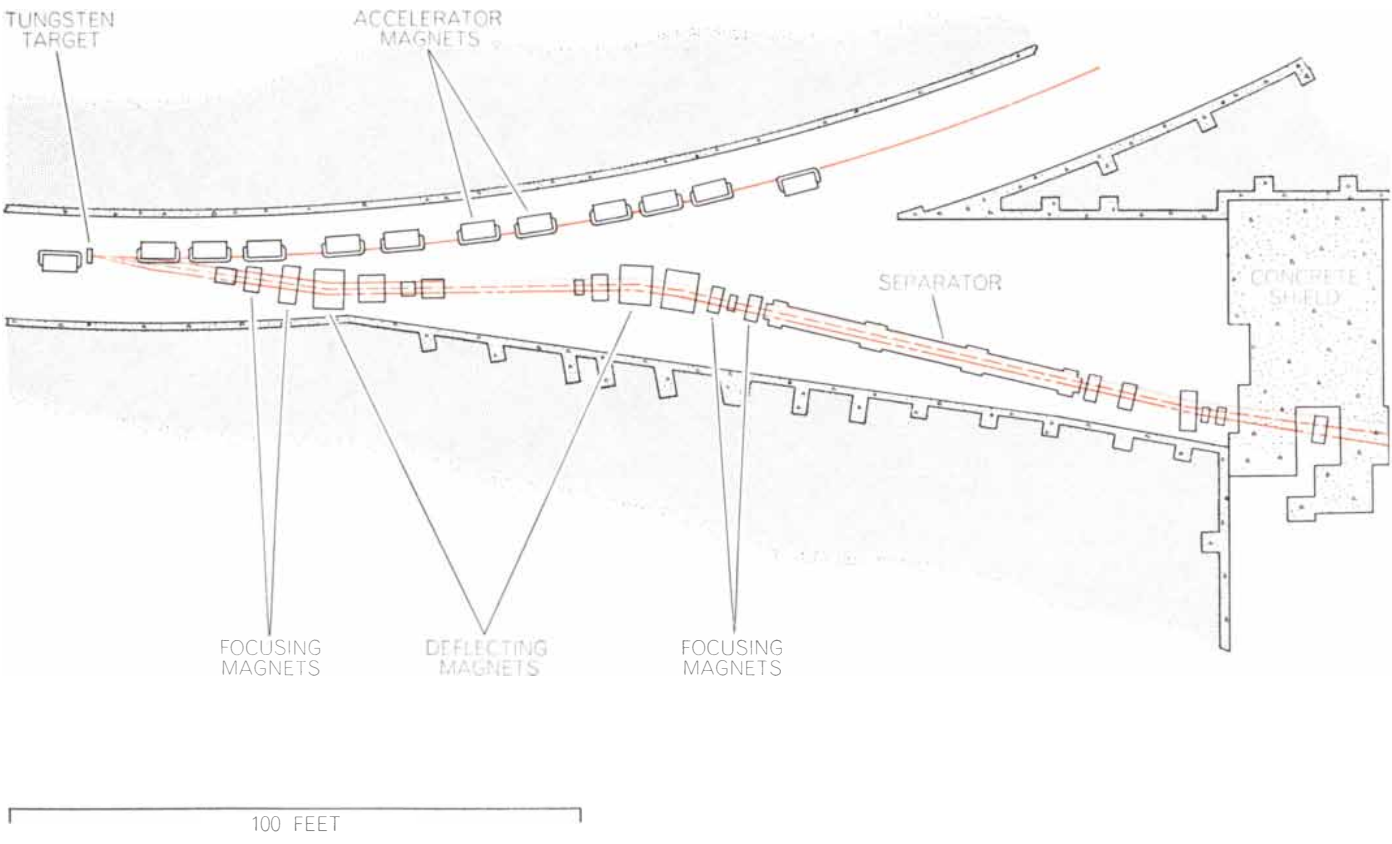
proton beam from the accelerator produces a veritable blizzard of secondary particles—pi mesons, K mesons and many others—when it hits a metal target. Webster devised a system for separating out the K mesons scattered from such a target and focusing them into a beam. His system, using electrostatic beam separators and deflecting and focusing magnets, is 450 feet long and produces a fine beam only six hundredths of an inch high when it emerges from the final transmitting slit. This beam, as we have mentioned, has an energy of 5,000 mev, or five bev.

Brookhaven's large new bubble chamber, 80 inches long and containing 900 liters of liquid hydrogen, is monitored by three cameras, so that the particle tracks within it can be located in three-dimensional space. Like all such instruments, it is equipped with a large electromagnet and other devices for identifying the charge and other properties of the particles that have formed the tracks. It can make photographs at the rate of one every second, allowing for recompression of the chamber after each recording of tracks.

Now came the critical question: What kind of photograph would identify the omega-minus particle? That is to say, into what products might the omega-minus decay? Consideration of the various conservation rules narrowed down the ways in which the omega-minus might decay into three most likely possibilities: it might break down into (1) a xi-minus particle and a neutral pi meson, (2) a xi-zero particle and a pi-minus meson or (3) a lambda-zero particle and a K-minus meson. These, then, were the results watched for in analyzing the photographs.

After six weeks of arduous labor in perfecting the operation of the beam equipment to obtain a sufficiently pure and intense beam of K-minus mesons, photography of the bombardment of the bubble chamber by the beam began on December 14, 1963. In the ensuing months the entire system—the accelerator, the beam equipment, the bubble chamber and the cameras—was operated on an around-the-clock basis. By January 30, 50,000 good photographs had been obtained. As the photographs were made the tracks were scanned and analyzed closely. This entailed making very accurate measurements and calculations of the precise locations within the chamber where interactions or decays took place and of the angles and curvatures of the tracks that were made by the new particles emerging from these reactions.

On January 31 there turned up a photograph with a set of tracks that seemed to signal the production of an omega-minus particle. The sequence of tracks indicated that the omega-minus had decayed into a xi-zero particle and a pi-minus meson, and both products had gone on to further decays. According to the predicted process for the creation of the omega-minus, the interaction of the K-minus projectile and the proton was expected to produce K-plus and K-zero mesons along with the omega-minus. The photograph showed the track of a K-plus meson emerging from the point of the interaction. There was no sign of the formation of a K-zero, but this was not surprising, because the uncharged particle itself would make no track and it might well have left the



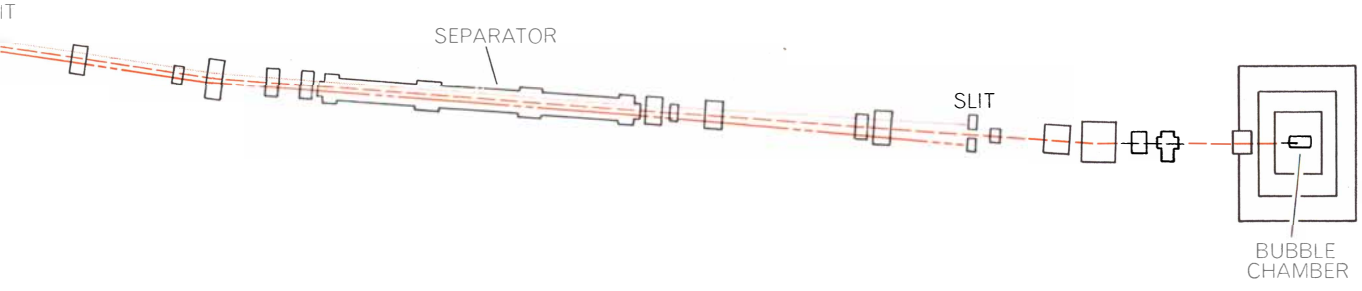

**EXPERIMENTAL ARRANGEMENT** shows the tungsten target (*left*) into which the accelerated proton beam is deflected after acceleration. Focusing magnets gather secondary particles from the target; deflecting magnets select, on the basis of momenta, which particles are to pass on to the electrostatic beam separator. This separator then deflects the particles to an extent dependent on their

bubble chamber before decaying into other particles.

These interpretations of the photograph rested simply on visual inspection. They now had to be verified in quantitative terms. In any reading of such an event in particle physics the burden of proof lies heavily on the experimenter. He must show, by precise measurements and calculations of the density, length, angles and curvatures of the tracks, that they actually identify the particles and reactions they seem to depict. The group proceeded to several days of feverish activity to check the photograph.

The photograph of this event and a diagram picking out the significant tracks appear on pages 38 and 39. To reconstruct what happened one starts with the final decays recorded and works backward to the main event. Let us start with the event signalized by the fork (called a "vertex") labeled *A* in the diagram. The right-hand track emerging from this vertex is clearly heavier than nearby parallel tracks that represent K-minus particles in the beam coursing through the chamber. Measurements identify this track as that of a proton. Similarly, the left-hand track from the same vertex identifies that particle as a pi-minus meson. On the basis of the measured momenta and masses of these particles, equations for the conservation of energy and of momentum allow one to calculate that the proton and pi-minus meson emerged from the decay of a lambda-zero particle with a mass of 1,115 mev. Now, the lambda-zero particle, having no electric charge, made no track in the chamber, but the direction of its path (indicated by a broken line in the diagram) can be calculated from the properties of the two tracks branching from vertex *A*. This path must lead to a point where the lambda-zero particle originated. There are no visible tracks indicating the location of that vertex, but two events shown in the photograph evidently stem from it. These events are the creation of electron-positron pairs at the points labeled *B* and *C* in the diagram. The two pairs of antiparticles must have been produced by energetic gamma rays. Although the gamma rays left no tracks in the chamber, their paths and point of intersection can be calculated from the measured momenta (including, of course, direction) of the electron-positron pairs. This point (*D*) also lies on the calculated path of the lambda-zero particle. Thus it is clear that the lambda-zero particle and the two gamma rays were generated by the decay of another particle at *D;* calculations show that this particle must have been a xi-zero baryon with a mass of 1,316 mev, and that it decayed into the lambda-zero particle and a pi-zero meson, which promptly decayed into the two gamma rays that proceeded to form electron-positron pairs.

The xi-zero, like the lambda-zero, left no track, but again the direction of its path can be calculated. Projecting this backward, we come at last to a visible vertex at point *E,* where the xi-zero originated; a track going off sharply to the right is consistent with a pi-minus meson that was produced at the same time. Adding up the momenta of the xi-zero and the pi-minus, we obtain the momentum of the parent particle from which they sprang. One can calculate



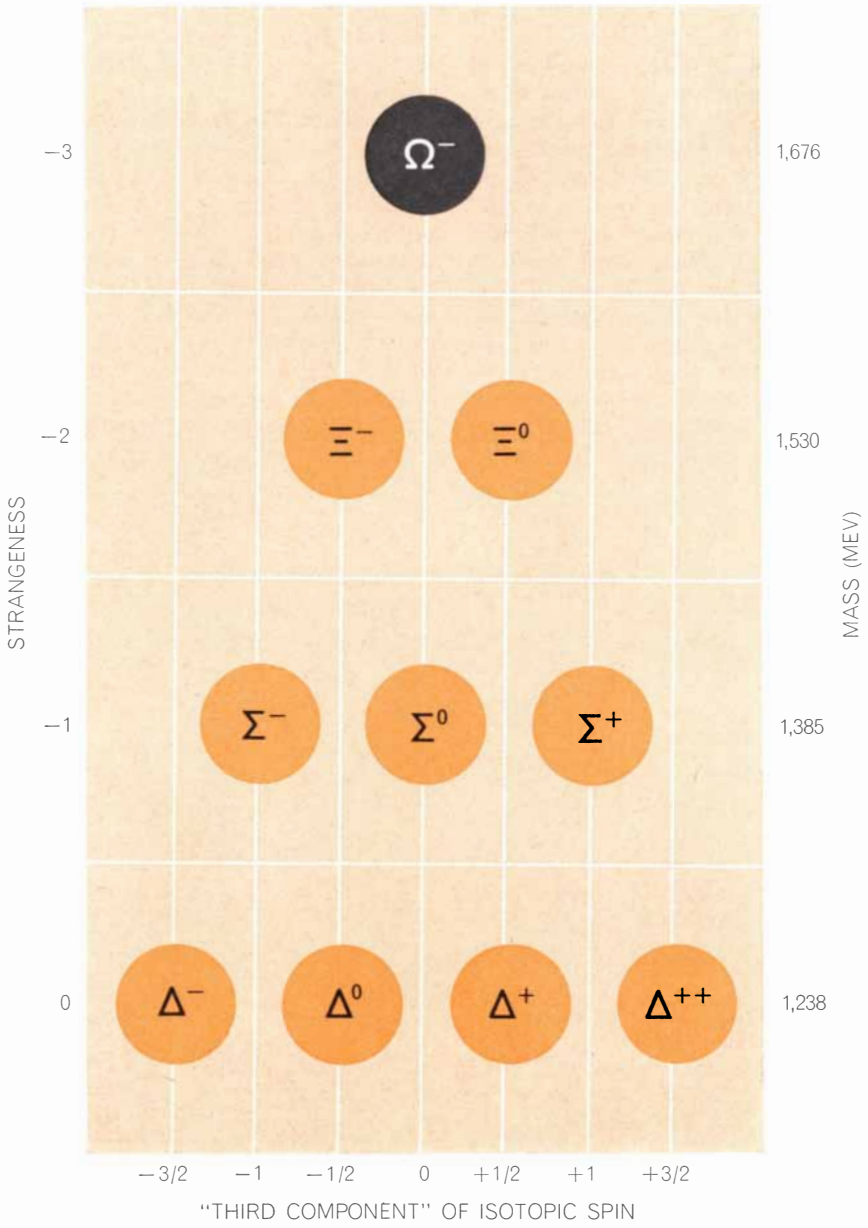

**mass and focuses them on a slit (one inch by .05 inch) that blocks most pi mesons (*light-colored line at top of the beam*) and most antiprotons (*colored line at bottom*). Before the slit the ratio of K-minus mesons (*line in middle of the beam*) to pi-minus mesons to antiprotons is 10 to 800 to 10. As the beam enters the bubble chamber, after another separator stage, the ratio is 10 to 1 to 0.**

that its mass must have been between 1,668 and 1,686 mev (allowing for the uncertainties in the calculations). This is precisely on the mark for the predicted mass of the omega-minus particle—1,676 mev.

If the decay at point *E* (into the xi-zero and pi-minus particles) was indeed that of an omega-minus particle, then the track between *E* and *F* in the diagram was that of the omega-minus itself, and the particle was born at *F*. At *F* we have a vertex with the visible track of the omega-minus going off to the right and a track identified as that of a K-plus meson curving off to the left. There is a deficit of about 498 mev from the interaction that gave rise to these visible products; that deficit represents the K-zero particle that left no track.

To reconstruct the events from the beginning now instead of from the end: At *F* an energetic K-minus meson colliding with a proton produced an omega-minus particle and K-plus and K-zero mesons; the omega-minus traveled on to *E* and there decayed into a pi-minus and a xi-zero particle; the xi-zero decayed at *D* into two gamma rays (which materialized into electron-positron pairs at *B* and *C*) and a lambda-zero particle; at *A* the lambda-zero in turn decayed into a proton and a pi-minus meson.

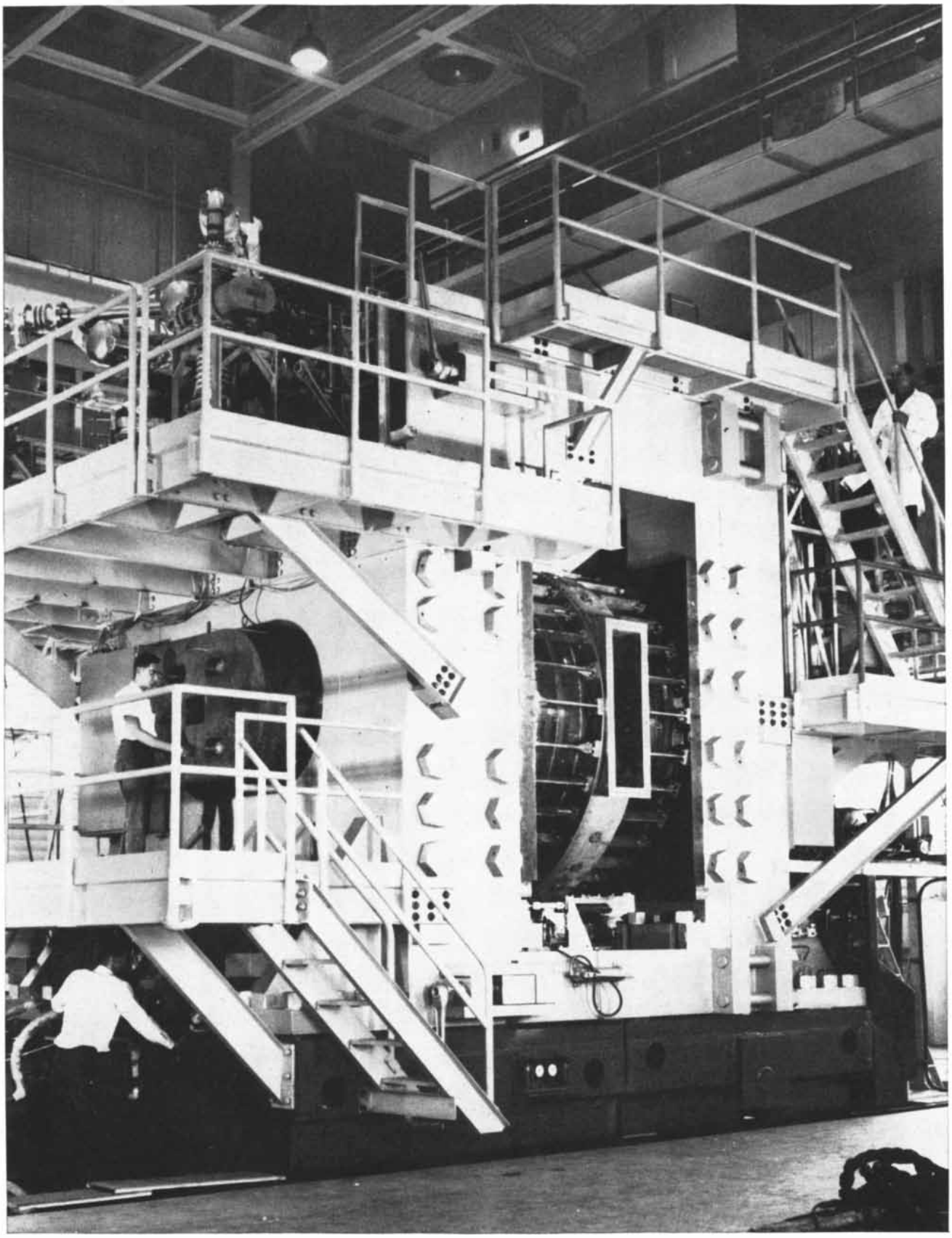
The length of the track made by the omega-minus particle in the bubble chamber (one inch) shows that its lifetime was almost a ten-billionth of a second, the typical lifetime of a strange particle. The decay of a strange particle is a "weak" interaction in which strangeness is not conserved but is changed by one unit. This rule provided confirmation that the particle caught in the photograph was the predicted omega-minus particle. The theory predicted that it should have a strangeness of minus three; its decay should therefore result in products with a total strangeness quantum number of minus two. That was, in fact, the observed result: the strangeness of the xi-zero particle is minus two and that of the pi-minus meson is zero.



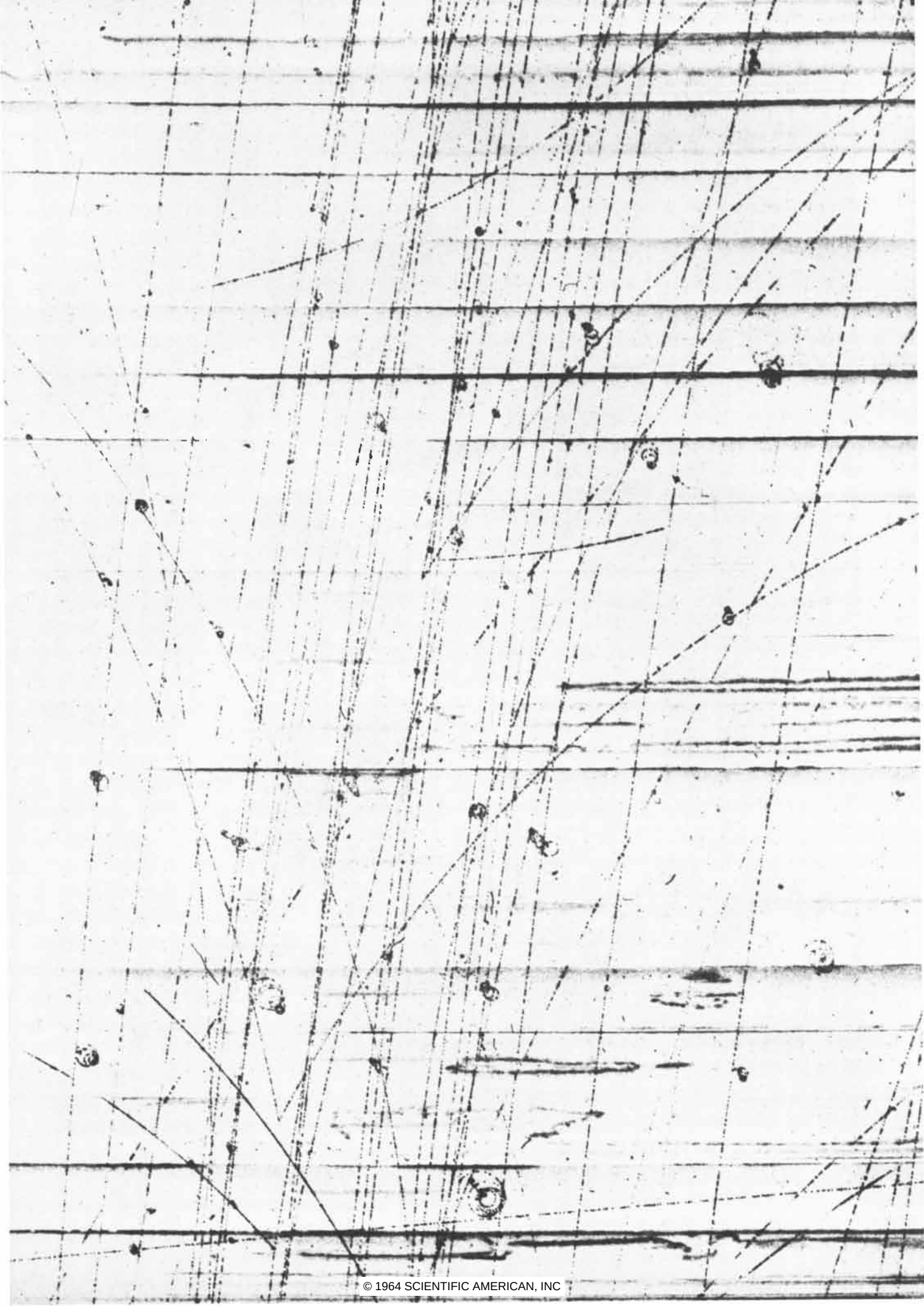

**THE EIGHTFOLD WAY as represented here groups together particles with the same intrinsic spin and the same parity in a pyramid indicating how the particles are related by certain rules. The particles differ in mass (*column at right*), "strangeness" (*column at left*) and a "third component of isotopic spin" (*bottom*) related to electric charge. The four-member delta family ($\Delta^-$, $\Delta^0$, $\Delta^+$ and $\Delta^{++}$), the three-member sigma family ($\Sigma^-$, $\Sigma^0$ and $\Sigma^+$) and the two-member xi-family ($\Xi^-$ and $\Xi^0$) suggested a single-member family with predictable properties to crown the pyramid. The omega-minus particle ($\Omega^-$) was then discovered, verifying the scheme. The isotopic spin of the delta baryons is 3/2; that of the sigma baryons is 1; that of the xi baryons is 1/2; that of the omega-minus particle is 0.**

A few weeks after the discovery of the first omega-minus particle a second one was produced in the bubble chamber. This time it decayed into a lambda-zero particle and a K-minus meson, one of the other predicted modes of decay for the omega-minus. The K-minus particle thereby produced then broke down by a rare decay process into three pi mesons—two negative and one positive. The photograph this time also showed the production of a K-zero meson along with the omega-minus, the K-zero being signaled by its prompt decay into a pi-minus meson and a pi-plus [*see illustration on page 44*]. Again the total strangeness of the products of the omega-minus decay was minus two. Moreover, the mass of the omega-minus particle was again as predicted, the measurements and calculations this time placing it between 1,671 and 1,677 mev. From the measurements of the particle's two appearances in the bubble chamber the average value derived for its mass was 1,675 mev, in astonishingly good agreement with the value of 1,676 mev predicted by the eightfold way.

The sequence of developments in this second materialization of the omega-minus, with the times involved, is illus-



**LIQUID-HYDROGEN BUBBLE CHAMBER** is located in the middle of this assembly at the Brookhaven National Laboratory. The 80-inch-long chamber is mounted behind the rectangular window, which is closed with a quarter-inch-thick metal cover during operations. Through a similar window the K-minus beam enters the chamber, which is surrounded by the copper coils and iron yoke of a 400-ton magnet. Above the staircase at left are openings through which three cameras photograph events in the chamber.

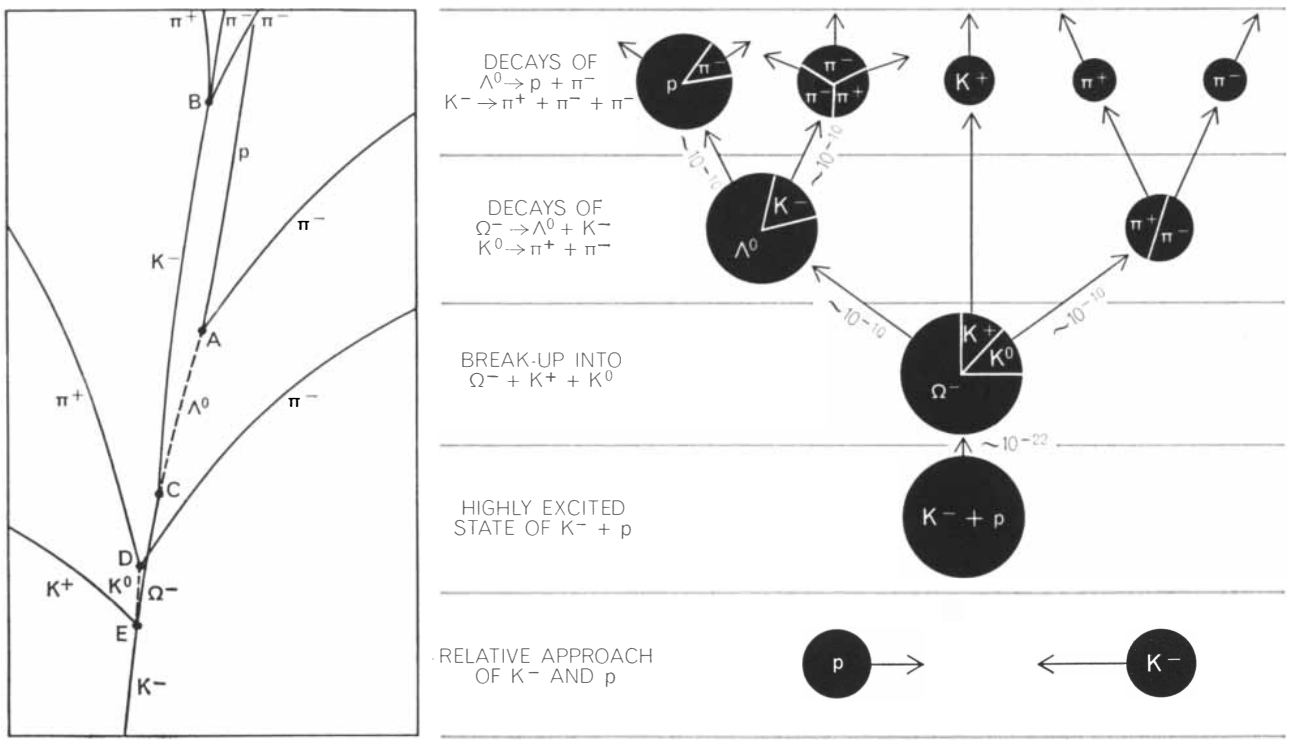


trated in the diagram on this page. A five-bev K-minus meson moving at close to the speed of light collides with a proton in the bubble chamber. The two particles form a very "hot," or highly excited, lump of nuclear matter that immediately breaks up into an omega-minus particle and K-zero and K-plus mesons, with the omega-minus carrying off most of the mass. The omega-minus decays into a lambda-zero particle and a K-minus meson, each of which decays further—the lambda-zero into a proton and a pi-minus meson, the K-minus into three pi mesons. Meanwhile the K-zero meson has decayed into two pi mesons. Thus from the original proton and energetic K-minus meson have come a proton, six pi mesons and a K-plus meson. Of these products only the proton is stable; all the mesons will eventually decay further.

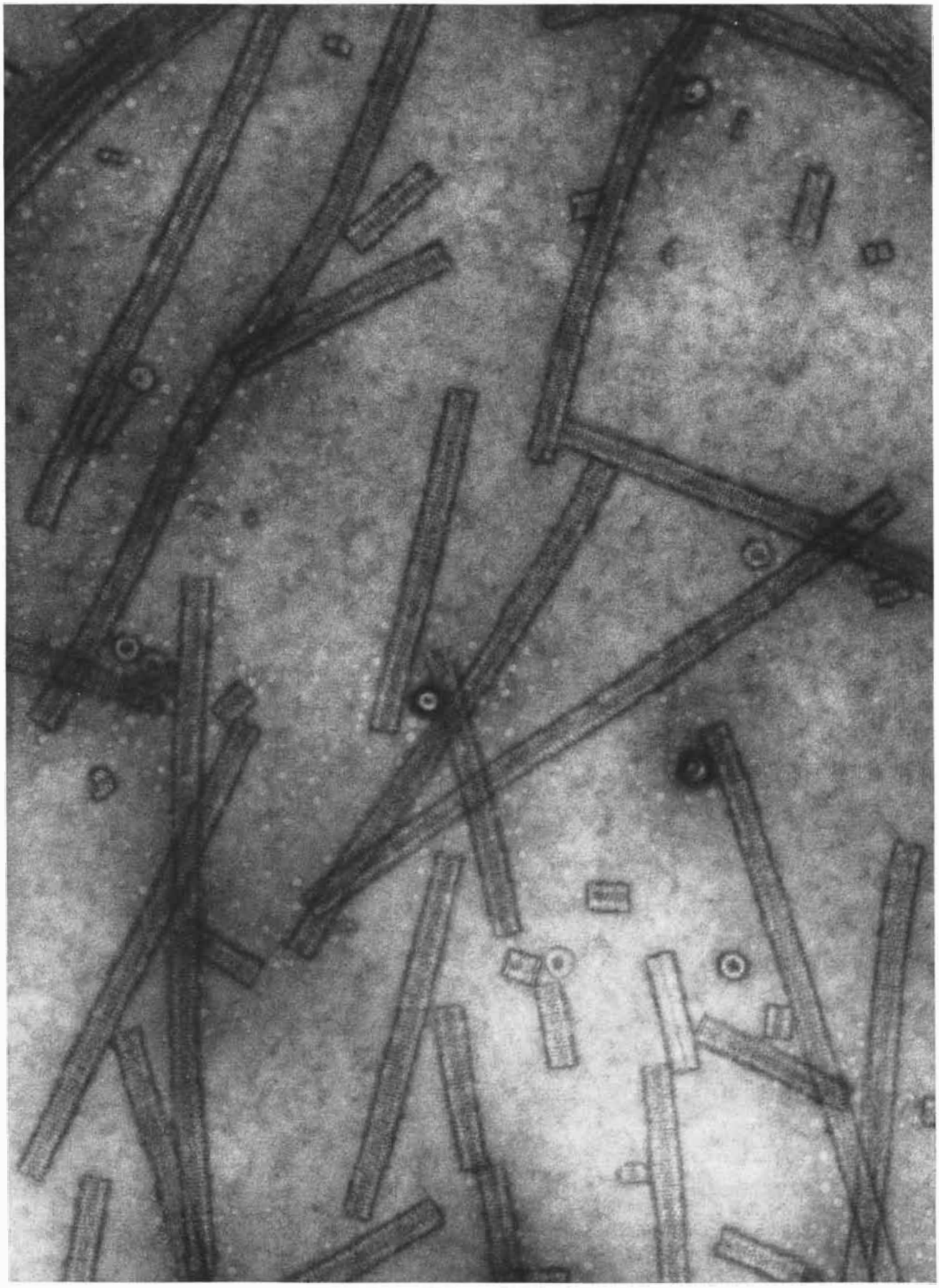
To verify the predictions of the eightfold way and establish the identity of the omega-minus particle beyond any question, three more proofs are wanted. The two photographs showed two different modes of decay of the omega-minus; we would like to see the third one that was predicted as being likely, namely, its decay into a xi-minus particle and a pi-zero meson. Then we need determinations of the spin and parity of the supposed omega-minus particle. The two photographs establish its mass and strangeness quantum number satisfactorily, but for calculation of its spin and parity we shall need many more photographs of the event, because these properties can only be deduced from the statistical distributions of the angles involved in the various decays.

At the time of the writing of this article hundreds of thousands of photographs have been made at Brookhaven and thousands more at the European Organization for Nuclear Research (CERN) in Geneva, which has started a similarly intensive search for the omega-minus with its own alternating-gradient synchrotron. Although many hundreds of events that may represent omega-minus particles have been detected, so far the only photographs that give unambiguous evidence of the production of the particle are the two described in this article. The discovery of two such events within a month of each other was an extremely lucky coincidence; it is now calculated that the "cross section," or probability, for the production of an omega-minus particle by a collision between a five-bev K meson and a proton must be only a few microbarns. (A microbarn is $10^{-30}$ square centimeter.)

Needless to say, the production of the omega-minus has greatly intensified the interest in the eightfold way, or SU(3) symmetry, as an opening wedge toward understanding the interrelations of the nuclear particles and their behavior as agents of the forces within the nucleus. A great deal of theoretical work is now under way in a search for possibly smaller and more basic families of particles, consisting of not eight or 10 but only three members per family. And, just as the experimental discovery of the omega-minus has quickened the theoretical studies, so is it likely that further developments in the theory will suggest new experiments, calling for larger particle accelerators, more complex beam arrays and larger bubble chambers.




**SECOND BUBBLE-CHAMBER PHOTOGRAPH** in which an omega-minus particle appeared ($\Omega^-$) helped to verify the existence of such a particle. It is shown at left, and the significant events are explained in the map at left above and presented in time sequence in the schematic chart at right. The collision of a K-minus beam and a proton ($K^-$ and $p$) at speeds close to that of light yields a K-plus meson ($K^+$) branching to the left, a K-zero meson ($K^0$) that in about $10^{-10}$ second decays into positive and negative pi mesons ($\pi^+$ and $\pi^-$) and an omega-minus that soon decays into a lambda-zero ($\Lambda^0$) and a $K^-$. This $K^-$ is seen (*top*) branching into three pi mesons. The lambda-zero gives way to a $\pi^-$ and a $p$, the latter being the only stable product of the original reaction. The K and six pi mesons take about 100 times longer to decay (*time is in seconds*) than the particles shown decaying in chart at right.



RODLIKE STRANDS of the tobacco mosaic virus are magnified 750,000 times in this electron micrograph made by H. L. Nixon of the Rothamsted Experimental Station in England. Only the larger particles are full-length viruses, capable of infecting cells.

# THE GENETIC CODE OF A VIRUS

## The tobacco mosaic virus consists of hereditary material and a single protein. Artificial changes in the hereditary material elucidate how it directs the synthesis of the three-dimensional molecule of protein

by Heinz Fraenkel-Conrat

A few years ago it seemed that the virus that causes the mosaic disease of tobacco plants might serve as a Rosetta stone for deciphering the genetic code. The sequence of amino acid subunits in the protein that forms the coat of the tobacco mosaic virus was almost completely established. The ribonucleic acid (RNA) of the virus was believed to carry the coded information needed for the construction of this one protein. It was hoped that it would not be too difficult to work out the sequence of nucleotide subunits in the RNA; the code could then be deduced directly by matching up the sequence of amino acids in the protein with the sequence of groups of nucleotides, or "words," in the RNA molecule. Such a translation would go a long way toward disclosing how the chainlike molecules of RNA and deoxyribonucleic acid (DNA) are able to direct the construction of three-dimensional living cells.

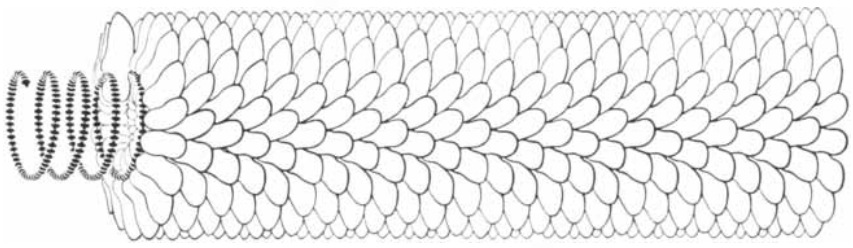
Unhappily (or happily, as some prefer to look at it) nature does not make things easy by providing simple Rosetta stones. The RNA molecule of the tobacco mosaic virus turned out to be an enormously long chain composed of 6,400 nucleotide subunits. Furthermore, the molecule bears various messages: it carries directions for synthesizing not only the coat protein but also other proteins, that is, certain enzymes. Thus it has become apparent that decipherment of its language will be a complicated task. This article will describe some current attacks on the problem and the progress that has been made.

The recent advances in chemical genetics have been recounted in several articles in *Scientific American* [see "The Genetic Code," by F. H. C. Crick, October, 1962, and "The Genetic Code: II," by Marshall W. Nirenberg, March, 1963]. I need review here only a few of the principal features of the chemical machinery for the reproduction of viruses. The tobacco mosaic virus consists of a long strand of RNA wrapped in a coat of protein [*see illustration on this page*]. The 6,400 nucleotide subunits of the RNA are of four kinds: guanine (G), cytosine (C), adenine (A) and uracil (U). After the viral RNA has invaded a tobacco leaf cell, it reproduces by acting as a template for the formation of complementary chains. Each guanine in the original chain combines with a cytosine from the intracellular environment and each cytosine with a guanine; similarly, each adenine combines with a uracil and each uracil with an adenine. Each of the subunits includes a ribose group and a phosphate group; the subunits are linked by bridges of phosphate. When a duplicate chain has been formed on the template, it peels off and is ready to combine with coat protein to form a new virus particle. The process requires the catalytic assistance of at least one enzyme—more probably two. It used to be supposed that the host cell supplied these enzymes ready-made, but it has now been established that the viral RNA directs the synthesis of the enzymes, using the cell's amino acids as the building material.

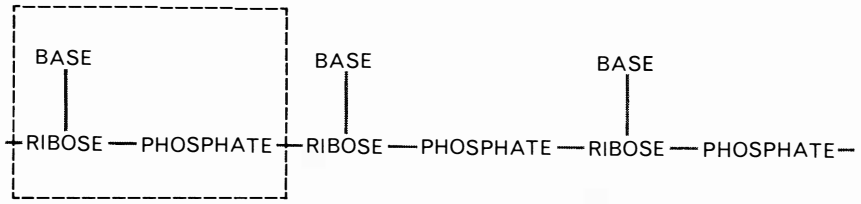
The coat protein of the tobacco mosaic virus has 158 amino acid subunits. If we suppose the RNA code word, or "codon," for each amino acid consists of three nucleotides, then a chain of 474 nucleotides would suffice to provide the information for synthesizing the coat protein. Adding the message required for synthesizing an enzyme (presumably a larger molecule than the coat protein) could raise the requirement to a chain of about 1,500 nucleotides. The fact that the RNA molecule of the virus is four times longer suggests that it probably directs the synthesis of more than one molecule of enzyme or other protein.

To decipher the code embodied in the virus's RNA we are confronted, then, with a molecule 6,400 nucleotides long carrying a series of different messages along its length. A beginning toward analysis of the structure of this molecule has been made by chopping off the nucleotides at the ends of the chain one by one with enzymes and alkalies [*see illustration on page 50*]. The RNA chain is so long, however, that this method is not likely to get us very far toward determining the full structure of the molecule or deciphering its code.

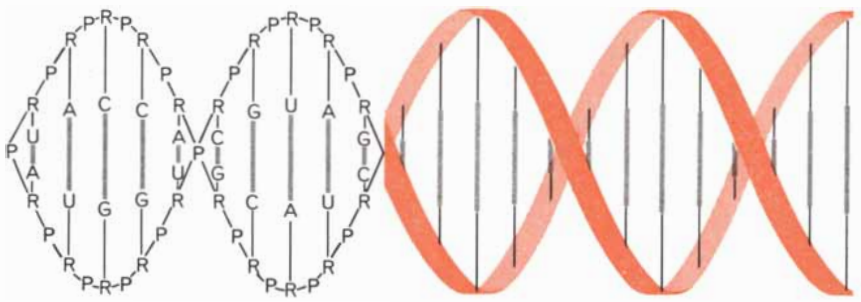
The specific topic of this article is



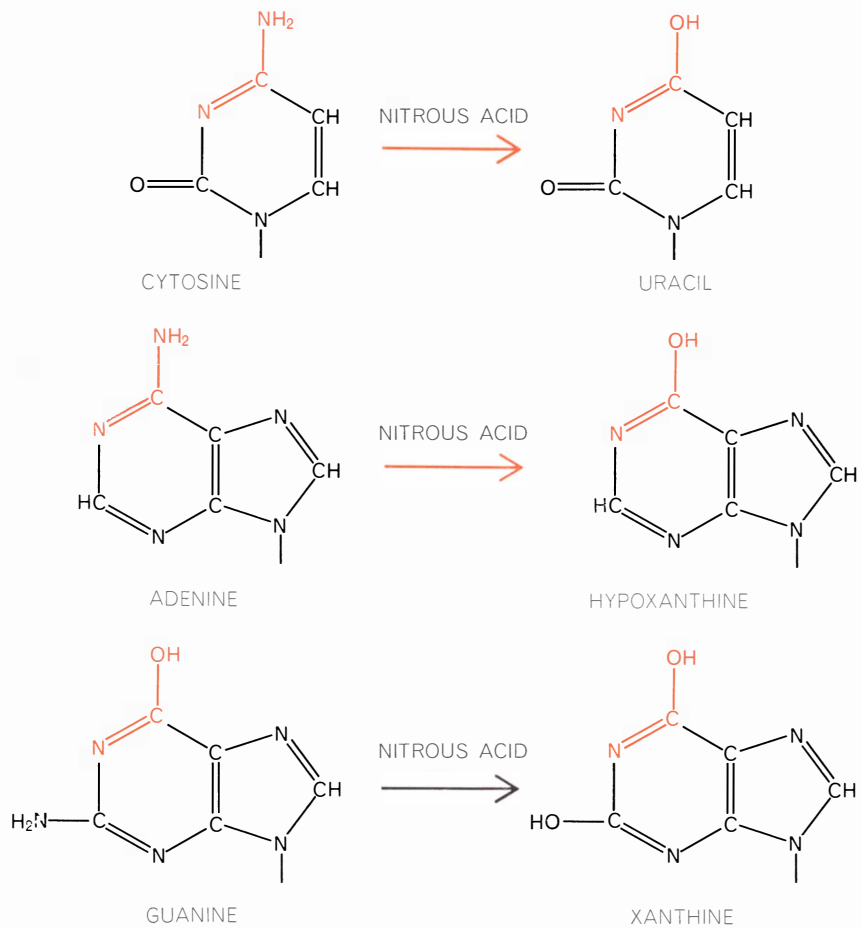
**TOBACCO MOSAIC VIRUS has a coat of protein molecules (*the radially arranged white structures*) surrounding a strand of ribonucleic acid (RNA), represented by the black helix.**




**RIBONUCLEIC ACID** is represented as a chain of repeating units of ribose sugar and phosphate. Extending from each ribose is a base: guanine, cytosine, adenine or uracil.



**VIRAL RNA** replicates by forming a double helix. The tobacco mosaic virus helix would consist of 6,400 subunits of guanine, cytosine, adenine and uracil (G, C, A and U).



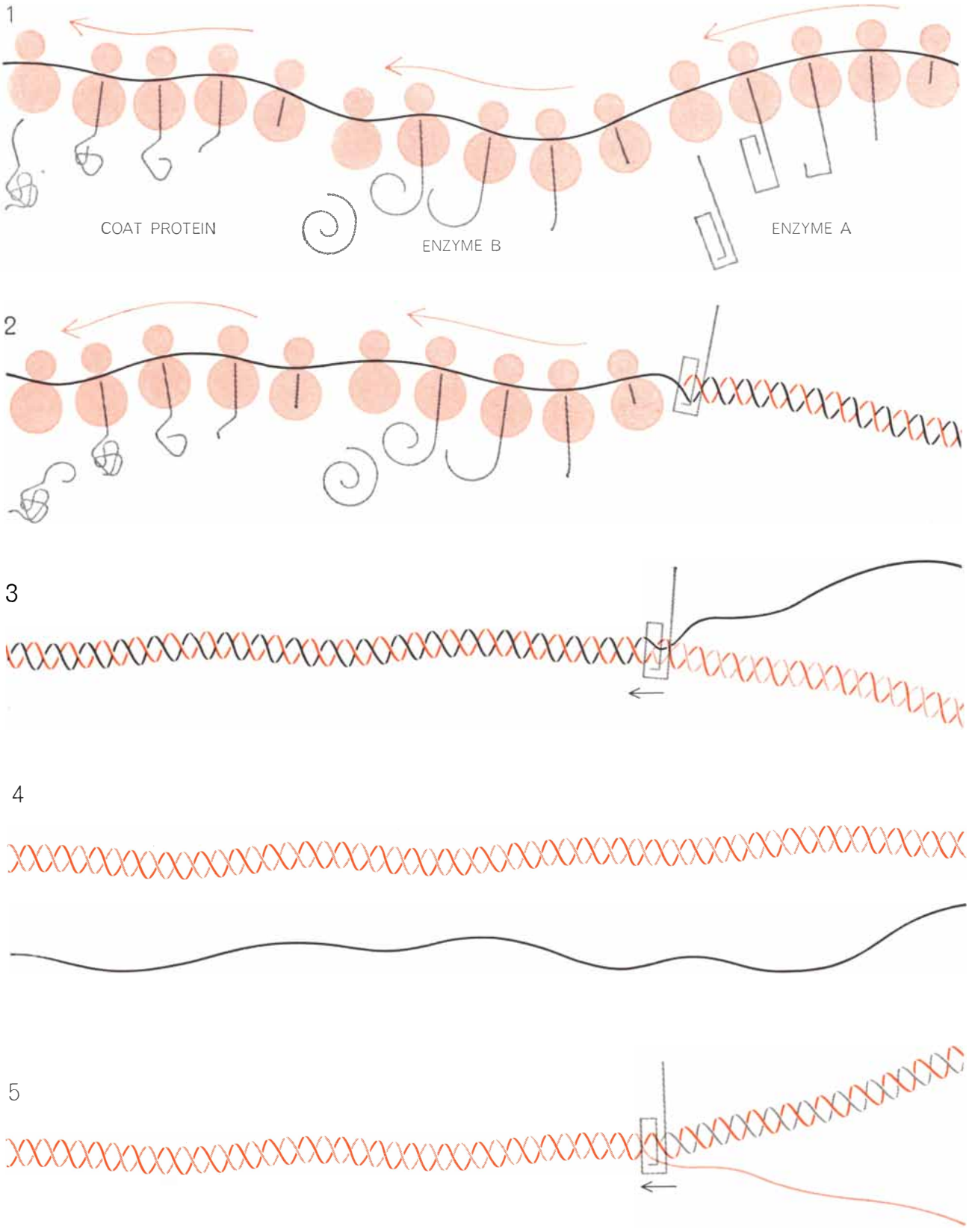

**CHEMICAL MUTATION** occurs when nitrous acid causes a replacement of the amino group ($NH_2$) in cytosine and adenine with the hydroxyl group (OH). The respective products of such mutation, uracil and hypoxanthine, appear at top and middle right. Guanine does not carry its amino group at a corresponding site on the molecule. Since the colored parts of the molecules are those interacting during replication or in double-strand molecules such as helical RNA, no mutant RNA results from the mutation of guanine to xanthine.

another approach to the problem, which, although more roundabout, has yielded some highly rewarding results. This method, pursued in our laboratory at the University of California at Berkeley and in several others, consists in making slight changes in the chemical structure of the RNA and then observing what effect these changes have on its genetic activity. Roughly speaking, the strategy is analogous to changing a letter or two in a verbal message to see how it changes the sense of the message.

Of the various reagents used to change the RNA, by far the most useful has proved to be nitrous acid. A particle of tobacco mosaic virus treated with this chemical is often so changed that it produces different disease symptoms in the tobacco plant it infects. Its new properties are transmitted to its progeny. Frequently the behavior of the altered strain of virus resembles that of a known natural strain—a known mutant—of the virus. Clearly in such cases the change in the treated virus represents a genuine mutation.

A study of the reaction between nitrous acid and the nucleotides of RNA shows how the mutation is brought about. Nitrous acid causes the replacement of the amino group ($NH_2$) in a nucleotide with a hydroxyl group (OH). In the case of cytosine this results in transformation of the cytosine to uracil [*see bottom illustration on this page*]. The conversion of one, two or three cytosines in the RNA chain into uracils may well convert the virus to a viable new strain that produces somewhat different disease symptoms. In the case of adenine the deamination by nitrous acid changes the adenine to hypoxanthine, a nucleotide that is not normally present in RNA but that is like guanine in part of its structure and therefore can combine with cytosine. Because adenine is thus converted to a base that resembles guanine (combining with cytosine instead of uracil), this change may sometimes result in a mutant virus. No mutation results, however, when guanine is deaminated to xanthine, because xanthine behaves like guanine itself; that is, it links up with cytosine as guanine does.

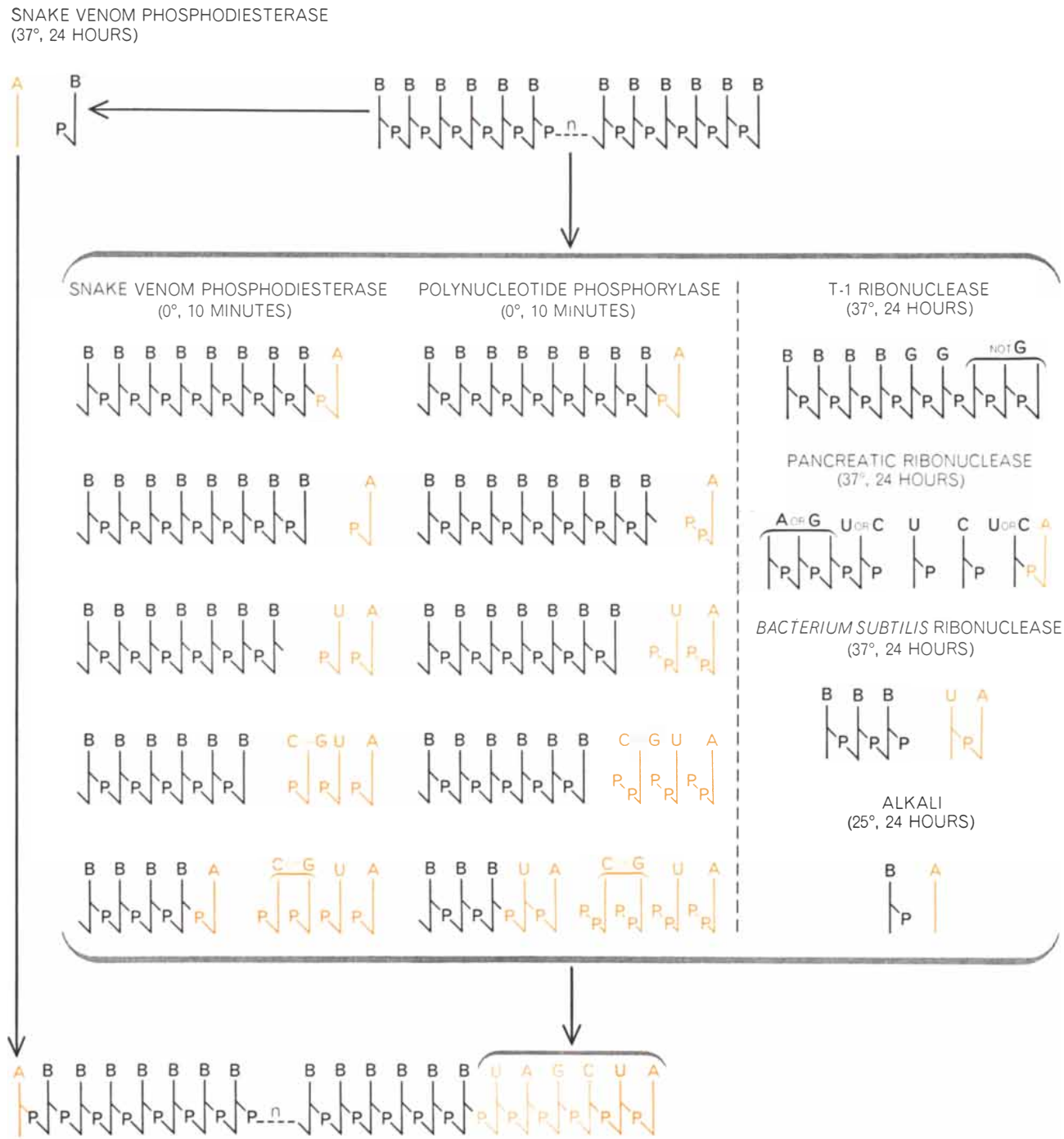
It has been established, then, that a localized change in the nucleotide composition of the viral RNA can produce a noticeable change in the activity of the virus. This circumstance does not provide a means for locating the changed nucleotides in the RNA's of different strains of tobacco mosaic virus. In a molecule with 6,400 nucleotides, comprising between 1,100 and 1,800 of




**WITHIN THE CELL** viral RNA (*black strand at top*) attaches to ribosomes (*double balls*) that travel along the strand synthesizing peptide chains of various proteins. Products of the process might include the material of the virus coat and two enzymes, represented by differently shaped structures emerging in the first step. In the second step the single RNA strand binds to an enzyme that catalyzes production of a complementary strand (*dark colored line*). This double strand RNA is shown uncurling (*step 3*), again under the influence of an enzyme. It makes a new strand (*light colored line in step 3*) and releases the original one. The first complementary strand then releases its progeny strand (*step 4*) and makes another (*gray curve in step 5*) under the influence of an enzyme. A released strand either can make protein as in step 1, or undergo a process of replication as in steps 2 through 4.

each of the four nucleotide types, the problem of detecting a difference of just a few nucleotides between one strain and another is beyond any present analytical technique. We therefore turned to studies of the proteins synthesized by artificially altered RNA.

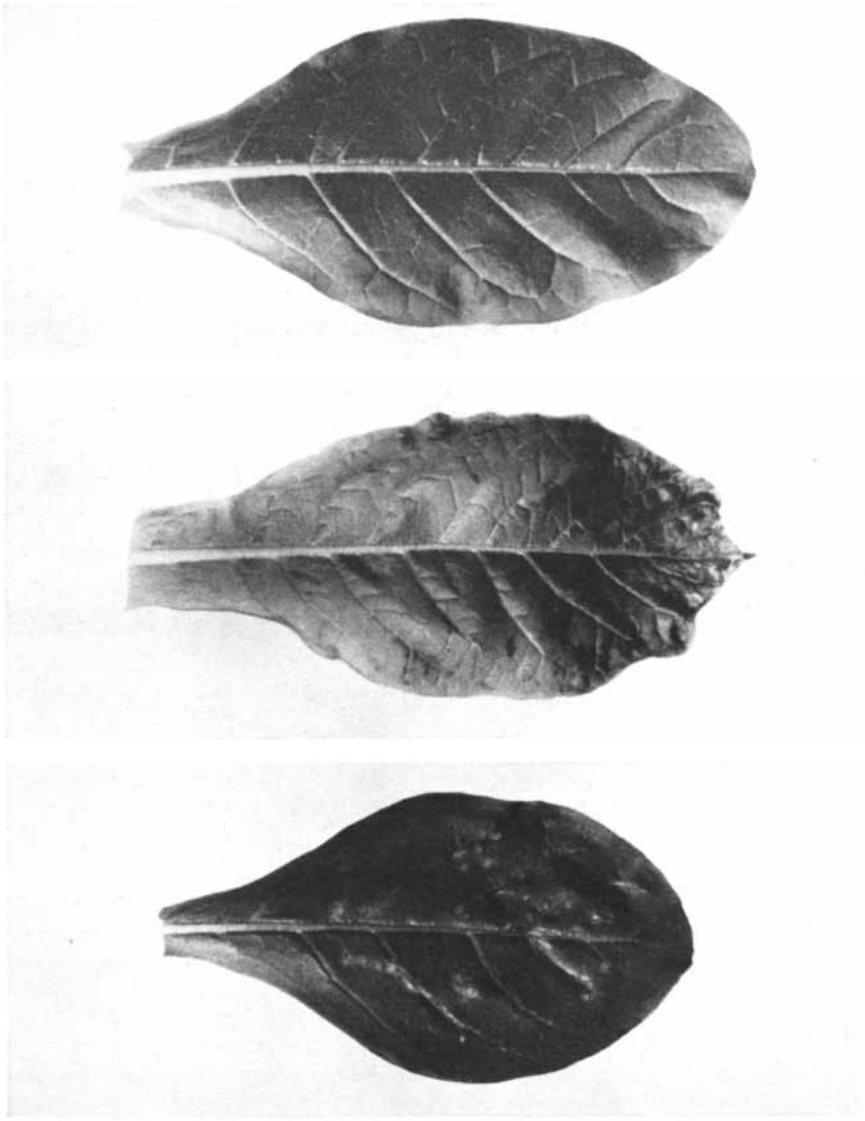
The protein coat wrapped around the RNA core of the tobacco mosaic virus consists of nearly 2,200 molecules. Thus any change in the RNA that is reflected in the construction of the protein is amplified many times, and the change in the structure of the protein should be comparatively easy to detect. Moreover, a change in just one of the 16 different kinds of amino acid composing the protein amounts to a change of 5 percent or more in the total amino acid composition of the molecule. This composition was known to vary considerably even among natural strains of tobacco mosaic virus, and it could be assumed that such variations in the




**END GROUPS removed from RNA provide clues to its structure. RNA appears at top right as a chain of bases (*B*), phosphates (*P*) and ribose (*symbolized by vertical lines*), the approximate length of which, 6,400 subunits, is denoted by *n* (for number of nucleotides). The method of removing an end group is given above the evidence thus gathered. The certain presence of guanine, cytosine, adenine or uracil at a given site is shown in dark color. If experiments only narrow the possibilities, light color is used. The effects of an enzyme from snake venom, phosphodiesterase, are shown in five stages, during which end groups are successively broken off. The effect of polynucleotide phosphorylase is similarly represented. In the RNA at bottom the identified nucleotides are dark-colored.**

chemically modified strains would be easily and accurately measurable. Systematic programs of analysis of the proteins in mutant tobacco mosaic viruses were undertaken in our laboratory by two visiting Japanese workers, Akira Tsugita and Gunku Funatsu, and at the University of Tübingen by Hans Wittmann.

Most of the studies undertaken in our laboratory made use of virus mutants that produce unusual lesions in tobacco plants of the variety *Nicotiana sylvestris*. The common tobacco mosaic virus causes a discoloration and a distortion of leaves that spreads over the entire plant. A typical mutant we have investigated causes only local, walled-off lesions at the sites of inoculation. Altogether some 200 chemically induced mutants have been studied in the two laboratories. In general both laboratories agree in their findings concerning the changes in the amino acids of these mutants' coats, but they differ in some respects, on which I shall comment later.



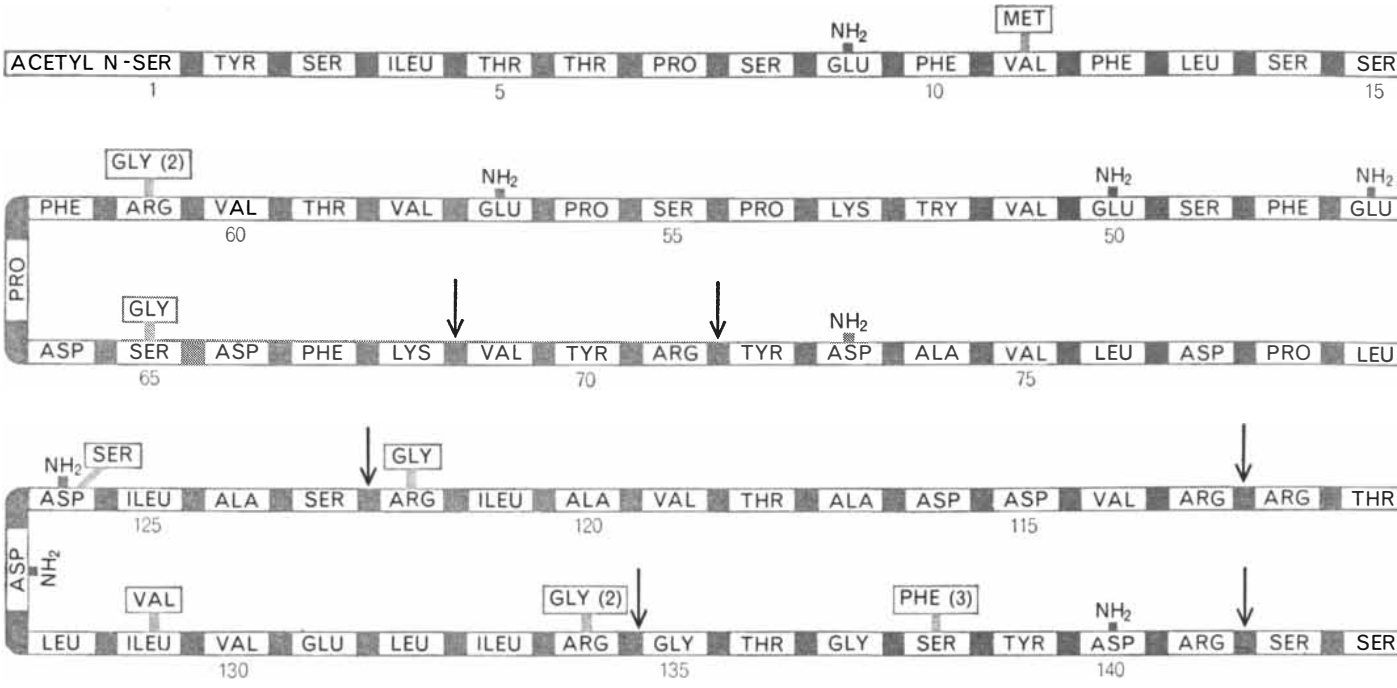
**LEAVES from the tobacco plant *Nicotiana sylvestris* are compared. At top is a leaf free from infection. Below it is a leaf generally discolored by infection with tobacco mosaic virus. At bottom is a leaf with local lesions, an effect caused by some 200 mutant strains.**

Of the 200 mutants, about 120 apparently still had the same coat protein as they had had before mutation. At least the protein's overall amino acid composition was unchanged. Although it is possible that changes of the amino acids within the molecule might have been masked by alterations in one direction offsetting those in another, we can safely dismiss this explanation as highly unlikely, in view of the very tiny probability that such precisely balancing changes would take place in more than half of the mutants. Of the approximately 80 mutants that did show a change in the coat protein, nearly all were altered in only one, two or occasionally three amino acids. (There were a few that differed radically—in as many as 30 amino acids—from the common strain of the tobacco mosaic virus; possibly these were not artificial mutants but uncommon strains that happened to be present in the inoculated material.)

Certain patterns showed up in the mutations. All the changes were one-way; for example, there were many cases of conversion of the amino acid serine to the amino acid phenylalanine but not a single instance of transformation of phenylalanine to serine. Most interesting was the fact that of the 272 possible conversions of one amino acid to another (among the 16 present in the virus) only 21 actually occurred, and of these transformations only 14 showed up more than once [*see illustration on next two pages*]. Let us now consider what interpretations we can extract from the results.

In their work on the genetic code Marshall W. Nirenberg and his associates at the National Institutes of Health had connected certain nucleotide combinations, or code words, with specific amino acids (as Nirenberg explained in the *Scientific American* article to which I have already referred). He had found that a synthetic RNA consisting only of uracils caused just the amino acid phenylalanine to form a chain, from which he concluded that the code word for incorporating phenylalanine into a protein was UUU. Similarly, an RNA-like molecule composed only of cytosine (thus constituting the codon CCC) carried specific instructions for polymerizing the amino acid proline. A combination of two parts of uracil with one part of cytosine, forming a codon containing two U's and one C in some unknown order, directed the polymerization of leucine; a switch in the nucleotide proportions to one part of uracil and two parts of cytosine, that is, to a codon containing one U and two C's, favored the polymerization of serine.

Applying these findings to our virus mutants, we found that the two corresponded remarkably well. Let us say that the treatment of the virus with nitrous acid deaminated one of the cytosines in its RNA and thereby changed it to uracil. This might alter a CCC codon to one containing a U and two C's, which would result in the replacement of a proline by a leucine in the protein coat of the virus. In the same way a CUU sequence would be changed to UUU, which would lead to




| | | | | | |
|---|---|---|---|---|---|
| ALA | ALANINE | $GLU\text{-}NH_2$ | GLUTAMINE | PHE | PHENYLALANINE |
| ARG | ARGININE | GLY | GLYCINE | PRO | PROLINE |
| ASP | ASPARTIC ACID | ILEU | ISOLEUCINE | SER | SERINE |
| $ASP\text{-}NH_2$ | ASPARAGINE | LEU | LEUCINE | THR | THREONINE |
| CYSH | CYSTEINE | LYS | LYSINE | TRY | TRYPTOPHANE |
| GLU | GLUTAMIC ACID | MET | METHIONINE | TYR | TYROSINE |
| | | | | VAL | VALINE |

**AMINO ACID SEQUENCE of the protein subunit of the viral coat is mapped. A key at bottom left gives abbreviations used in the**

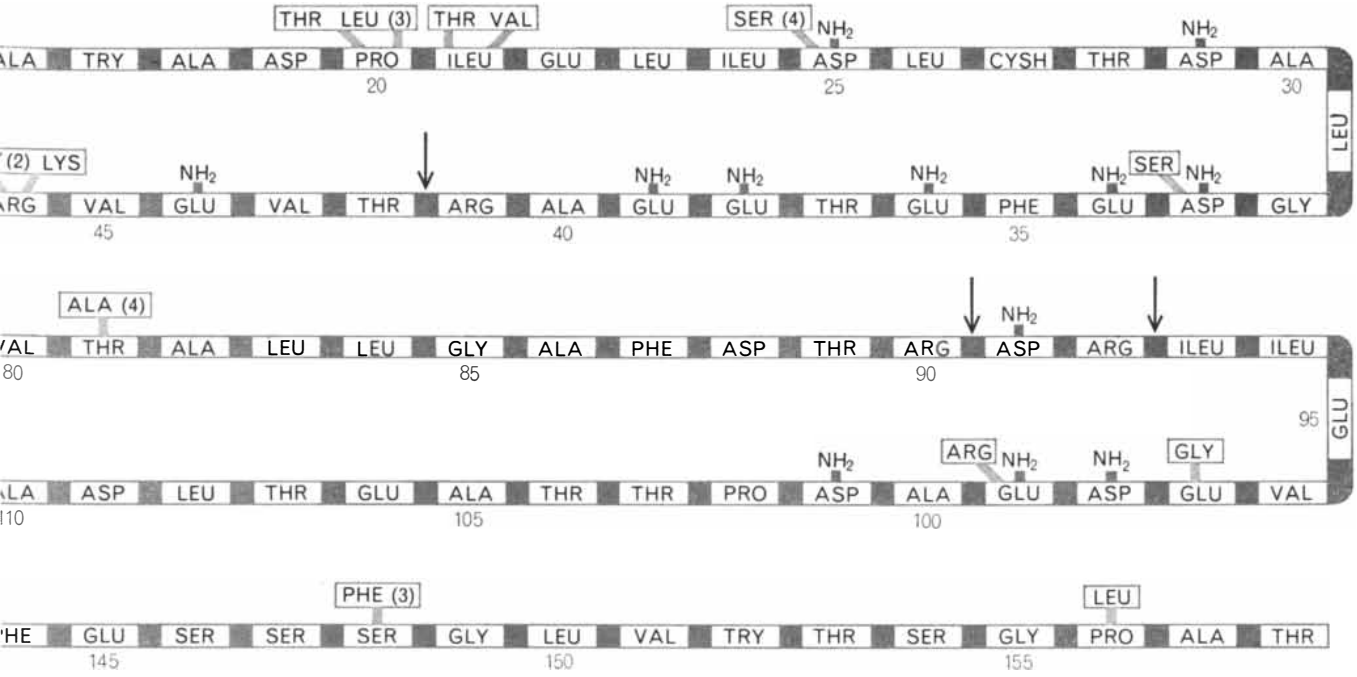
the replacement of a serine in the protein by a phenylalanine. As we have noted, in our mutants there was often a change from serine to phenylalanine or from proline to leucine, but it was never the other way around.

Studying the protein-building effects of various nucleotide combinations, Nirenberg and others have steadily enlarged the codon dictionary. Unfortunately the dictionary has grown in ambiguity as it has grown in size. Some amino acids apparently can be coded by as many as five different codons, or nucleotide triplets; leucine, for example, has been found to be represented by five codons and serine by four. This indicates that the code is highly ambiguous, or "degenerate." The reasons for this ambiguity in the genetic language remain obscure and certainly hide complexities still not understood. At all events, Wittmann has proposed a scheme of step-by-step transformations of the codons for four amino acids that illustrates the degeneracy of the code and may provide a way to determine the sequence of the nucleotides in each codon, which is not yet known [*see top illustration on page 54*].

The table at the bottom of page 54 summarizes all the amino acid changes in artificial mutants that have been observed in our laboratory and in Wittmann's at Tübingen. It includes cases in which the RNA nucleotides were altered by the attachment of a bromine atom or a methyl group instead of by deamination. The summary shows that all the amino acid transformations that occurred more than once in our laboratory can be accounted for either by a conversion of cytosine to uracil or by a change of adenine to guanine by way of hypoxanthine. But it also raises some puzzling questions. What about those cases, particularly some of the transformations obtained repeatedly by Wittmann, that cannot be explained by such conversions? By what chemical mechanism can methylation or bromination give rise to the same amino acid replacements, even though they do not affect the cytosine or adenine as deamination does? These questions are still unanswered.

Pursuing another line of investigation, Nirenberg initiated an intriguing experiment in collaboration with our laboratory. His system for exploring the coding effects of RNA uses a medium containing extracts from cells of the bacterium *Escherichia coli*. It contains ribosomes, enzymes, adenosine triphosphate (as the energy source) and amino acids attached to "transfer" RNA—in short, all the apparatus needed for the synthesis of proteins or polypeptides with the exception of the genetic material itself. The addition to this system of any type of RNA or DNA, even a synthetic RNA of the simplest kind, will bring about the linking of amino acids into chains in a sequence specified by the added RNA. Would the tobacco mosaic virus RNA induce the system to synthesize the tobacco mosaic virus coat protein?

The experiment was undertaken, and our first interpretation of the results was guardedly optimistic. This interpretation, however, was later corrected; there was no evidence that the system produced any identifiable tobacco mosaic virus protein. On the other hand, Daniel Nathans and his colleagues at the Rockefeller Institute found that the RNA of a virus that attacks *E. coli* would cause a cell-free extract of the bacterium to produce the coat protein of that virus. The most plausible explanation for this discrepancy seems to be that the code is too ambiguous, or degenerate, to carry over from a plant to a bacterial system. The tobacco plant cells and the *E. coli* system may preferentially use different codons to represent a given amino acid, and therefore a message may become garbled when it is transferred from one system to the other. It is as if the genetic code, although universal in principle, contained varying dialects, the cells of different species




**map. When the protein is decomposed by the enzyme trypsin, it fragments at sites marked by arrows. Replacements of amino acids occur in chemically induced mutants as shown in rectangles above sites at which they appear, with numbers indicating instances of observation. The protein coat of a virus particle has nearly 2,200 subunits. Its RNA, now under study, contains three times as many.**

using different versions of the general language.

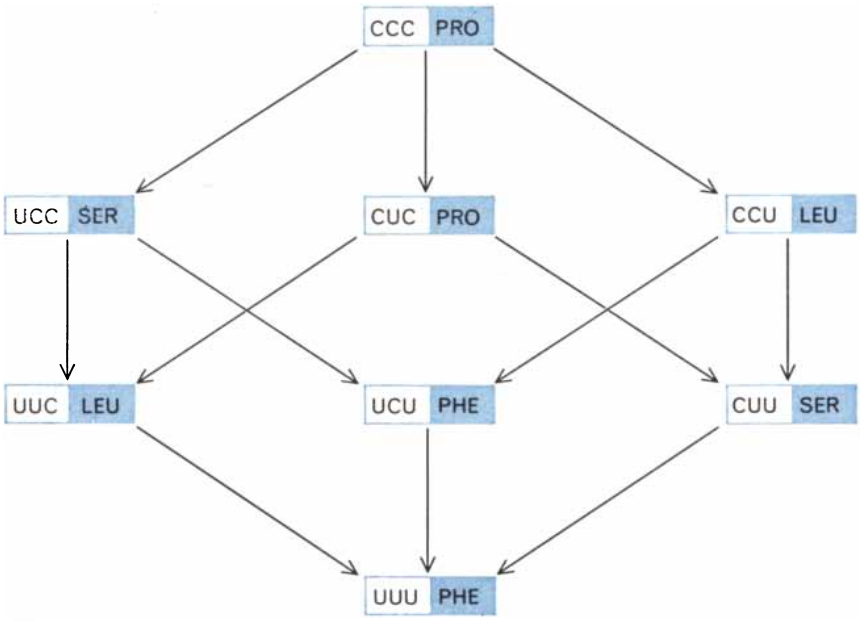
Apart from what our virus mutants may reveal about the genetic code, they interest us profoundly for another reason. The experiments in controlled alteration of their protein coats promise to help unravel the three-dimensional structure of the protein. The elucidation of protein structure is widely recognized as a central problem in biology. Next to the machinery of heredity, the three-dimensional structure of proteins holds perhaps the most important key to all the processes of life. Molecular structure determines the activities of enzymes in catalyzing biochemical reactions, of antibodies in precipitating foreign substances, of protein hormones and other specific proteins in regulating metabolism; in sum, it is a prime factor accounting for the properties and functions of all proteins from those in the coat of a virus to those in the cells of the brain. Each protein is characterized by specific internal bonds that maintain its three-dimensional form and by special surfaces that selectively bind to it certain ions, simple molecules or other proteins.

The spatial organization of a few proteins has been worked out by studying the patterns of X rays diffracted by crystals of the proteins in a dry state. Such analyses do not necessarily show what form the proteins take in their natural condition in water solution, nor do they throw light on the nature of the internal bonds that maintain the protein molecule's shape. These questions are being investigated indirectly in many laboratories by gentle chemical methods probing the reactivity of specific protein molecules at various points in the molecular chain. Along this line our virus mutants have provided helpful information.

The protein coat of the tobacco mosaic virus performs certain definite functions in protecting the integrity and promoting the infectivity of the virus, and we have studied these functions in detail in our laboratory [see "Rebuilding a Virus," by Heinz Fraenkel-Conrat; SCIENTIFIC AMERICAN, June, 1956]. One can assume that the protein coat of the common strain of the virus, as it has evolved by natural selection, is highly efficient, and that any mutation is likely to reduce the virus's viability. We were therefore interested in seeing just how and to what extent each chemically induced change in the amino acid sequence would affect the virus.

As I have mentioned, almost the entire sequence of the 158 amino acids in this protein was known. It was also known that, when one attacked the protein coat of the common tobacco mosaic virus with an enzyme that removes amino acids from the carboxyl (COOH) end of a protein chain, it was able to chop off only a single amino acid, threonine, at the very end of the chain. Surprisingly, it turned out that this amputation (removing a total of 2,200 threonine units from the 2,200 protein molecules forming the coat of the virus) did not markedly affect the biological properties of the virus. Our very first mutant, however, showed a dramatic increase in vulnerability. As it happened, this mutation had replaced a proline near the end of the chain (No. 156 in the sequence) with leucine. The change made the protein much more susceptible to digestion by the enzyme. The enzyme was now able to clip three amino acids off the protein in the virus (and many more than three when it attacked the protein alone, stripped away from the virus). The three-amino-acid amputation made the virus distinctly less viable. This showed clearly that a single mutation, producing only an apparently minor change in the protein, could greatly reduce the virus's chances of survival.

Later studies have indicated that some RNA mutations render the RNA incapable even of forming the protein




**DEAMINATION that changes cytosine to uracil is represented by this octet arrangement of single steps from the triplet CCC to UUU. Amino acid equivalents given at right of the "codons" represent often-observed exchanges in mutants induced by deamination.**

| NATURE OF EXCHANGES | DEAMINATION | BROMINATION | METHYLATION | POSSIBLE CODON EXCHANGES |
|---|---|---|---|---|
| ASP → GLY | (2) | | | AGC → GGC |
| ASP → ALA | (4) | | | |
| ASP-$NH_2$ → SER | 4 (2) | 3 | | ACA → GCA |
| THR → ALA | 2 | | | ACA → GCA |
| THR → ILEU | (8) | | | CAA → UAA |
| THR → MET | (3) | | | |
| SER → PHE | 4 (4) | 2 | 2 | CUU → UUU |
| SER → GLY | | 1 | | ACG → GCG |
| SER → LEU | (2) | | | |
| GLU → GLY | 1 (1) | | | AUG → GUG |
| GLU-$NH_2$ → ARG | 1 | | | |
| GLU-$NH_2$ → VAL | (2) | | | |
| PRO → LEU | 3 (1) | 4 | 4 | CUC → UUC |
| PRO → SER | (3) | | | CCU → UCU |
| VAL → MET | 1 | | | |
| ILEU → VAL | 2 (3) | | | AUU → GUU |
| ILEU → THR | | 1 | | |
| ILEU → MET | (1) | | | AUA → GUA |
| LEU → PHE | (1) | | | CUU → UUU |
| ARG → GLY | 3 | 3 | 1 | AGA → GGA |
| ARG → LYS | 1 | 1 | | |

**REPLACEMENTS in chemically induced mutants of the tobacco mosaic virus are charted by frequency of observation. At left is the amino acid exchange taking place; in middle, the process that induced it; at right, possible codon exchanges for various mutants. The figures listed parenthetically were obtained by Hans Wittman of the University of Tübingen.**

coat. Most often, however, the mutant proteins that were examined showed exchanges of amino acids only near the ends of the chain, where the alteration might do the least damage to the functioning of the protein.

In contrast to the chain ends and certain inner parts around the middle of the chain, which also showed exchanges, there is a certain segment (between No. 108 and No. 122 in the sequence) that strongly resists attack. This part of the chain is the same in all natural strains of the virus and remains unchanged in all the mutants that have been investigated. Its stability suggests that it constitutes a portion of the molecule that is particularly important for the proper folding of the chain. In this segment there is a pair of arginines close to a pair of aspartic acid units, and it may be that these amino acid pairs play a role in the folding.

It should be recognized that the frequently recurring exchanges are probably not the result of mutations occurring preferentially at these sites, but are due to natural selection. It appears certain that these are sites where exchanges cause the least harm to the function of the protein of forming a protective shell for the RNA. Thus the exchanges greatly predominate among those mutants that are viable enough to be isolated in amounts sufficient for chemical study. A change of a serine to a phenylalanine elsewhere in the molecule than at positions No. 138 or No. 148 presumably renders the protein nonfunctional.

By means of chemical probing and genetic mutation the entire protein molecule is being explored for clues to its three-dimensional structure. Such clues include the distances between specific groups in the chain and the chemical reactivity of the various parts of the chain. It can be deduced, for instance, that units in the chain that resist reaction with applied reagents are likely to be inside folds where they are tied up in internal bonding. One such probe has shown that the tyrosine at position No. 72 in the sequence is remarkably recalcitrant to reaction with any chemical applied to the intact virus; the tyrosine at position No. 139, on the other hand, readily reacts with iodine.

Gradually, through genetic and chemical soundings of this kind, we hope to build up a complete picture of the protein bonding and structure that give the tobacco mosaic virus its extraordinary architectural perfection and stability.

# Kodak advertises: Rapid Access Recording ... ytterbium in glass ...

**what learned people of non-commercial motivation have discovered**

**The time has come this autumn to quit kidding ourselves.** Beautiful photography is a great art that has virtually nothing to do with the purposes for which physical scientists and engineers justify their heavy consumption of 16mm, 35mm, 70mm, and larger widths of film during working hours. We had better see things their way. We now know they are seldom in a mood to treat film as an object of veneration, a subject for mystic rites that can be short-cut only at grave peril to conscience.

All they seem to want are the data—the quicker the better.

The exact nature of these data is really none of our cotton-pickin' business, except insofar as the users care to talk or honor us with reprints some fine day. The best we can contribute to their spark-chamber or bubble-chamber physics, their radar recordings, their studies of bioluminescence or of the stratigraphy of Antarctica, their improvement of sugar-beet pulping machinery or of ignition systems for vernier rockets, their logging of oil wells, their probing of the Saturnine atmosphere, their counting of taxis on the Golden Gate Bridge, and all the other vaguely imagined tasks they perform with film—the best we can contribute is a fierce determination to make them demonstrably better film for their multifarious purposes than anybody else can make.

To this end we are placing upon the market a new line of films. We don't want them confused with films designed for beautiful movies either by us or by our competitors. You will get to know them by a trademark that hardly suggests softness and beauty. It happens to consist of the initials for "Rapid Access Recording."

The five films which will first carry this mark are *primarily* designed for processing at temperatures up to 130°F. Four of the five are on ESTAR Base, tops for dimensional stability in film with strength and thinness. A sixth new one, KODAK 2475 Recording Film, likewise on ESTAR Base, has extended red sensitivity to make it the fastest film you can buy, but it is not yet suitable for hot processing.

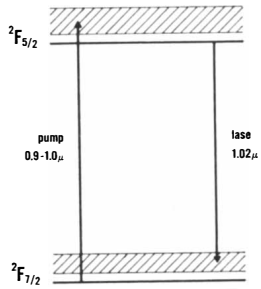
*Hardly less important than the characteristics of the new films is ready information about said characteristics so that user and maker can sit down together and make the best choice for the work at hand. Get in touch with Eastman Kodak Company, Photorecording Methods Division, Rochester, N. Y. 14650, phone 716 - 562 - 6000, Ext. 3257. See what happens. The new trademark, by the way, is:*

## A goal for the customers

Hereby offered for sale is a new KODAK Laser Glass, Type Yb-20, a borate glass doped with 3% of ytterbium. This rare earth has been waiting offstage many years for this day of possible glory. A certain tourist guide to Sweden claims ytterbium and yttrium were named after the town of Ytterby near Göteborg. Nonsense. They were named for the old Ytterby quarry near Vaxholm fortress, only three miles from Stockholm. It may take more than that, however, to make Yb desirable in the eyes of prospective purchasers. What can they do with it?

Well, as of the moment this is written we expect (but do not promise) that with this glass one of them will make the first nongaseous CW power laser. Let him have the honor for every ingenious part of this notable accomplishment, save only the glassmaking.

The reason for the bright promise of $Yb^{+++}$ is a narrow energy band that the field effect of the borate matrix creates just above the $^2F_{5/2}$ excitation level of the ion. $Yb^{+++}$ lingers at this level prodigiously long—1200 $\mu$sec. This sojourn makes KODAK Laser Glass, Type Yb-20, an excellent candidate for giant-pulse work, whether the CW hunch works out or not. With another band just above the $^2F_{7/2}$ ground state emptied by cooling to 77°K, a xenon or argon arc with its forest of lines in the 0.8 – 1.0$\mu$ region readily pumps the system. Little else from these arcs can be absorbed to heat the glass and fight the refrigerant. From the upper energy band a short non-radiative drop feeds the $^2F_{5/2}$ state and keeps it nicely populated for laser action at 1.02$\mu$.



The situation in ytterbium

We offer the glass in ¼″ to ½″ circular cross-section; 1″ to 12″ long; with flat ends, Brewster-angle ends, a roof-prism end, dielectric-coated for high end-reflection, or anti-reflection coated for use with external mirrors. When asked for figures on threshold and output, we offer only an habitual optimism.

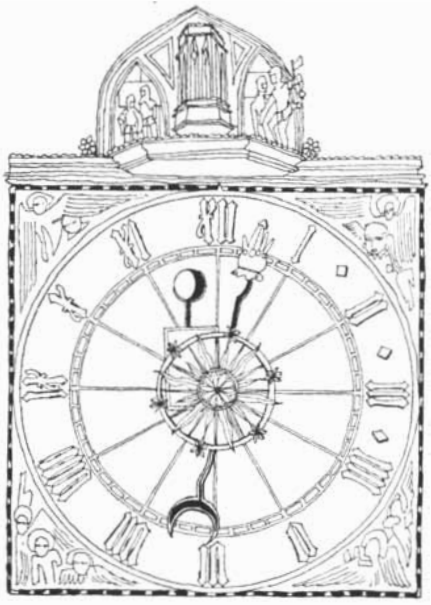
*Check what's in stock or how long it will take to make what's not in stock by writing Eastman Kodak Company, Apparatus and Optical Division, Rochester, N. Y. 14650. For those with slightly less pioneering spirit we also offer neodymium-doped laser glass, both borate and silicate. The silicate features an upper lifetime of 300 to 400 $\mu$sec. All three types of* KODAK *Laser Glass are famous for low beam-divergence. This suggests that their vaunted superiority of optical quality is not hooey.*

## The new trifluoroacetylator

Think of us as engaged in upgrading the practice of biochemistry. Increasingly it becomes unrealistic to picture the authors of the papers as the ones who personally did all the work with their bare hands. When, in synthesizing a peptide, the boss needs a compound to block off the reactivity of an amino acid derivative, he really oughtn't make it himself if the people paid to work for him are smart enough to make it. At the next stage of progress, their time in turn becomes too valuable for such work when the compound can be purchased ready-made from us.

This stage we reached years ago for *Trifluoroacetic Anhydride* (EASTMAN 7386). Now it is reached for the successor in favor as a source of trifluoroacetyl groups. The new one, *S-Ethyl Trifluorothioacetate* (EASTMAN 8176), is less reactive with water and unlikely to racemize the end-product. In ethyl mercaptan it yields a co-product of high volatility that requires no tedious purification steps nor tedious humorous remarks, retaining the advantage of hydrolytic cleavage at pH 10 of the protecting trifluoroacetyl group without imperiling the fragile peptide link.

*Learned people of non-commercial motivation discovered all this. We do our part by echoing their assertions and offering both the old and the new trifluoroacetylators among the vast array of* EASTMAN *Organic Chemicals available from Distillation Products Industries, Rochester, N. Y. 14603 (Division of Eastman Kodak Company).*



# SCIENCE AND

## *Scientists on the Hustings*

Calling for "ever greater exploitation of the nation's scientific and engineering capacity to build the 'great society,'" a bipartisan committee of scientists and engineers has entered the current political campaign in support of the election of President Johnson. Among the organizers are George B. Kistiakowsky, science adviser to President Eisenhower and professor of chemistry at Harvard University, and Jerome B. Wiesner, science adviser to President Kennedy and dean of science at the Massachusetts Institute of Technology. The group will conduct a "strong vote drive at the grassroots level" and "speak out" on issues within the professional competence of its members as such issues arise in the course of the campaign.

In testimony before the platform committee of the Democratic party, Kistiakowsky, Emanuel R. Piore, vice-president in charge of research for the International Business Machines Corporation, and Michael E. De Bakey, professor of surgery at Baylor University, reviewed some of the prospective campaign issues. Affirming "...unqualified support for the time-tested policy of *exclusive* Presidential determination of the use of nuclear arms, whether strategic or tactical" and "unswerving dedication to the goals of limiting and ultimately terminating the arms race through international disarmament with adequate safeguards," they urged "that intensive studies be undertaken to prepare the economy for increased nonmilitary production." In the "constellation of urban problems...water and air pollution, inadequate transportation and poor housing" they saw "a profound opportunity for our technological talent." The Federal Government should continue its support of medical research, they declared, and "must also make certain that the great advances in health care are available throughout the population.... Services must be available to all regardless of ability to pay." Observing that "technological innovation often leads to social and economic dislocation," they recommended "both public and private efforts to enable all Americans to profit from technological innovation." "This nation's scientific resources should be further employed," they said, "in improving the lot of human beings in other lands.... New mechanisms should be established to assist developing nations to create their own technological capabilities."

"The 'great society' ultimately rests on education," they concluded. "We favor imaginative Federal programs directed at improving the quality of education at every level.... We support programs of financial aid to talented and needy students. The nation must no longer deprive itself of talent by reason of discrimination based on race, creed or sex. We reject discrimination as immoral, undemocratic and savagely wasteful of the nation's human resources."

## *Embattled Textbooks*

Biblical fundamentalists are once again in conflict with biologists, this time as a result of efforts by the National Science Foundation to raise the level of high school biology teaching. After five years of preparation and classroom testing, three new textbooks have been offered to state and other educational agencies across the nation. They are the so-called "blue," "yellow" and "green" books, respectively *Biological Science: Molecules to Man* (Houghton Mifflin), *Biological Science: An Inquiry into Life* (Harcourt, Brace and World) and *High School Biology* (Rand McNally). All were produced by a $5 million Biological Science Curriculum Study (BSCS) project. All present the theory of evolution as a logical explanation of the known facts in biological history. Con-

# THE CITIZEN

trary to the practice of some publishers, none is issued in regional editions rewritten to avoid conflict with local prejudices.

During the school year 1963–1964 some 250,000 copies of the three texts were sold, a number sufficient to reach 12 percent of the high school biology students in the U.S. All three have been offered to and accepted by state adoption boards in Georgia and Florida. In Arizona an effort by one church group to place a referendum opposing "atheistic teaching" on next month's ballot failed to obtain the required 55,000 petition signatures.

The outcome of another fundamentalist campaign will soon be determined in Texas. There Reuel Gordon Lemmons, a lay evangelist associated with the Churches of Christ, is spearheading a drive to petition the Texas Textbook Committee not to adopt these "completely materialistic texts," which make no provision for "a spiritual world, or for a soul, or for the resurrection of the dead, or heaven." The Textbook Committee must select five high school biology texts from among the many—including the BSCS books—submitted by publishers and recommend their adoption to the State Board of Education before December.

### *Private Nuclear Fuels*

Congress has passed and President Johnson has signed legislation permitting private ownership of fuels for nuclear reactors. The legislation, which had been sought by the Atomic Energy Commission, is regarded as the most significant change in the Atomic Energy Act since the extensive revisions made 10 years ago in the basic law of 1946. Those revisions gave private industry its first entry into the atomic field by authorizing the A.E.C. to license ownership of nuclear plants by organizations other than the Federal Government. Among the major undertakings thus licensed are 19 electric power plants, of which 13 have been built and six are under construction. The 1954 enactments, however, required the Government to keep control of the fuel for the reactors in those plants, the chief reason being that nuclear materials were still somewhat scarce and the Govern-

ment wanted an assured supply in case of military emergency. As a result, the usual arrangement has been for reactor operators to lease fuel from the Government. The rates charged have been low and have in effect provided a subsidy for the fledgling atomic power industry.

Among the reasons why the A.E.C. sought the latest revision of the law were the plentiful supply of nuclear materials, the belief of the commissioners that the nuclear power industry is on the verge of economic competitiveness and so has a diminishing need for subsidies, and their concern that the Government's investment in fuel inventories would become substantial under the present arrangement—perhaps $3.5 billion by 1980. The new law provides a transition period in which private industry may either lease or buy fuel from the Government. After 1970 the Government will enter into no new leases, and after June 30, 1973, all fuel previously leased must be under private ownership. The law undertakes to prevent the sale of nuclear materials that a foreign government could use to make weapons. It specifies that all international transactions in nuclear materials must take place under intergovernmental agreements stipulating that the materials are not to be used for military purposes and that the use is to be subject to some form of inspection.

### *Antivivisection for High Schools?*

The New Jersey courts will soon be the scene of a possibly far-reaching test case concerning the right of high school students to undertake animal experiments. Under an existing statute the New Jersey Department of Health can authorize various groups, including "schools maintained by the State or Federal Government," to engage in "properly conducted" animal experimentation. High school science-fair projects involving laboratory animals have been criticized by humane society groups in the state for several years. Last spring complaints about exhibits at the 11th Annual Greater Newark Science Fair resulted in a civil action being filed by the New Jersey Society for the Prevention of Cruelty to Animals against the East Orange Board of Education.

The exhibit singled out by the state S.P.C.A. was an experiment testing the susceptibility to cancer of poultry injected with Rous sarcoma virus. It is the S.P.C.A.'s specific contention that the word "schools" in the regulatory statute refers to institutions of higher education and not to high schools. More general objections are that high school students are too immature to undertake unsupervised animal experimentation, that high school science teachers are not competent supervisors, that animal experimentation at the high school level is repetitious, trivial and uncreative and therefore without merit, and finally that, in the words of one humane society spokesman, "kids shouldn't be allowed to whittle on animals."

Opponents of the S.P.C.A. action include the National Society for Medical Research, which has petitioned to enter the case as *amicus curiae*. Those opposing the action specifically contend that when the statute says "schools" it means "schools," because "universities" are also specified among the institutions eligible for Department of Health authorization. More general objections are that proper instruction in the life sciences requires the study of living things and that the high school level is by no means too early a starting point for such studies. Opponents of the action also point out that all the animal experimentation carried on by New Jersey's extensive pharmaceutical industry is illegal under the statute. Should a charge of $100 per injection—the damages being sought by the S.P.C.A. in the East Orange action—be levied against the industry's biological assays, pharmaceutical research would be bankrupt.

### *The Disappearing U.S.*

The question of how fast the U.S. land mass is being washed into the sea has been given a new answer by two Princeton University geologists, Sheldon Judson and Dale F. Ritter. They calculate that solid and dissolved material carried by the rivers of the U.S. is sufficient to lower the average land surface by 2.4 inches in 1,000 years, a rate about twice as high as previous estimates.

To reach this conclusion, reported in *Journal of Geophysical Research,* Judson and Ritter examined the annual records of suspended sediment in the country's major rivers compiled by the U.S. Geological Survey and the Army Corps of Engineers. The highest erosion rate, 6.5 inches per 1,000 years, is found in the Colorado River basin. The next highest rate, 3.6 inches, is recorded for the rivers draining California. The largest river basin, that of the Mississippi, is eroding at the rate of two inches per 1,000 years. The lowest rate is for the Columbia River basin: 1.5 inches.

The authors conclude: "Taking the

average height of the United States above sea level as 2,300 feet and assuming that the rates of erosion reported here are representative, we find that it would take 11 to 12 million years to move to the oceans a volume equivalent to that of the United States lying above sea level. At this rate there has been enough time since the Cretaceous to destroy such a landmass six times."

*Lost Particle*

Early this year physicists at the European Organization for Nuclear Research (CERN) believed they had found evidence for the existence of the "intermediate boson," an elementary particle also designated as *W*. It has now been definitely established that the particle was not observed in the CERN experiment.

The *W* particle was invented to act as the field quantum, or carrier, of the "weak" force of physics, in the same sense that the photon acts as the carrier of the electromagnetic force and the pi and K mesons act as carriers of the "strong" force. In their search for the *W* particle CERN workers attached special magnetic focusing devices to CERN's 25-billion-electron-volt synchrotron, thereby producing a neutrino beam 100 times stronger than the one generated at the Brookhaven National Laboratory two years ago in the experiment that demonstrated the existence of two kinds of neutrino (see "The Two-Neutrino Experiment," by Leon M. Lederman; SCIENTIFIC AMERICAN, March, 1963).

Originally the CERN workers believed they had seen the "signature" of the *W* particle in a few rare particle tracks produced in a 20-ton spark chamber and in a bubble chamber containing three-quarters of a ton of heavy liquid. The signature would be a V-shaped track consisting of two "leptons": either two muons, a muon and a positron or an electron and a positron. One of the leptons would be produced by the interaction of a neutrino and an atomic nucleus that resulted in a *W* particle. The other lepton would arise from the nearly instantaneous decay of the *W*. Although the CERN photographs showed V-shaped tracks that looked like lepton pairs, closer study showed that in each case half of the V was due not to a lepton but to some other particle.

The probability of producing the *W* particle depends in part on the mass of the particle, which is difficult to predict. The greater the mass, the greater

the energy needed to produce it. The CERN experiment shows that if the particle exists at all, it must have a mass equal to at least 1.8 proton masses.

### *New Planetary Facts for Old*

Two time-honored hypotheses concerning the planet Mercury and some enigmas concerning Venus have been eliminated by radio-astronomy observations reported at the recent meetings of the International Astronomical Union held in Germany. Mercury, with a rate of rotation identical with its rate of revolution around the sun, always has one hemisphere facing the sun (as the moon always has one hemisphere facing the earth). As a result the planet's opposite hemisphere is constantly in darkness and its temperature has usually been equated with the deep cold of space. Australian astronomers working with the 250-foot steerable radio telescope at Parkes in New South Wales have now obtained readings for the dark side of Mercury that indicate a temperature of about 60 degrees Fahrenheit. The explanation advanced for this surprisingly high temperature provides another surprise: that in spite of Mercury's small mass and its exposure to solar radiation pressure, which had suggested that it retains little or no atmosphere, it has enough of an atmosphere to transfer some of the sunlit side's abundant heat ration to the dark side.

The orientation of Venus' axis, its speed of rotation and direction of rotation, hitherto unknown because the surface of the planet is obscured by clouds, have been revealed by astronomers working with the 1,000-foot fixed radio telescope operated in Puerto Rico by Cornell University and by another group using equipment at the Jet Propulsion Laboratory of the California Institute of Technology. The axis of the planet proves to be within six degrees of an orientation perpendicular to the plane of its orbit around the sun. Its speed of rotation is quite slow: one turn every $247 \pm 5$ terrestrial days.

The most surprising new fact is that Venus' direction of rotation appears to be clockwise with respect to a view from above its north pole; this direction is opposite to that of all other members of the solar family. (Four of Jupiter's satellites and one each of Saturn's and Neptune's orbit their planets in a clockwise direction, but the solar system's only anomalous case of rotation until the Venus finding was that of Uranus; its axis is tilted 98 degrees from the perpendicular, so that its spin is either clockwise or counterclockwise depending on which of its poles is regarded as north.) A tentative explanation of Venus' peculiar rotation equates the sun-Venus pair with both the earth-moon and the sun-Mercury pairs. In all three cases, it is proposed, any original rotation of the smaller partner has long since been converted into a one-for-one, day-equals-year motion by the gravitational attraction of the larger partner. In the case of Venus, however, the sun's gravity continued to exert force on an asymmetric bulge that developed in the planet's turbulent atmosphere. The action eventually set Venus slowly spinning once again but this time clockwise.

### *Expansive Cement*

A cement that counteracts the tendency of concrete to crack from shrinkage during setting has been developed by Alexander Klein of the University of California at Berkeley and by the Chemically Prestressed Concrete Corp. of Van Nuys, Calif. Known as ChemComp, the cement achieves its effect by causing concrete to expand just enough during the first few days of setting to offset the subsequent shrinkage. Large areas of concrete can therefore be laid without the joints normally needed to allow for volume changes. Among the applications in which the cement has worked successfully are a bank roof that consists only of concrete, without any cover of waterproofing material, and a stretch of highway.

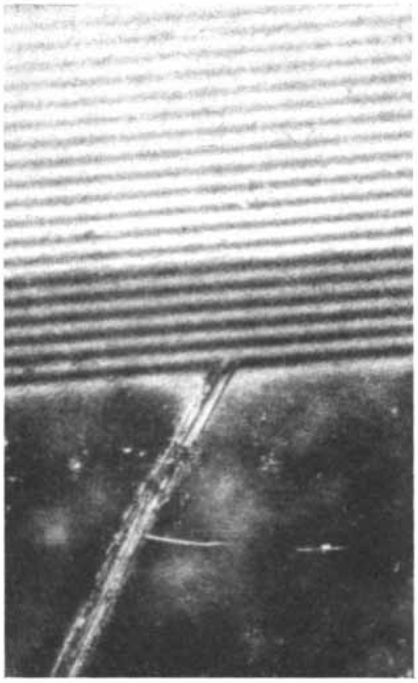
The key ingredient in the cement is ettringite, an expanding form of calcium sulfoaluminate that has long been known in concrete chemistry but has not been used because of the difficulty of controlling its expansion. Klein's approach was to establish control at the point of manufacture, where the raw materials of cement are burned in a kiln and react chemically to produce a new material known as clinker (see "The Chemistry of Concrete," by Stephen Brunauer and L. E. Copeland; SCIENTIFIC AMERICAN, April). The technique developed by Klein was to make a separate clinker that has calcium sulfoaluminate as its chief ingredient and to grind that clinker with portland cement clinker in a proportion that would achieve the desired amount of expansion. The cement thus made has an appreciably higher price than normal portland cement; the producers contend that economies resulting from the use of the expansive compound can offset the difference.

# New technologies that are moving forward —faster— with HVEC Particle Accelerators

*simulation of space environments*

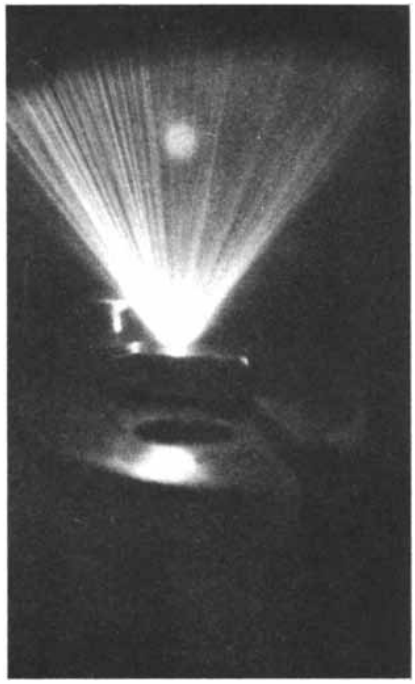
Simulation of micrometeoroid impact on materials . . . by accelerating micron-sized carbonyl spheres to hypervelocities . . . is one way HVEC Particle Accelerators are being used effectively to research the effects of space environments on missile parts and men.

*solid-state "genetics"*



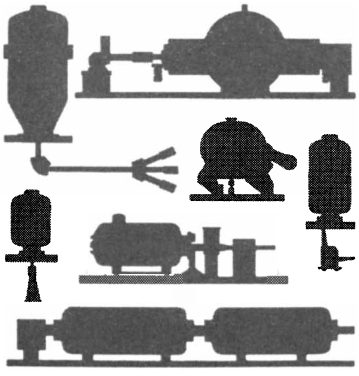
Implantation of Boron-11 ions to a depth of 1.5 microns into a silicon substrate typifies the significant research achievements made possible by HVEC Particle Accelerators in microcircuitry, thin-film components, and other areas of solid-state technology.

*materials evaluation by irradiation*



Bombardment of zinc by a 2-MeV electron pulse from an HVEC Particle Accelerator enables space researchers to study the effects of high-energy radiation. HVEC accelerators have proved particularly useful for destructive and non-destructive testing.

**High Voltage Engineering Corporation Particle Accelerators — with their precisely controllable energy, intensity, and low energy spread with freedom of particle choice — are ideally suited for applied nuclear research.**



**HVEC produces a complete line of particle accelerators from 300-keV to 30 MeV.**

For more details on particle accelerators, write High Voltage Engineering Corporation, Burlington, Mass. or HVEC (Europa) N.V., Amersfoort, The Netherlands. Subsidiaries: Electronized Chemicals Corporation, offering contract radiation service; Ion Physics Corporation, providing contract research and development.

**HIGH VOLTAGE ENGINEERING**

# MICROMETEOROLOGY

## This branch of meteorology deals with atmospheric phenomena within a few hundred feet of the ground. Its findings are proving useful in such practical matters as air pollution and agriculture

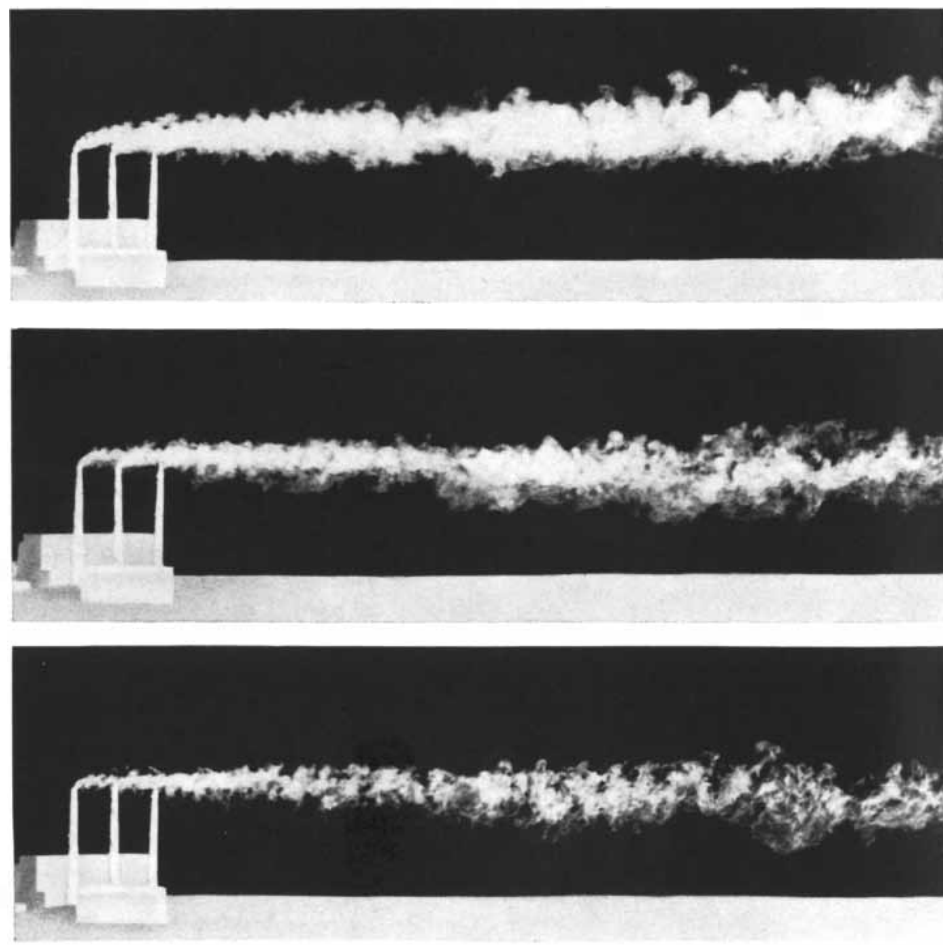
by Sir Graham Sutton

Meteorology now has more than a dozen recognized branches, and one of the newest is micrometeorology. Micrometeorology is concerned with the fine structure of atmospheric processes, particularly with what happens in the first few hundred feet above the earth's surface. It is in this shallow layer that much of the solar heat absorbed by the earth is trapped and the heat balance that sustains life on our planet is maintained. By detailed study of the physical processes involved, micrometeorology is providing an intimate knowledge of mechanisms controlling the weather—knowledge that promises practical benefits to man's health, agriculture and living conditions.

Up until half a century ago man was better acquainted with the movements of the heavenly bodies than he was with the basic processes of heat transfer and water evaporation at the earth's surface that determine his living environment. Today it is fair to say that micrometeorology is approaching the ideal of an exact science. The micrometeorologist can stage experiments, make precise measurements and test mathematical theories in ways that are not possible in the study of the large-scale features of the atmosphere. He employs techniques of the physicist in the laboratory; indeed, micrometeorology represents a particularly effective merger of laboratory investigation with observation of nature.

The atmosphere has sometimes been likened to an onion, in that it is made up of many layers. A gross dissection shows the main layers to be, from the inside out: (1) the troposphere, or the region of weather, extending up to an altitude of about 11 miles at the Equator and about five miles at the poles, (2) the stratosphere and (3) the ionosphere, the electrically conducting outer region. The micrometeorologist confines his attention to the lowest part of the troposphere.

Throughout most of the troposphere the temperature of the air decreases with height at the rate, on the average, of about .3 degree Fahrenheit per 100 feet. The actual rates at various levels and places of course vary considerably from the average. It can be calculated that if the atmosphere were dry, well mixed and in hydrostatic equilibrium, a volume of air pushed upward would become cooler (by expansion) at the con-



**WIND-TUNNEL STUDIES** of smoke plumes show two of the variables involved in the pollution of downwind areas by combustion products. The smokestacks of the model plant rise to the scale equivalent of 320 feet above ground level. When the ejection speed of the stack gases is 52 feet per second (*top photograph*), even the thrust of a 30-mile-per-

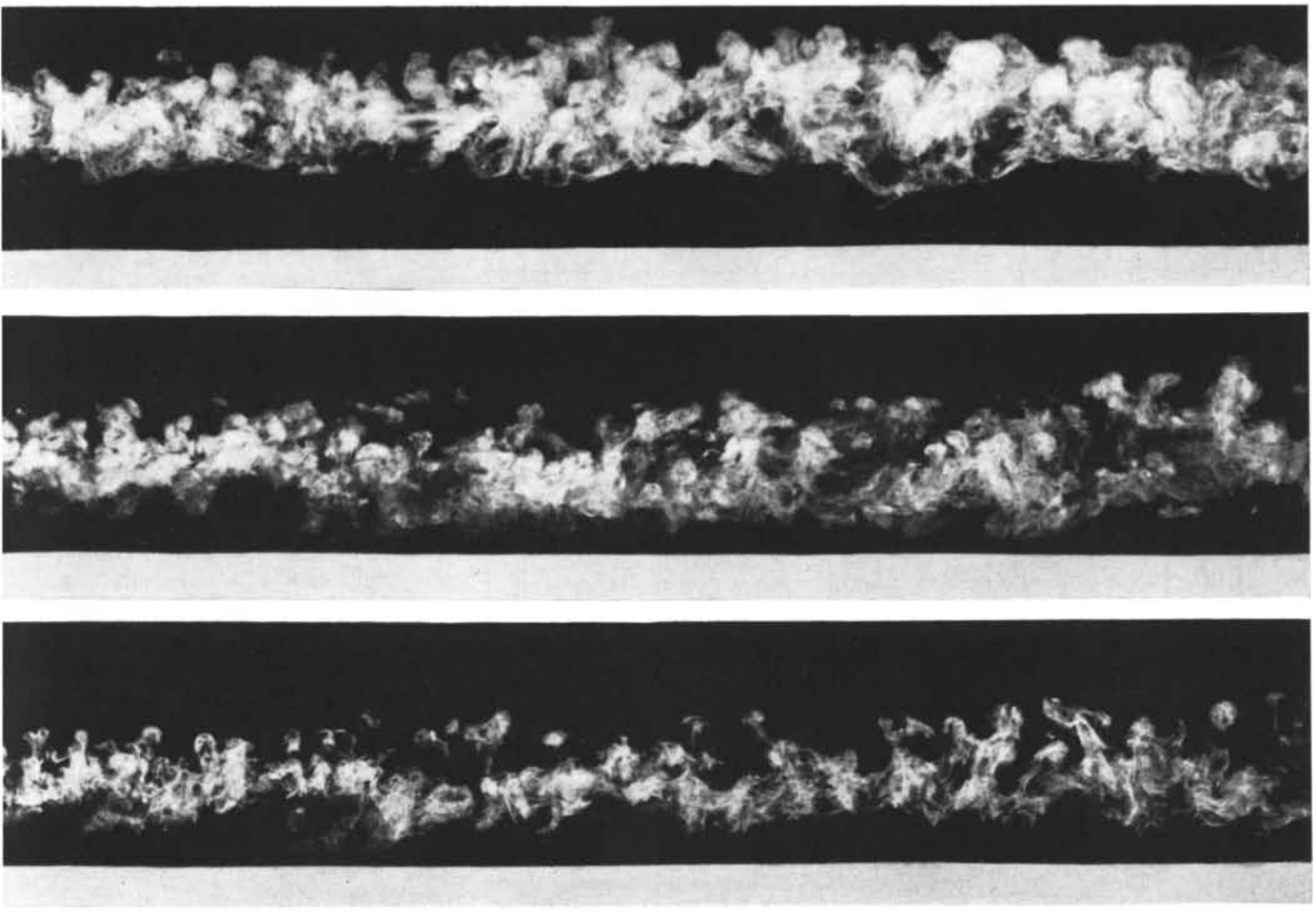
stant rate of almost exactly .54 degree F. per 100 feet. This rate of cooling, called the "dry adiabatic lapse rate," is a theoretical standard that determines the stability or instability of an atmosphere. An atmosphere whose actual lapse rate is greater than the dry adiabatic rate must be unstable in terms of vertical motions, because any volume of air that is displaced upward (cooling at the adiabatic rate) will be less cold, less dense and thus lighter than its surroundings, and it will therefore go on rising. By the same token, if the volume of air is displaced downward, it will become colder and heavier than the ambient air and therefore will have a tendency to go on sinking. On the other hand, an atmosphere with a lapse rate less than the dry adiabatic rate will be stable in structure. Any air that is moved upward will become colder and denser than its surroundings and hence will tend to sink back to its original level, and air displaced downward will become less dense than its environment and tend to rise again. The same thing is true of any atmosphere or atmospheric layer in which the air becomes warmer instead of colder with increasing height —the familiar "inversion" phenomenon. In that situation any air moved upward (and thereby inevitably cooled by expansion) will of course be cooler than its surroundings and will sink back.

All these arguments apply to a moist atmosphere as well as to a theoretically dry one. The moisture factor introduces a complication into the calculations, but the conclusion remains the same: any atmosphere, moist or dry, will be structurally stable, unstable or in neutral equilibrium according to whether its actual lapse rate is less than, equal to or greater than the adiabatic rate.

In these terms the earth's troposphere tends to be on the stable side; that is, the decline of temperature with height is on the average slightly less than the adiabatic lapse rate. Reversals of this situation, however, are common. Soundings by balloon-borne instruments in the middle latitudes often show fairly deep layers of air that have a superadiabatic lapse rate or a temperature inversion. Either is generally a sign that unusual weather is in store. A markedly superadiabatic lapse rate extending through several thousand feet in an upper-air sounding puts the weather forecaster on the alert for thunderstorms or perhaps a tornado; an inversion in the first few thousand feet usually indicates subsiding air, with perhaps a threat of fog. The significant point here is that in the troposphere as a whole these conditions are departures from the norm, usually associated with movements of large air masses that bring about changes in weather; the normal situation aloft is a slightly subadiabatic lapse rate.

## The Atmosphere near the Ground

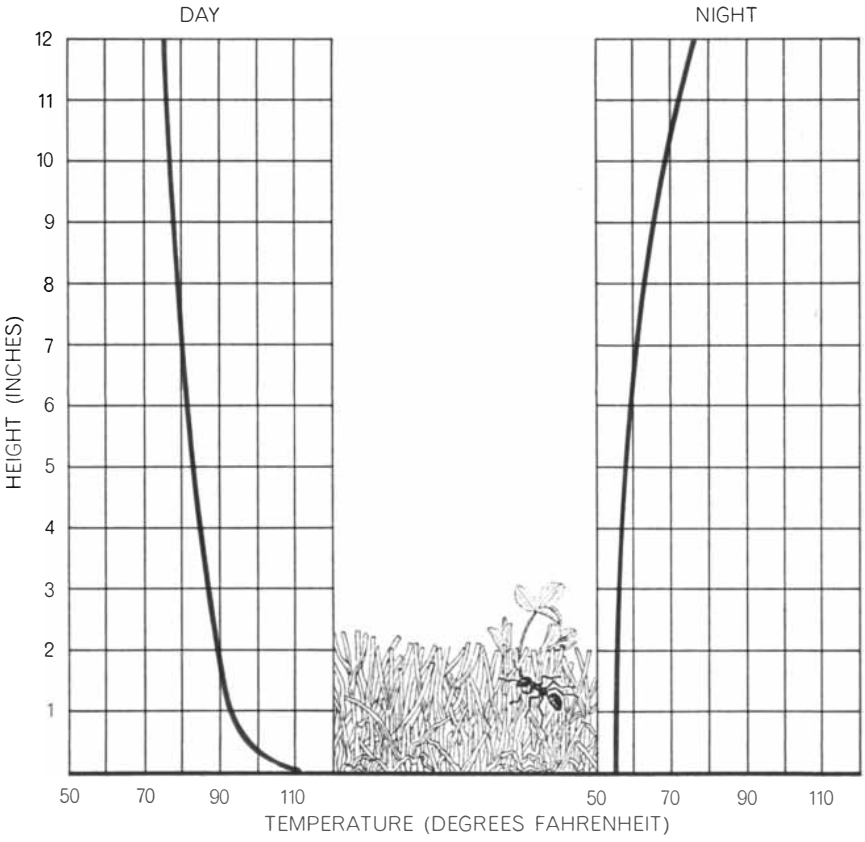
In the realm of micrometeorology—the first few hundred feet above the ground—the situation is quite different.



**hour wind is not sufficient to bring much of the rising plume into contact with the ground in the course of a mile. When the wind velocity is increased to 40 miles per hour (*middle photograph*), there is much more ground contact, as is the case when the wind velocity remains unchanged but ejection speed is reduced to 17 feet per second (*bottom photograph*). These photographs are from a study made with the Air Pollution Wind Tunnel of the School of Engineering and Science at New York University.**

There large departures from the adiabatic lapse rate are a regular, daily occurrence, particularly during periods of clear, sunny weather. Consider what happens in the shallow layer near the ground during the 24 hours of a clear summer day. After sunrise the sun rapidly heats the surface of the ground to very high temperatures. To take an extreme case, measurements made in the desert near Tucson, Ariz., in June have shown the daytime ground temperature to be 161 degrees F. or higher. Even in the relatively cool climate of southern England surface temperatures have been recorded at 141 degrees on a highway and 111 degrees on a closely cropped lawn. From such hot surfaces the temperature decline in the air immediately above is, of course, quite sharp. For example, in the interval between one inch and one foot over a lawn on a sunny afternoon in southern England the temperature difference has been recorded as nearly 18 degrees F., and most of that decrease must take place in the first inch or so of the interval. In short, the daytime temperature gradient very near the ground frequently amounts to thousands of times the dry adiabatic lapse rate. Then, as the sun sets, the picture changes rapidly. If there are no clouds, the ground radiates heat away freely and at a high rate. Because the air cools more slowly, an inversion soon occurs: the ground, having dropped to a lower temperature, takes heat from the air immediately above it, and thus the air temperature increases with height.

This diurnal cycle of temperature change, varying from an enormous negative gradient near the ground by day to an inversion at night, has profound consequences for all life on the planet. Consider the teeming life, both animal and vegetable, whose world is encompassed within an inch or so of the ground surface. The climate of this Lilliput is altogether different from that at man's breathing level (which averages about four feet). A seedling pushing its first leaf through the soil may, even in a temperate latitude, experience in a single day a range of temperature that for man and other large forms of life would correspond to daily commuting between the Tropics and the Arctic.



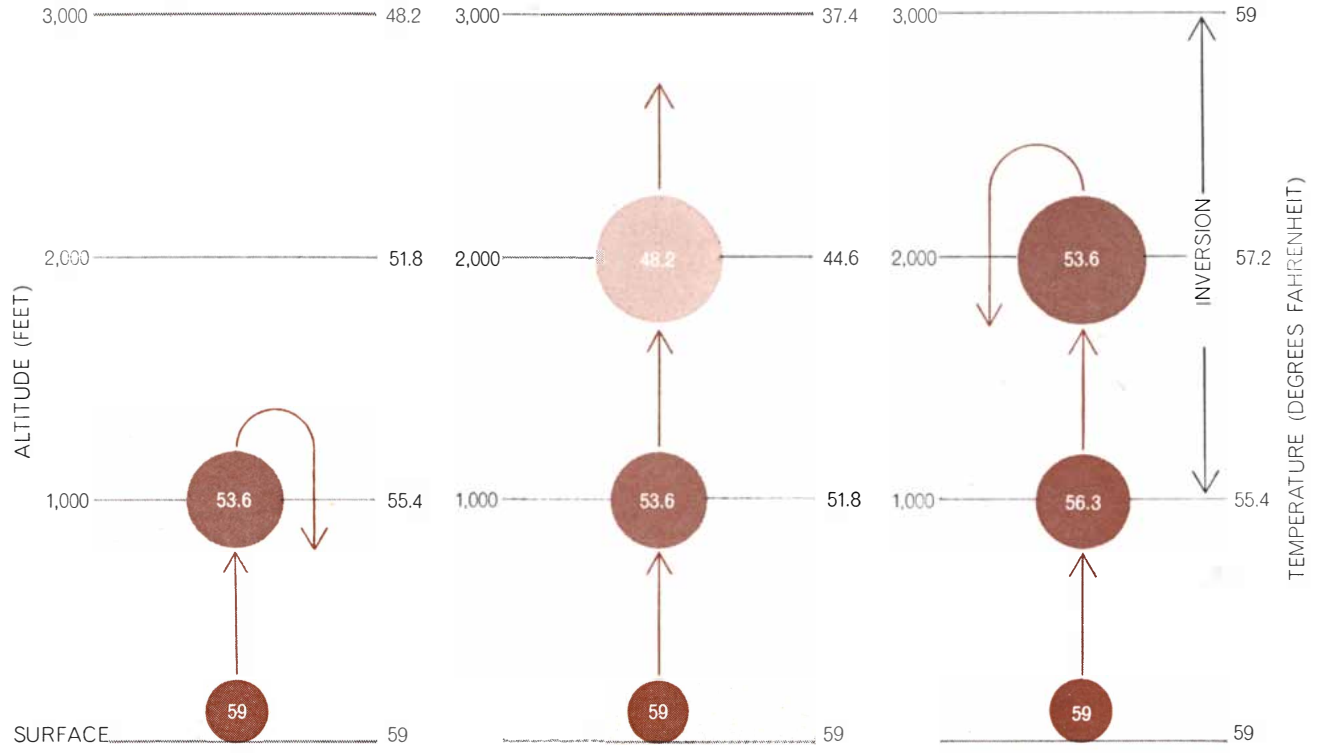

**EXTREMES OF TEMPERATURE are characteristic of the microenvironment at and just above the surface of the ground even in temperate climates. A drop of 18 degrees Fahrenheit has been recorded in the first 12 inches of air over a sunlit lawn in southern England, with most of the decrease occurring nearest the surface (*graph at left*). In clear weather the surface heat is rapidly lost after sunset (*graph at right*). As a result low plants may experience daily variations of temperature that range from tropical heat to polar cold.**

In a larger sense, the steep gradient of temperature near the ground is of central importance to all forms of life. It leads to turbulent airflow and a rapid mixing of air between different levels without which life as we know it could hardly exist. The surface of the earth would alternate between extreme heat and extreme cold; evaporation and the water cycle would almost cease to exist, because the layer of saturated air forming over water surfaces would simply lie there, and living creatures could never congregate in large numbers without being poisoned by their own products. We had a dramatic demonstration of this in the great London smog of 1952. In four days of December, when an anticyclone brought a cessation of wind and created a deep inversion that acted as a lid over the city, some 4,000 persons died of respiratory ailments attributable to the bottling up of the city's smoke. This toll of life stemmed from only a small percentage decrease in the normal rate of escape of sulfur products into the atmosphere at large. It serves as a sharp reminder that dwellers in large cities with many open coal fires and other sources of sulfurous fumes live within a narrow margin of safety.

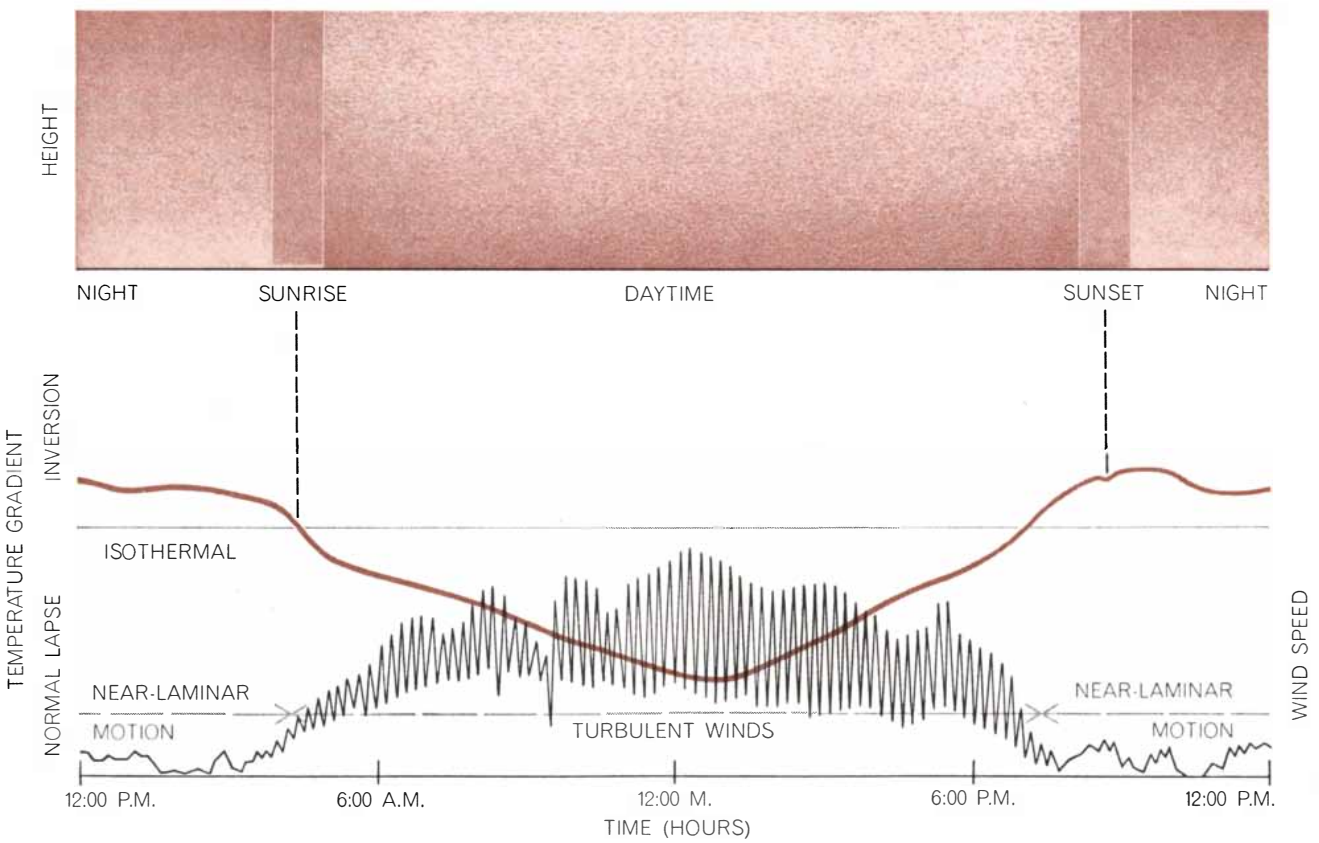
## Slope Winds and Sea Breezes

Major airflows are generated by large-scale gradients of pressure associated with cyclones (lows) and anticyclones (highs). But there are also local surface winds or air currents, usually confined to within 1,000 feet of the ground, that are caused primarily by local temperature differences and are related to the presence of hills or bodies of water. They are known respectively as slope winds and sea breezes.

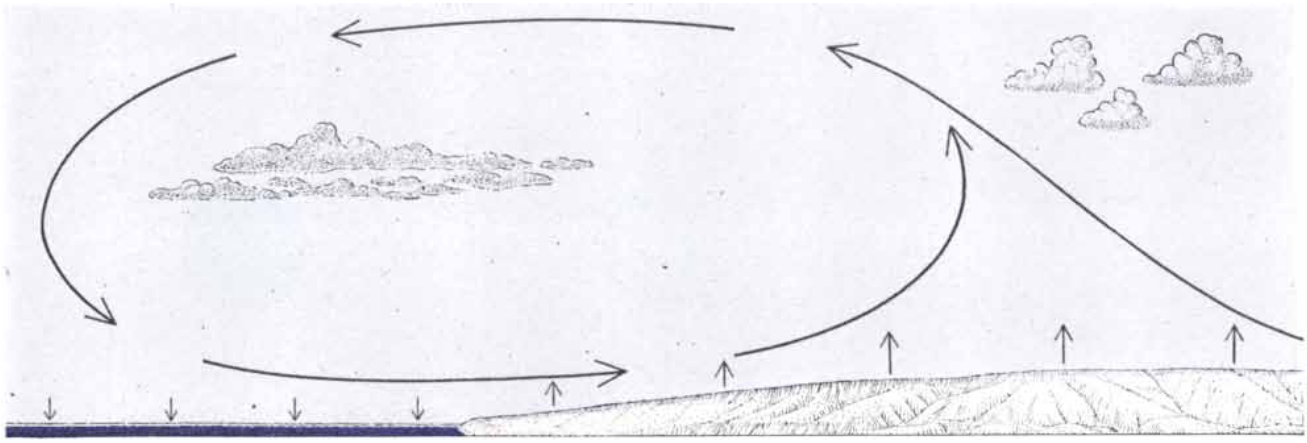
The familiar phenomenon of the sea breeze, a steady blow from the water inland that occurs along seacoasts and lakeshores on days of strong sunshine, is a result of the fact that the sun heats the surface of the land to a higher temperature than the water surface (where water movements conduct much of the absorbed heat below the surface). As the warmed ground heats the air above it, the pressure aloft becomes greater than that above the sea, and the upper air therefore moves seaward. This reduces the pressure near the land surface below, and as a result air then flows in over the land from the sea. The circulation thus set up maintains the sea breeze throughout the day. (At night the circulation is reversed and a "land breeze" blows in the opposite direction.) At Ismailia in Egypt, some




**STABILITY OF THE ATMOSPHERE** depends on the rate at which the air temperature decreases with altitude. When an air mass is displaced upward and cools with expansion, it will soon sink again if it is cooler (and thus denser and heavier) than the air surrounding it (*left*). The result is a stable atmosphere. If the rising air mass is warmer than its surroundings (*middle*), it will continue to rise; such an atmosphere is unstable. A temperature inversion (*right*) also halts unstable movements of air masses.




**DIURNAL CHANGES** in air temperature near the ground show the normal kind of decrease with altitude during daylight hours, brief sunrise and sunset periods of equal temperature regardless of height, and temperature inversion at night (*contrasting tones, top*). When temperature is plotted against wind speed (*bottom*), the function of a normal temperature gradient in the production of turbulent winds and the consequent interchange of the lower atmosphere is evident. Such interchanges make urban areas habitable.



**SEA BREEZE** is set in motion as the surface of the land heats more rapidly than the adjacent water. On sunny days increasing pressure from the warming air over the land moves the upper masses of air seaward. This movement reduces the pressure just above the land surface and the sea air then flows inland. The circulation thus set up continues for the remaining daylight hours.

40 miles inland from the Mediterranean, there is a particularly well-marked sea breeze that arrives promptly on schedule every sunny summer afternoon at about 3:30 and blows steadily for six or seven hours until sunset. The breeze is a dependable event that controls the local weather and the comfort of the inhabitants.

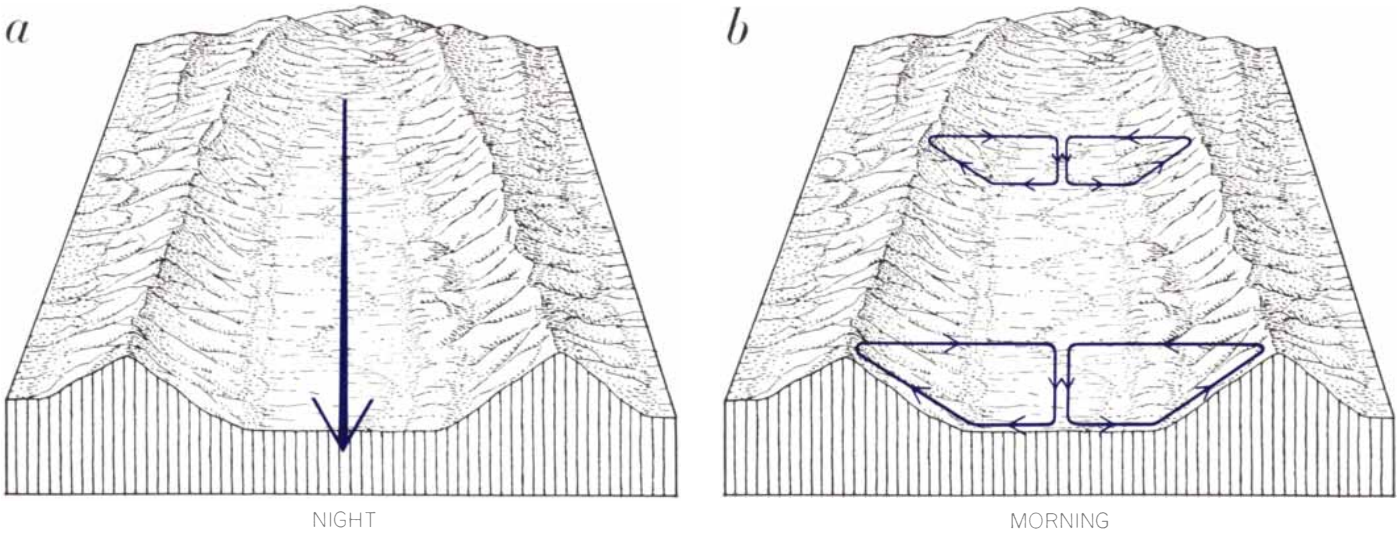
Slope winds are common in hilly or mountainous country. On a clear night, when the earth radiates its heat rapidly into space, the air on a hill is cooled to such density that it slides down the hillsides by gravity. It will flow down a valley onto a plain and continue to blow if there is no topographical obstacle to block its movement. During the day the sun's heating of the air in the low places may cause it to flow up the hills again as a "valley wind." Detailed studies have shown that the diurnal cycle is rather complicated, with cross-valley circulations occurring in the morning and early evening, but the general picture is clear.

This fact of microclimatology suggests that the buyer or builder of a house would be well advised to think twice before choosing a site in a "sheltered valley." If the valley is hemmed in, frost pockets are likely to form on clear nights in winter and even in the spring. A recent comparison in the environs of the city of Toronto provides a good illustration. On a winter night when the temperature on the lakefront side of the city was 15 degrees F., the temperature in the valley of the Don River, only seven miles away, was 17 degrees below zero!

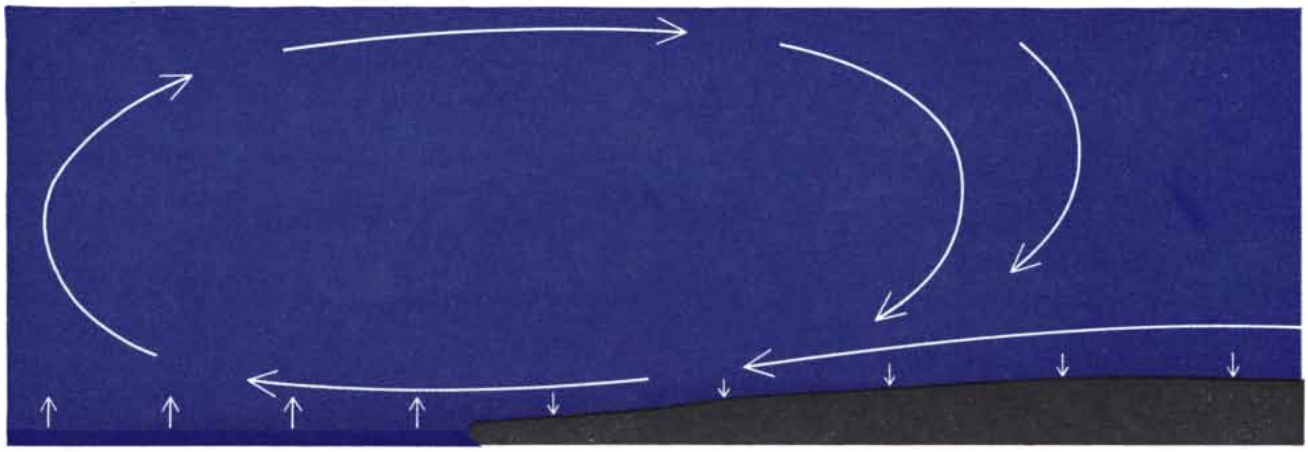
There are other seemingly minor factors that affect the microclimate. One is the nature of the soil. A house on a well-drained loam or clay soil is likely to be warmer on a cold night and cooler on a hot afternoon than one on a light, sandy soil, because the latter —owing to the air space between the particles of soil—undergoes greater surface temperature changes. Even the height of the grass around the house can be important. Long grass makes the area colder at night and tends to promote mist and fog. So there are climatic as well as aesthetic reasons for keeping lawns well trimmed.

## The Study of Fluid Dynamics

The work of micrometeorologists is devoted above all to analyzing the processes responsible for turbulent air movement in the lower atmosphere, which in turn brings about the rapid diffusion of air that makes life possible. The main aim of the investigations is to arrive at a quantitative understanding of these processes, with a view to gain-




**SLOPE WINDS** follow a complex diurnal pattern that has as its basis the rapid heating and cooling of the surface during clear days and nights. In the predawn hours of darkness (*a*) cooled air literally slides downhill under the influence of gravity, creating a "moun-



**LAND BREEZE is caused by the slower loss of heat by the water surface during the hours of darkness compared with the quite rapid loss of heat by the adjacent land surface in clear weather. It is the air over the water that is now warmer and the pattern of circulation is the reverse of that during the day (*see illustration at left*). These local airflows seldom extend higher than 1,000 feet.**

ing information that will be helpful on a great variety of problems, from atmospheric pollution to the conservation of water and the advancement of agriculture. The inquiry has led the micrometeorologist into deep and difficult questions of fluid dynamics.

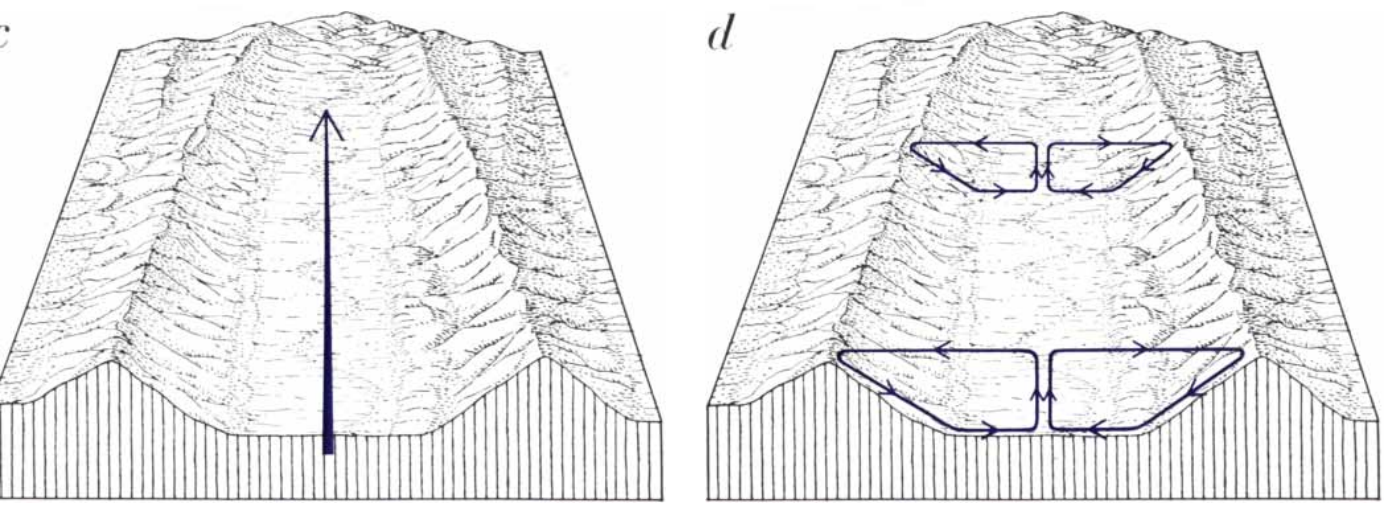
There are two general types of fluid motion: laminar (that is, smooth) and turbulent. Laminar flow is like the marching of a well-disciplined regiment: the pace may vary somewhat from point to point, but the whole movement is orderly and the ranks do not intermingle. Turbulence is more like the wild rush of a crowd: the motions within the body are characterized by large, rapid, apparently random variations in velocity. Nearly all natural motion of liquids and gases is turbulent. This is particularly true of winds; measurements with a sensitive anemometer show that even an apparently steady breeze is gusty, varying from instant to instant in velocity and direction.

The detailed study of turbulent motion began in 1883 with a simple laboratory experiment performed by the British physicist Osborne Reynolds. He ran a stream of water through a long, horizontal glass tube held firmly in place so that the flow would not be disturbed by any outside influence. To observe the nature of the flow he fed in a thin tracer stream of dye at the inlet. As long as the flow of water through the tube was slow, the dye moved downstream as a narrow filament, occasionally snaking slightly from side to side but remaining intact all the way to the outlet. Reynolds gradually increased the speed of the main stream; when it had reached a certain velocity, the filament of dye suddenly broke up near the inlet and the color quickly filled the whole tube. The laminar flow had abruptly changed to a turbulent flow.

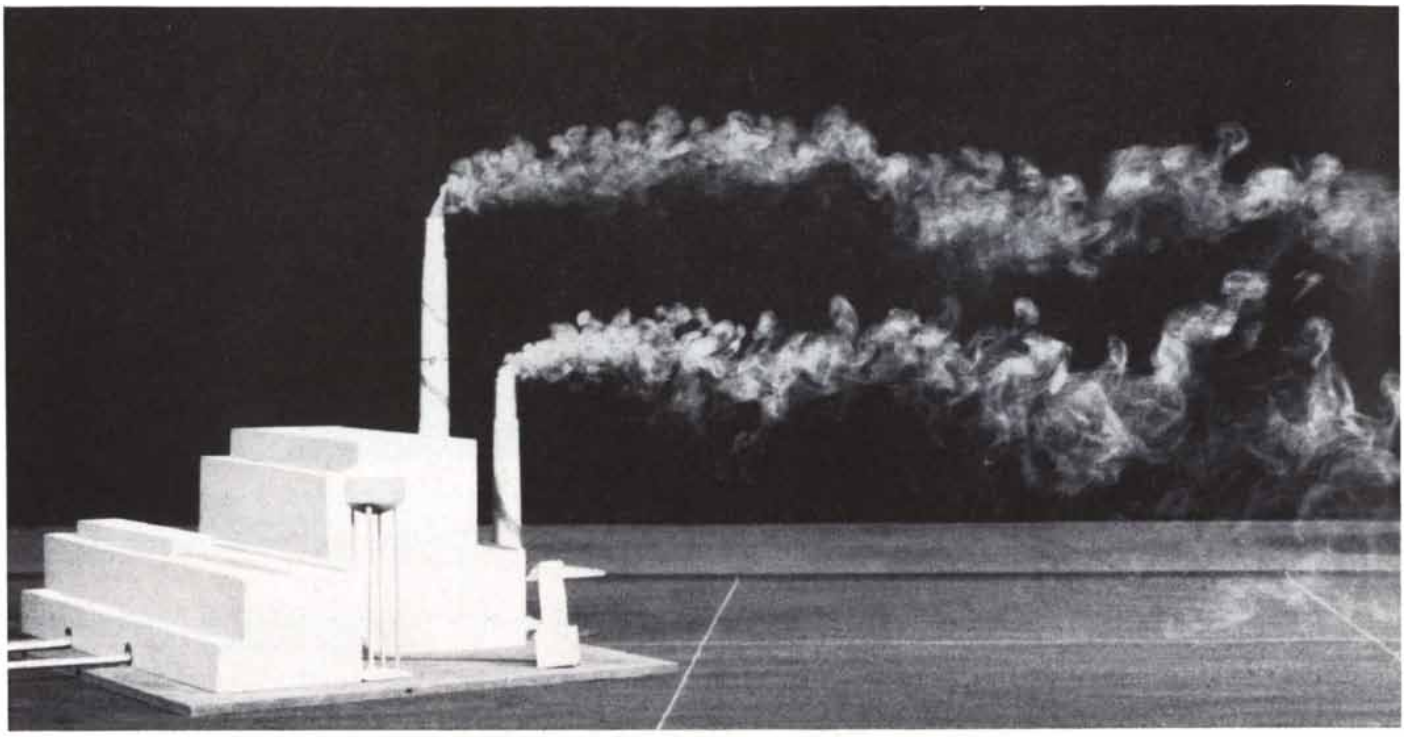
In one-directional laminar flow the only movement of particles across a stream is that resulting from the normal thermal motion of molecules; diffusion by this process in a moving stream is so slow that the filament of dye hardly widened at all in its passage from one end of the tube to the other. As soon as turbulence set in crosscurrents promptly spread the dye throughout the stream.

By varying the conditions Reynolds found that the change from laminar to turbulent flow depended on three factors: the speed of flow, the diameter of the tube and the viscosity of the fluid. The product of the speed and diameter, divided by the kinematic viscosity, constitutes what is now known as the "Reynolds number," and turbulence arises when this number exceeds a certain value.

Reynolds' formula applies only to a

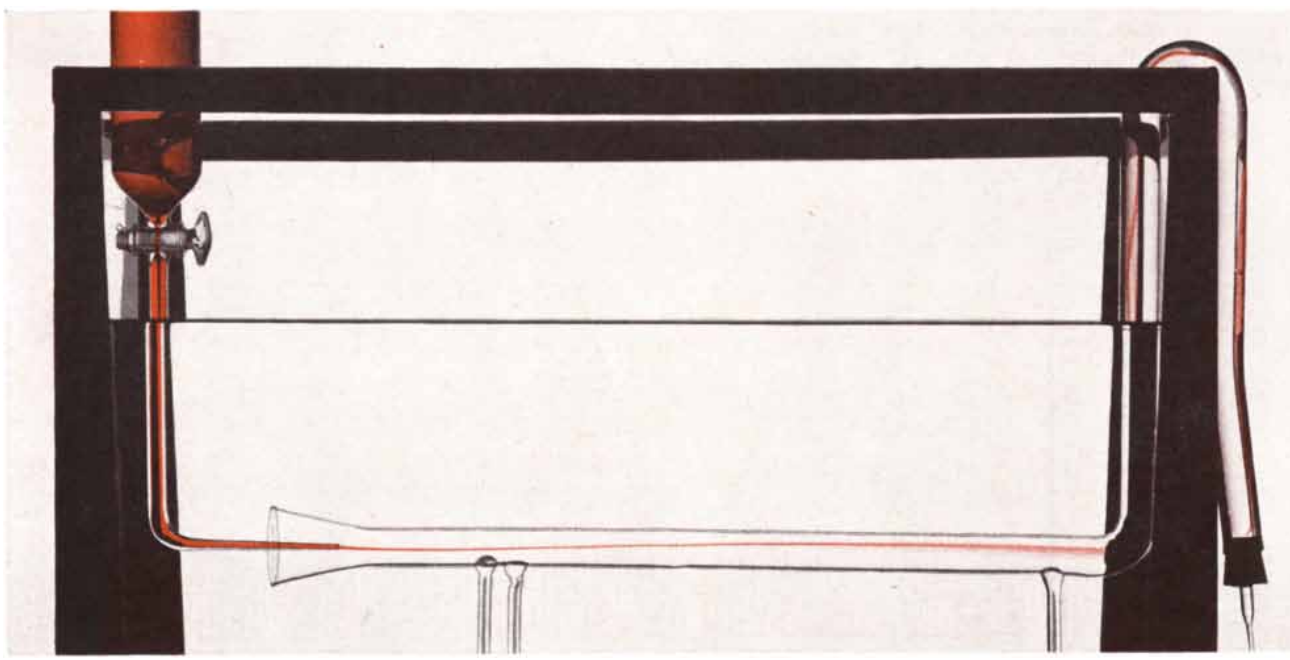



**tain wind." During the forenoon (*b*) the warming earth of the valley floor induces a cross-valley circulation of air that is a prelude to the general uphill flow of the late afternoon "valley wind" (*c*). An opposite cross-valley pattern (*d*) begins after nightfall.**

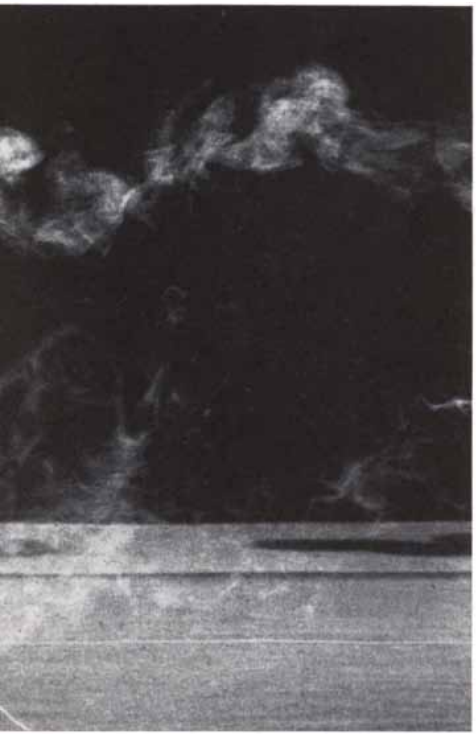


**SMOKE CONCENTRATION downwind from an industrial source is a function of smokestack height, other factors being equal. In theory, when stack height is doubled, ground concentration is reduced by a factor of four and the maximum concentration point is**

fluid of uniform density throughout. The air of the lower atmosphere, of course, is not uniform in density, and in this case the transition from laminar flow to turbulence is determined primarily by the variation in density, or, what amounts to the same thing, the rate of change of temperature with height. In the daytime, when the temperature gradient is vastly greater than the adiabatic lapse rate, the air is generally turbulent and gusty; at night, on the other hand, the nocturnal inversion results in a nearly laminar airflow [*see bottom illustration on page 65*]. The smoke from leaf-burning on a clear day and evening in the country acts as a counterpart of Reynolds' experiment. In midday the smoke will fan out widely; after sunset it drifts as a thin, meandering plume. The familiar quiet of a summer evening and the freakish breezes of the day have a simple physical explanation. During the day, when the lapse rate is superadiabatic, air that is deflected upward by a tree, house or boulder will go on rising and start a gusty circulation;



**LAMINAR FLOW is the only orderly natural motion of gases and fluids. A stream of dye traces the slow and smooth flow of water through a transparent tube in a demonstration patterned after the 19th-century studies by the British physicist Osborne Reynolds.**



**twice as far downwind. This is another New York University wind-tunnel photograph.**

in the evening the temperature inversion tends to damp out upward air motions and thereby quench turbulence.

## The Role of Turbulence

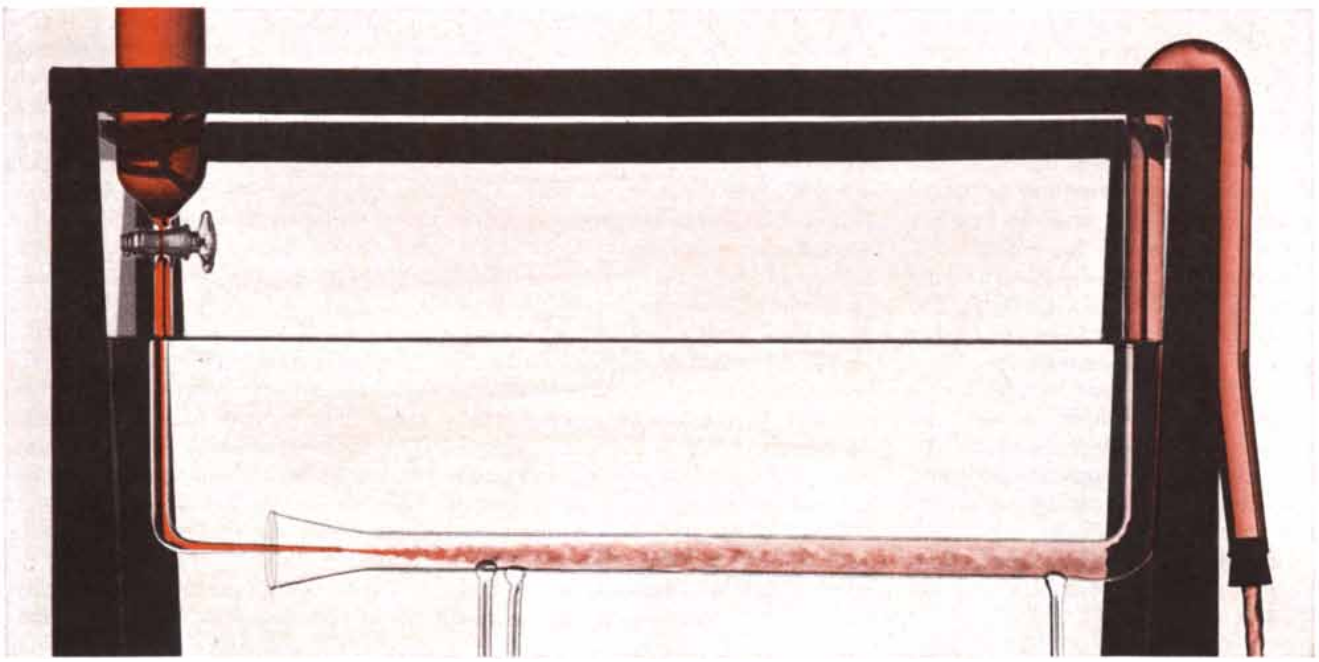
Turbulent motion itself is still something of a mystery, not yet defined by a mathematical description such as has been developed for laminar motion. Progress has been made, however, toward a mathematical understanding of how turbulence plays its role in the diffusion of air in the lower atmosphere.

Looking at a turbulent river, one can see that it is filled with eddies. The individual eddies arise from various origins, differ considerably in size and move in irregular paths. Ultimately all of them blend into the main stream, presumably contributing their physical properties—momentum, heat and so on—to the stream as a whole. One is tempted to draw an analogy between these eddies and the molecules of a gas. Can one think of the eddies as macroscopic molecules, diffusing momentum and matter throughout the stream by collisions and mixing with one another? Do they obey statistical laws like those that govern the behavior of a gas?

Early in this century this hypothesis was pursued mainly by three leading investigators of atmospheric turbulence—Wilhelm Schmidt of Austria and G. I. Taylor and L. F. Richardson of Britain. By that time the mathematical physics of molecular diffusion had been well established, and it was known that solution of the differential equations involved called for knowledge of three physical properties of the medium: its conductivity of heat, its viscosity and the rate of diffusion of a given form of matter in the medium. For air these constants had been determined to a high degree of accuracy.

Taylor began by calculating, on the basis of balloon soundings indicating the relation between winds and air friction, the theoretical "eddy viscosity" (analogous to molecular viscosity) of the atmosphere. He found the eddy viscosity of air to be about 100,000 to a million times the molecular viscosity. Taylor and Schmidt, working independently, then obtained a theoretical value for the atmosphere's "eddy conductivity" of heat, and this proved to be of the same large order of magnitude as the eddy viscosity. Since that correspondence paralleled the situation with respect to the *molecular* coefficients of air (that is, the values for viscosity, conductivity and diffusivity are all of the same order of magnitude), the findings seemed to argue that diffusion by the mixing of eddies was indeed analogous to diffusion by collisions between molecules. They suggested that the two processes differed only in scale, the exchange between eddies being vastly greater than that between molecules.

Richardson threw this hypothesis into doubt, however, by some actual observations of the scattering of material by the wind. Richardson, a Quaker, had worked in the British Meteorological Office (the counterpart of the U.S. Weather Bureau), but he resigned when it was incorporated into the Air Ministry in 1921. Although he no longer had laboratory facilities at his disposal, he undertook to collect what information he could about the diffusion of matter by turbulence in the air. He observed the scattering of dandelion seeds by the



**TURBULENT FLOW takes the place of laminar flow when the water-stream speed exceeds a threshold value proportional also to the tube diameter and the viscosity of the liquid. Rapid, random crosscurrents spread dye throughout the water stream.**

**CONVECTION CURRENTS rise from a sun-warmed bur oak leaf. Sunlight could raise foliage to lethal temperatures except for the reradiation of solar energy and the cooling effects of transpiration and convection currents. The air movement, here revealed by schlieren photography techniques, causes an exchange of gases: water vapor and oxygen are carried away and fresh supplies of carbon dioxide are brought in. The photograph was made by David Gates of the National Bureau of Standards Boulder Laboratory.**

wind, noted the travel of toy balloons in a children's balloon-flying competition sponsored by a newspaper and examined the records of the drift of debris from a volcanic eruption. Thus his data included examples of diffusion over distances ranging from a few yards to hundreds of miles. Crude as the data were, they yielded a consistent and significant finding, namely that in every case the rate of diffusion of the material increased rapidly with distance from the source. That is to say, the "eddy diffusivity" in turbulent air seemed to be different at a distance from the source from what it was near the site of the source—a plain absurdity, since a true law of nature cannot depend on distance from an arbitrarily chosen point. This meant that the concept of a constant coefficient of diffusion, which had succeeded at the molecular level, could not be applied in the same way to eddy diffusion in air.

What Richardson had learned about turbulent diffusion from his elementary observations was actually confirmed and explained at about the same time in a secret research establishment in Britain. Because the work was military, however, the results were not made public until many years later. After World War I the British government had set up at Porton in Salisbury Plain in southern England a project for the study of defense against poison gas and other chemical weapons. This work included a systematic examination of the meteorology of the lower atmosphere, with particular reference to the dispersion of gases and clouds of particles by natural winds. (The Porton establishment can be regarded as the birthplace of micrometeorology as a full-fledged, organized discipline.) With instruments arrayed over a wide area, the investigators made accurate measurements of the diffusion of clouds of gas and smoke at distances up to more than half a mile downwind of the point at which the source had been placed. They found that as the wind dispersed this material its concentration away from the source declined not in direct proportion to the distance, as in the case of molecular diffusion, but at a much more rapid rate, amounting to something approaching the *square* of the increase in distance. In short, the difference between molecular and turbulent diffusion proved to be not just a matter of scale but of a difference in kind. Other studies showed that the eddy conductivity of heat also differed from molecular conductivity so drastically that it could not be expressed by the same formula.

Meanwhile, without benefit of these secret experimental discoveries (which were not fully released until after World War II), the entire theory of turbulence was being recast anyway, partly as a result of vexing questions raised in aerodynamics. Many approaches have been explored. I shall mention only one that has been highly useful both in the investigation of atmospheric turbulence and in dealing with certain practical problems.

This is the statistical theory of turbulence, developed by Taylor (now Sir Geoffrey Taylor). It starts with the mathematical concept of the random walk. Consider a cluster of particles. Let us say that each particle is buffeted at random, that it travels in a straight line after each push, that it is as likely to be pushed backward as forward and that the successive steps are entirely independent of one another. How rapidly will this cluster spread out, or, putting it another way, how much will the total volume of the cluster have expanded after any given interval?

If the initial concentration of the particles and the average energy of the buffeting impulses are known, it is possible to make a statistical prediction. Given the conditions specified above, the random-walk theorem states that each particle will tend to wander away from its starting point at a rate such that on the average its distance from that point will increase as the square root of the elapsed time. Another way to put it would be to say that an inebriated walker who is as likely to step backward as forward will on the average take four times more steps (that is, he will take four times longer) to walk two miles than he took to walk one mile. This square-root law is actually demonstrated by the Brownian motion of particles bombarded by molecules in a fluid, from which the theory was originally derived.

Taylor considered the deeper problem of turbulent diffusion in the atmosphere. He assumed that this diffusion must be by continuous movements, in the sense that the successive move-

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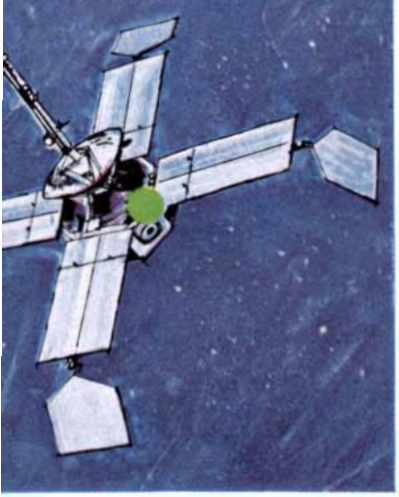

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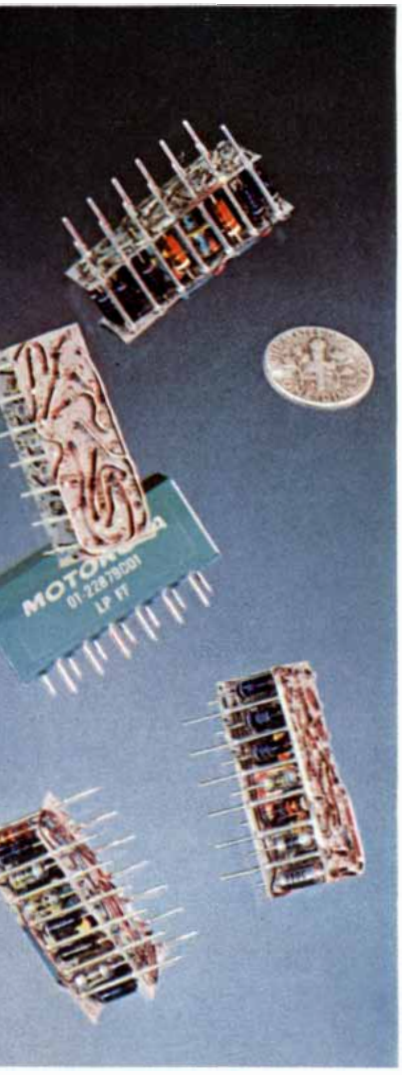
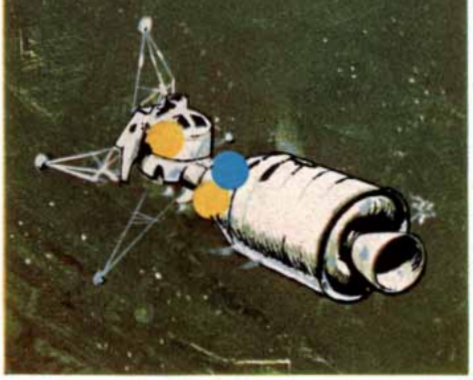
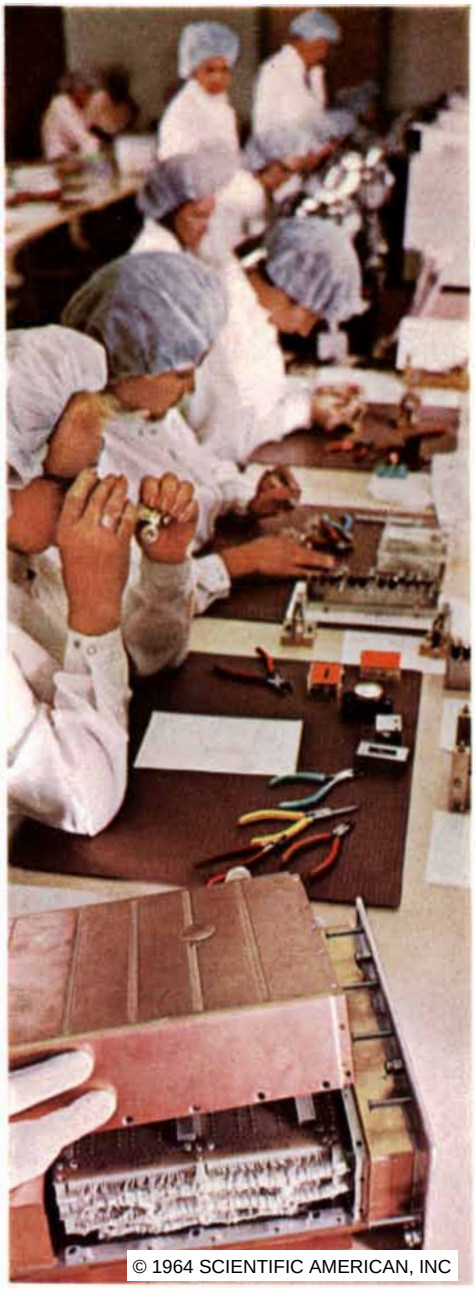
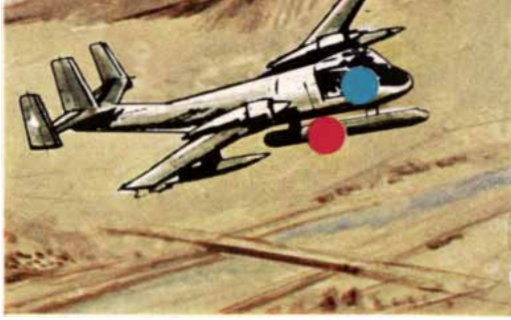




**COMMUNICATIONS FOR APOLLO/LEM.** Motorola is providing the up-data link and vital communications transponder for the Apollo Spacecraft as well as the transponder for the Lunar Excursion Module. Critical electronic circuitry is assembled in the special, controlled environment of Motorola clean rooms to meet rigid NASA quality assurance specifications.





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*continued next page*

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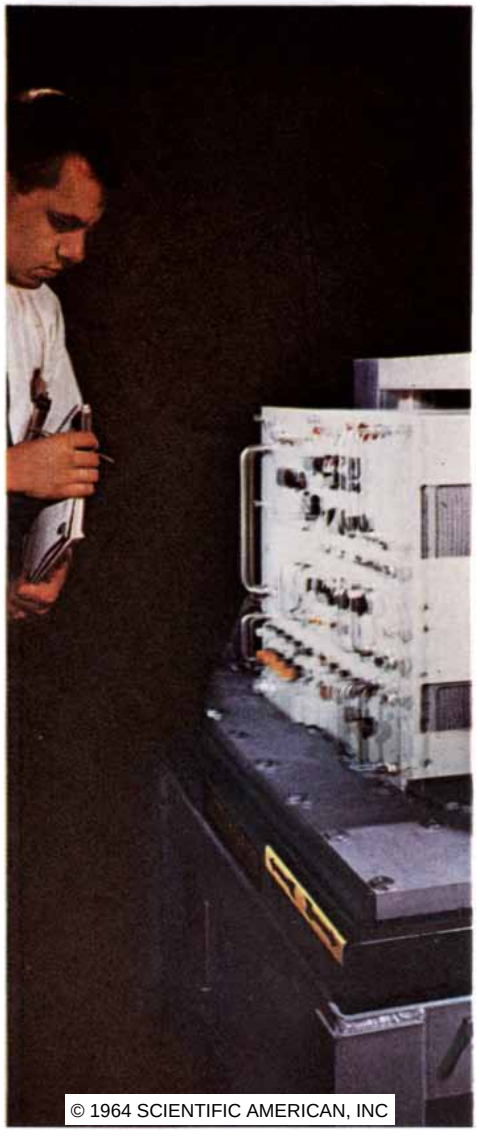

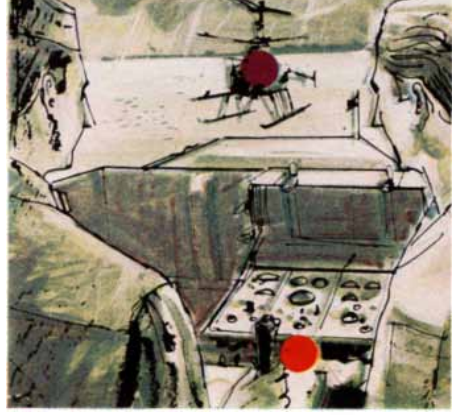

**ASW AND UNDERSEA SENSORS.** For the Navy's DASH (Drone Anti-Submarine Helicopter) program. Motorola provided the heart of the command guidance system—shipboard transmitter controls & coders, and airborne decoders—to guide weapons-carrying drone helicopters to precise target locations. And, Motorola's capabilities extend well into the ocean depths; e.g., advanced air-dropped sonobuoys extend the range of underwater sonic detection systems. For undersea navigation, the new Motorola-developed all-electronic Solid State Compass, with no moving parts, provides an accurate and dependable direction reference at extreme depths, even under violent shock or vibration.

*continued*

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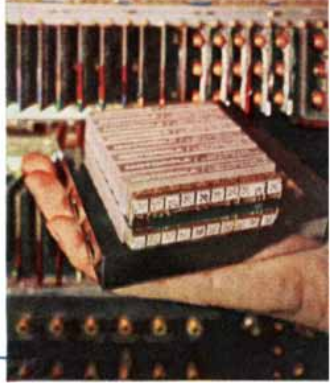
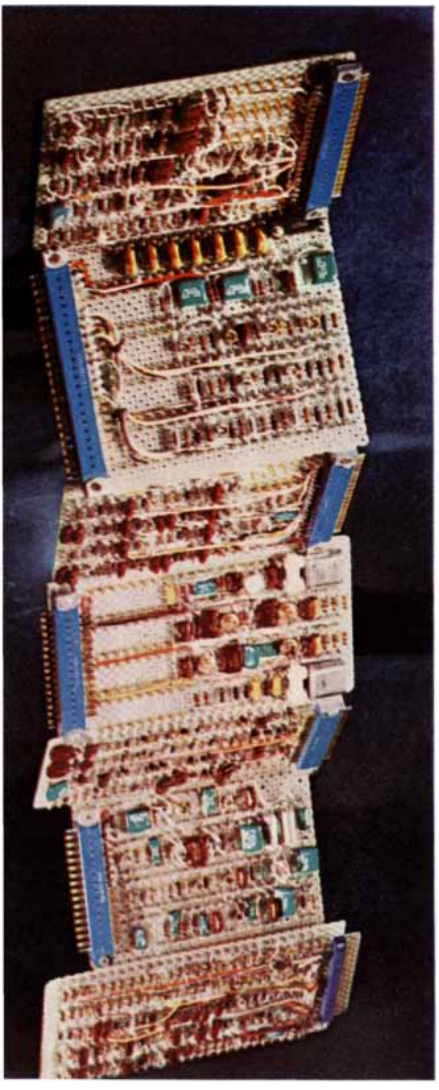


**ADVANCED COMMUNICATIONS STUDY.** RADEM (Random Access Delta Modulation) is a continuing study program at Motorola to develop a digitally modulated voice and data communications system permitting person-to-person direct-dialing for many users on a common frequency channel. Operational in areas of high interference, the RADEM concept requires no central exchange or fixed nets and is ideal for random access, discrete addresses, high mobility and message security. Extensive application of integrated electronics offers significant advantages in terms of size, weight, reliability and cost.



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**INTEGRATED CIRCUIT APPLICATIONS LEADERSHIP**
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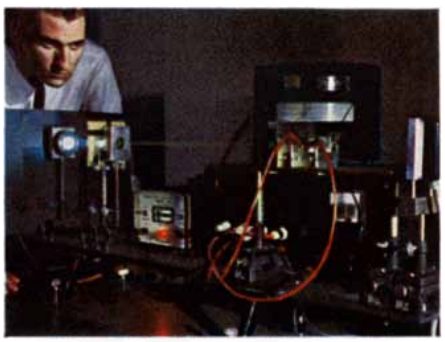

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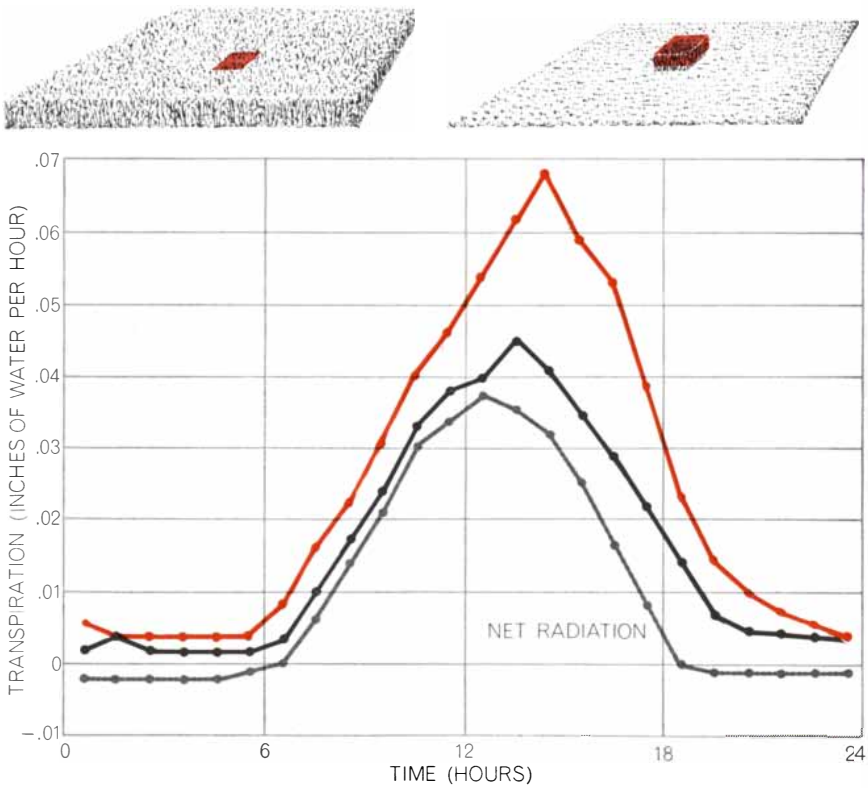
ments of the particles are not entirely random but are connected with one another—or, in mathematical language, are "correlated." Consider this time the cluster of particles that make up a cloud of smoke in the atmosphere. At first the particles are pushed about by a coherent series of wind motions, one motion leading to the next. As time goes on, however, new eddies arise and intervene. As a result the correlation between impulses weakens with time. Taylor worked out a simple formula describing the dynamics of the situation, and his concept has given rise to many interesting developments in turbulence theory and to solutions of a number of technical problems in turbulent diffusion. In particular these solutions indicate that the rate of growth of a puff of smoke in a turbulent wind is much more rapid than would be implied by the square-root law of Brownian motion, which would hold in laminar flow.

## The Uses of Micrometeorology

Although the theories are far from providing any complete solutions, they enable micrometeorologists today to answer with fair confidence many questions about phenomena such as the spread of smoke from industrial stacks and the evaporation of water from lakes and reservoirs. They have provided considerable enlightenment on the problems of atmospheric pollution.

Smoke emerging from a stack stretches out in a long plume that ultimately reaches the ground. Given the rate of emission from the stack and the necessary meteorological data, a mathematical solution derived from Taylor's random-walk theorem makes it possible to predict the concentration of smoke at any point downwind [*see illustration at top of pages 68 and 69*]. The amount of smoke reaching the ground depends on the height of the stack and the amount of turbulence in the wind. (It is found to be in inverse proportion to the speed of the wind and the square of the stack height.) Thanks to the formula, a plant designer can calculate precisely how much the pollution at ground level can be reduced by raising the height of the stack. There is a way to increase the effective height of the stack without going to great expense. This was satisfactorily demonstrated not long ago at a smelting plant in Murray, Utah. From a 200-foot stack the smelter was seriously




**MICROCLIMATES OF CROPS** vary with the plants' exposure to the wind. One square meter at the center of a field of sorghum was grown in a weighing lysimeter, so that its exact uptake of water through transpiration was known. When this area was surrounded by other sorghum plants, the test plants transpired about four inches of water in 24 hours (*black curve*). When the sheltering plants were cut, the test sorghum, exposed to turbulent air, transpired a third more water (*colored curve*) although net radiation (*gray*) was the same.

polluting the air of the surrounding countryside with sulfur dioxide. A moderate addition to the height of the stack brought no relief. The operators of the plant then attempted to drive the smoke higher into the air by blowing a draft of cold air up the stack, but this only made matters worse: the smoke plume actually fell to the ground more quickly. When hot air was substituted for the cold air, there was a striking improvement: the smoke then rose instead of falling. With this device and a buildup of the stack structure to 450 feet, the pollution of the surrounding countryside was reduced to an innocuous level.

The growing problem of pollution of our atmosphere will eventually have to be dealt with by heroic measures, just as, in the past century, cities had to deal decisively with the problem of sewage disposal in order to avoid suicide. This necessity alone is a compelling reason for pursuing the work in micrometeorology.

There is another important application of micrometeorology of quite a different kind—not a purely defensive stand against disaster but a positive step to make more effective use of nature. It has to do with the economics of food production. Specifically it is concerned with the question: How much water do plants need to sustain vigorous growth? The factor involved here is the process known as evapotranspiration: the uptake of water from the soil by plants and its evaporation into the air by way of the plant leaves. Plants grow most vigorously when this process goes on at a maximum rate, and to maintain that rate the plants require a certain amount of water. In order to determine the amount needed, meteorologists have developed a measure called "potential evapotranspiration," which is the ideal rate of transfer of water from the soil to the air by way of plants in a given region. If the actual water income from the soil is less than this, the difference should be supplied by irrigation.

The concept of potential evapotranspiration and its application to agriculture is mainly the work of the late American climatologist C. Warren Thornthwaite, who devised both theoretical and experimental methods for its determination. Experiments have amply verified the predictions of this measure concerning how much watering is needed in given situations. Thus the young science of micrometeorology has removed the guesswork from irrigation and introduced a new measure of precision into man's oldest industry.

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# Tears and the Lacrimal Gland

*Human beings shed continuous tears as well as those induced by emotions, chemicals and various irritants. Study of the gland that produces tears may help to explain the process of secretion*

by Stella Y. Botelho

*Tears, idle tears, I know not what they mean.*

When Tennyson wrote this line, he was referring to the fluid that flows from the eyes and nose when one weeps for sorrow, pain, anger, joy, sympathy or patriotism. These are psychogenic tears, which are only one of four categories of tears shed by man. Psychogenic tears, however, appear to be unique to man; in spite of the term "crocodile tears" there is no evidence that any other animal weeps in response to emotional stress.

Human tears are formed by a group of glands named the lacrimal system after the large gland that secretes fluid through a series of ducts onto the surface of the eye [*see illustration on page 80*]. The tears perform such essential functions as keeping the cornea transparent, clean and lubricated. Aristotle observed that normal infants cry without shedding tears during the two weeks following birth. A recent study by Saree Penbharkkul and Samuel Karelitz of the Long Island Jewish Hospital showed that whereas some infants shed tears within the first six hours, only 13 percent of a large sample accomplished this feat within the first five days, and after 30 days 25 percent still had not produced fluid when crying. This delayed capacity for psychogenic crying (which is delayed in premature infants) suggests that the connections within the central nervous system that indirectly innervate the lacrimal system are not fully developed in most newborn infants.

The tears that flow from the eye when its surface is excessively exposed to light, cold, wind, foreign bodies or irritating gases and liquids are called reflex tears because they are produced by the excitation of sensory receptors located in the surface membranes of the eye and nose (respectively the conjunctiva and the mucous membrane). Reflex tears occur in man, domestic animals and perhaps all terrestrial and amphibian vertebrates with the probable exception of snakes. The eyeball of the snake moves beneath a "brille," a tough, transparent membrane that protects it from scratching by grasses and other plants. Many aquatic and amphibian animals possess similar membranes.

Every animal that has a backbone and spends all or part of its life out of water sheds a third type of tears: continuous tears. Air-dwelling and amphibian vertebrates such as frogs, salamanders, lizards, tortoises, turtles, crocodiles, snakes, birds, quadruped and primate mammals all have glands that slowly secrete tears to form a liquid film on the surface of the eye. Invertebrates (whose eyes have no movable parts) possess no analogous system, nor do aquatic animals, for whom water plays the role of tears. Two sea mammals, the whale and the seal, are exceptions.

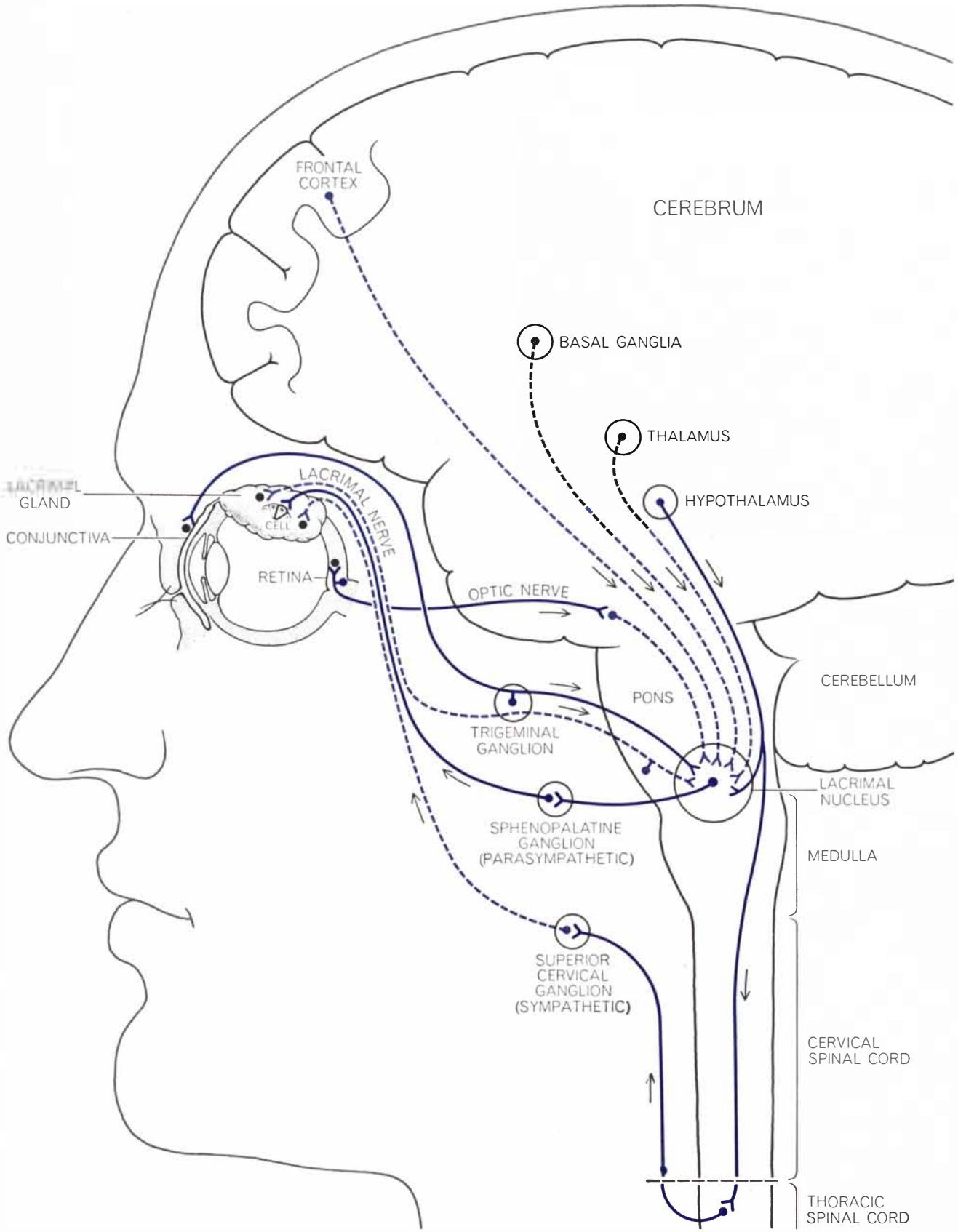
A fourth type of tearing is induced when such substances as Mecholyl, pilocarpine and various war gases are administered not to the eye but elsewhere in the system, ultimately reaching the tear glands by way of the bloodstream. These "secretagogues" are distinct from the irritant substances contained in many tear gases (and perhaps in onions) that induce reflex tearing.

The lacrimal system not only secretes tears but also collects them. The eyelids sweep fluid toward the lacrimal punctae, small openings at the nasal angle of the eye. Tears pour through these openings into the lacrimal sac and its downward continuation, the nasolacrimal duct, until they pass the "valve" of Hasner at the bottom of the duct.

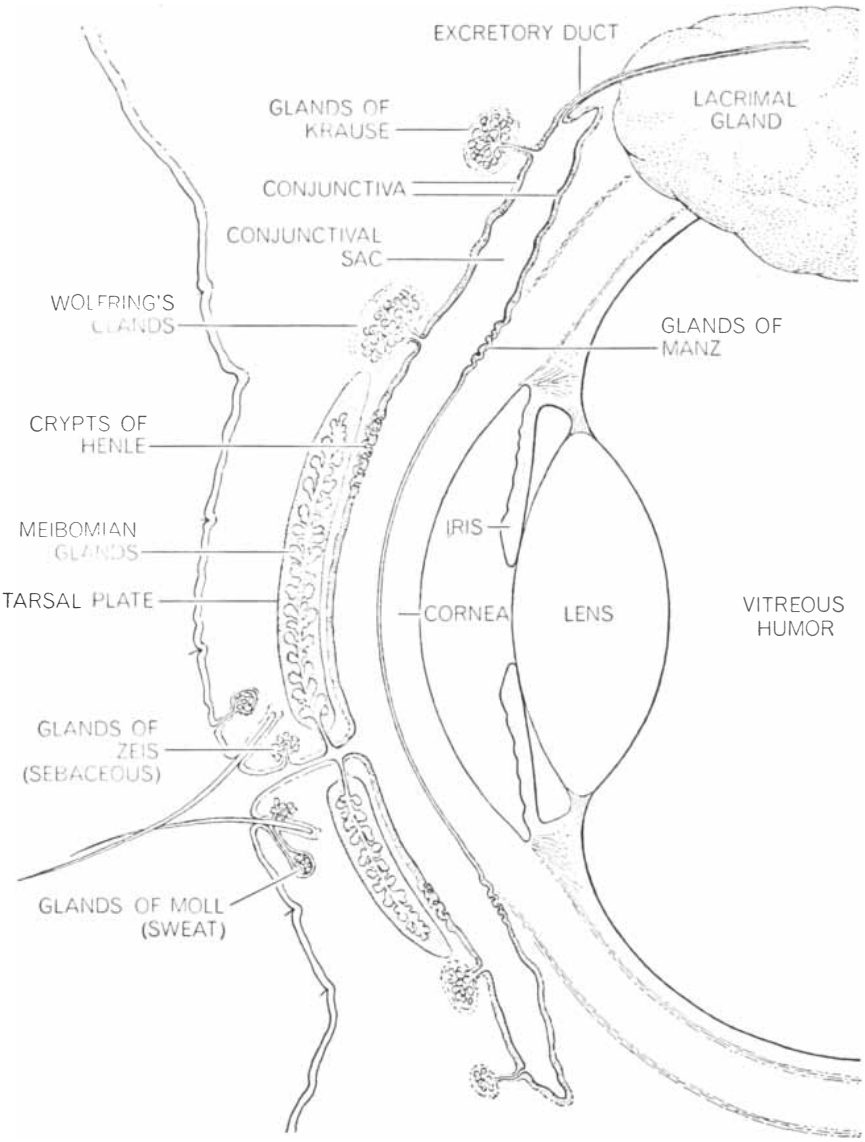
In most species the nasolacrimal duct opens into the nose, but in certain blind, burrowing snakes it opens into the mouth. In lizards and in most snakes it opens into Jacobson's organ, where the animal's forked tongue casts odoriferous particles, and in the wormlike caecilians it opens into a retractable tentacle used for touch and smell. The differences among these organisms suggest that tears developed not only to moisten the eye but also to moisten the nose and mouth. The similarities between salivary glands and lacrimal glands have often been noticed by histologists, by physicians who observe decreased salivary secretion and decreased tearing simultaneously in a disorder called Sjögren's disease, and by anyone who realizes that excessively hot or pungent food may cause an outpouring of fluid from eye and nose.

Man is in the minority in possessing only two eyelids. Most animals have, in addition to an upper and lower lid, a transparent "nictitating" membrane that can act as a third lid. This membrane is most active in animals that operate under circumstances that endanger the cornea: birds (whose corneas tend to be dried by the wind), grazing animals such as sheep and stalking animals such as wolves. Another evolutionary price man pays for his highly developed lacrimal system is the absence of Harder's gland, an analogue of the lacrimal gland that is found in almost all other vertebrates [*see bottom illustration on page 81*].

The film of tears covering the human cornea seems to consist of three layers: a deep mucoid layer adjacent to the cornea, an intermediate watery layer




**NERVE CONNECTIONS** of the lacrimal gland and accessory regions of the eye and brain that apparently contribute to the formation of tears are represented schematically. Fibers from the lacrimal nucleus in the brainstem carry a motor impulse to neurons in the sphenopalatine ganglion, a knot of nerves shown by a circle. The fibers that carry impulses from this ganglion to the lacrimal gland are part of the parasympathetic system. Sensory fibers connect the lacrimal nucleus with the lacrimal gland by way of the trigeminal ganglion. Such fibers in the optic nerve may carry impulses to the lacrimal nucleus from the retina. The unknown role of some fibers, such as those between the lacrimal gland and the superior cervical ganglion (sympathetic system), is indicated by the broken lines.




**GLANDS THAT PRODUCE TEARS sheathe the eye when the lids close. The lacrimal gland (*top*) helps form the watery substance in tears, along with the glands of Krause and Wolfring. The crypts of Henle and the glands of Manz produce a mucoid layer. The tarsal and Meibomian glands and the glands of Moll and of Zeis help to make the oily layer.**

and a superficial oily layer. Each layer is apparently secreted by a different group of glands. The mucoid layer is attributed to the conjunctival glands (the crypts of Henle and the glands of Manz), the watery layer to the lacrimal gland proper and the accessory lacrimal glands (the glands of Krause and of Wolfring, the infraorbital gland and the glands of the plica and the caruncle), and the oily layer to the glands of the eyelids (the tarsal, or Meibomian, glands and the glands of Moll and of Zeis).

The tears secreted by all these glands and collected from the nasolacrimal duct or the conjunctival sac contain 1.8 percent solids. The chemical composition of such tears [*see lower illustration on page 86*] can be considered with respect to the composition of serum, the fraction of the blood that remains after the rest of the blood has clotted. Sodium and bicarbonate are present in tears and serum in equal concentration, but chloride and potassium are present in larger amounts in tears. There is 30 to 40 times less glucose in tears and 10 times less total protein. The ratio between the proteins albumin and globulin in reflex tears is about the same as in serum, but psychogenic tears may contain less albumin. At least three and perhaps as many as six protein fractions have been identified in tears by electrophoretic and immunoelectrophoretic techniques; age and genetic differences have been reported to alter the pattern of the fractions' relative abundance.

Present in tears but not in serum is lysozyme, a powerful enzyme considered a protective agent because it can kill many bacteria by destroying their cell wall. Lysozyme in tears was first reported by Alexander Fleming, the discoverer of penicillin. Subsequent investigations by Jona Allerhand and his co-workers at the Long Island Jewish Hospital showed that after 36 hours of life in full-term infants and about a month in premature infants the immunoelectrophoretic pattern of tears resembles the pattern of adult tears, and differs from the pattern of serum in that it lacks alpha-1 globulin and much of the alpha-2 and beta globulins. These investigators suggested that mature tear glands secrete either proteins different from the serum proteins or unidentified enzymes that modify the serum proteins. Since abnormally high concentrations of protein and unusual immunoelectrophoretic patterns have been reported in the tears of patients with such genetic disorders as mongolism and cystic fibrosis, the study of how cells secrete tears may elucidate the metabolic defects causing these disorders.

Much of what is now known about the nerve pathways to the lacrimal gland has been uncovered by physicians who were assessing the effect of a given neurological injury on the flow of tears. Both psychogenic and reflex tears are apparently shut off by lesions that involve groups of cells in either the sphenopalatine ganglion or the lacrimal nucleus and fibers from these centers [*see upper illustration on page 82*]. Psychogenic tears may be decreased or increased by lesions involving the frontal cortex, the basal ganglia or the thalamus, and they may also be regulated by a region of the brain associated with emotional response: the hypothalamus. It has been reported that the stimulation of certain groups of neurons within the hypothalamus may influence the flow of tears and alter the appearance of the cells of the lacrimal gland in experimental animals. Reflex tears are blocked by lesions involving the sensory pathways, whereas continuous tears are augmented by a lesion of the cranial nerve that produces paralysis of the facial muscles, including those that activate the eyelid.

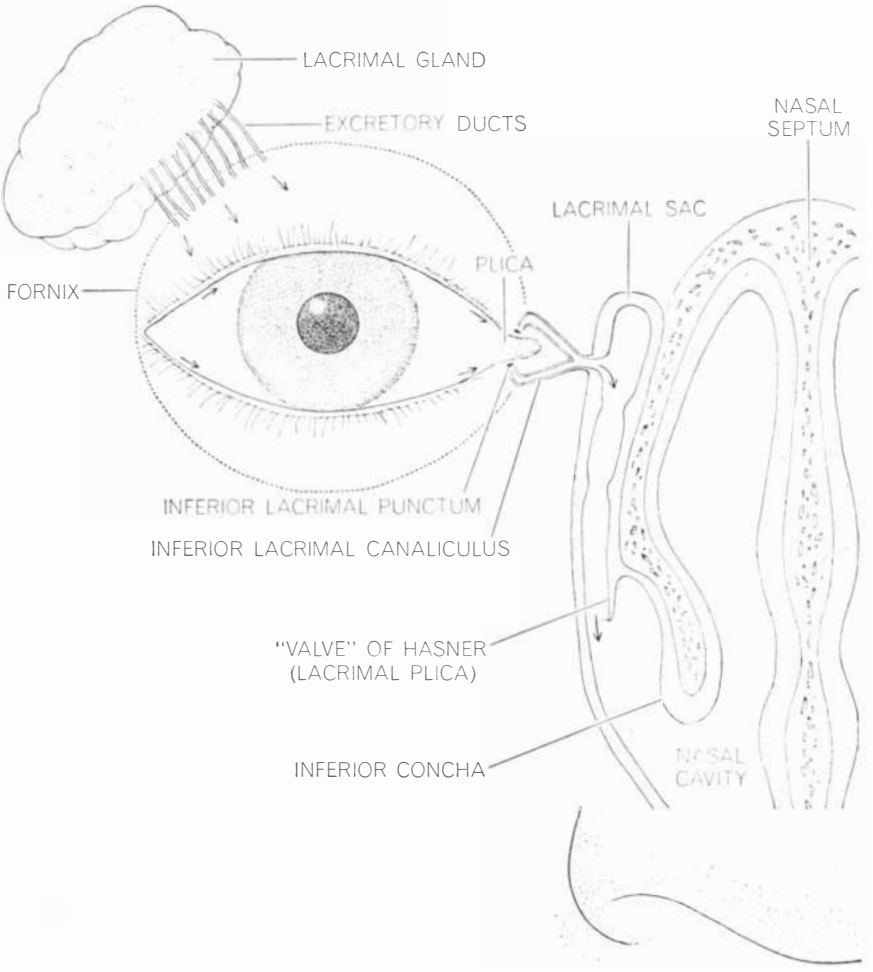
The lacrimal gland is an exocrine gland: it empties a secretion onto the body surface through ducts. Like all

exocrine glands, it is innervated by the autonomic nervous system. This system is divided into two parts, the sympathetic system and the parasympathetic. Most investigators agree that nerve impulses traveling along parasympathetic fibers from the sphenopalatine ganglion are responsible for the outpouring of fluid by the lacrimal gland in reflex and psychogenic tearing. There is a dispute, however, concerning the role of the nerve impulses traveling along sympathetic fibers from the superior cervical ganglion. Some hold that these impulses are specifically responsible for continuous tearing; others think they usually inhibit the flow of tears. Attempts to answer this question indicate the limits of various traditional styles of investigation.

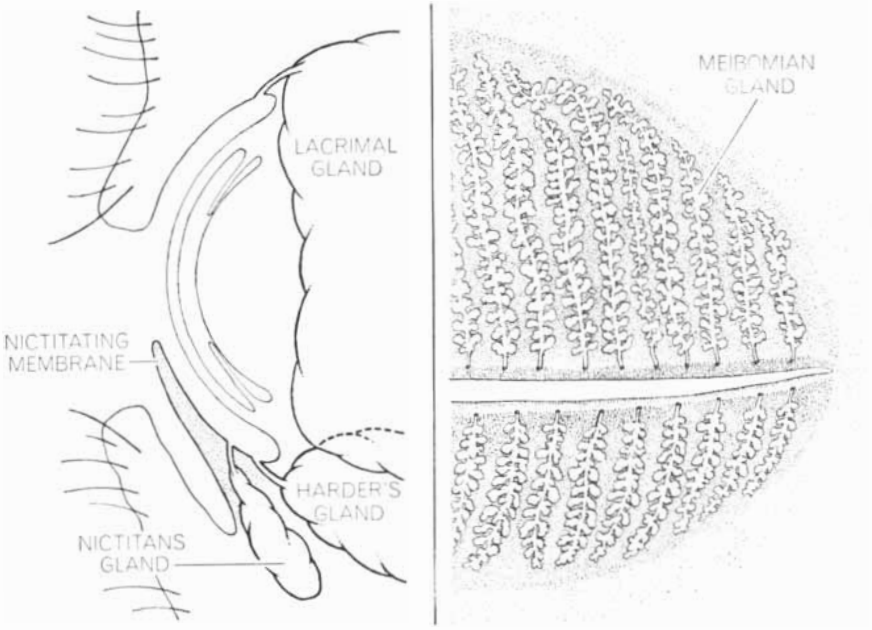
Gross anatomy is of little help in such studies; even if the anatomist can follow nerve fibers all the way from the sympathetic ganglion to the gland, he cannot discern which structure in the gland is innervated by these fibers. The electron microscopist goes one step further, tracing nerve fibers to the immediate vicinity of secretory cells. The histochemist, knowing that sympathetic and parasympathetic fibers release different substances as chemical transmitters, can identify both types of fiber in the lacrimal gland. He is unable, however, to trace fibers to their ultimate destination inside the gland and therefore does not know whether a given fiber innervates secretory cells or myoepithelial cells. He can only guess at whether the nerve fibers within the gland are carrying nerve impulses to or from the gland and whether the impulses stimulate or inhibit the cells of the gland.

The pharmacologist has still another tactic. He tries to determine the change in the flow of tears after injecting agents that mimic the actions of the autonomic nervous system. Thus an agent such as adrenaline, which has the effect of stimulating sympathetic nerve endings, is found to enhance reflex and chemically induced tearing. The conclusion is ambiguous, however; adrenaline and other "sympathomimetic" drugs may well act directly on the gland cell to alter its secretory level, or they may act to increase the flow of tears from the nasolacrimal duct by stimulating other glands that contribute to the flow of tears, or they may cause contraction of the muscle in the orbit of the eye and squeeze fluid from the orbital glands.

The physiologist can study the functional innervation of a gland by destroy-



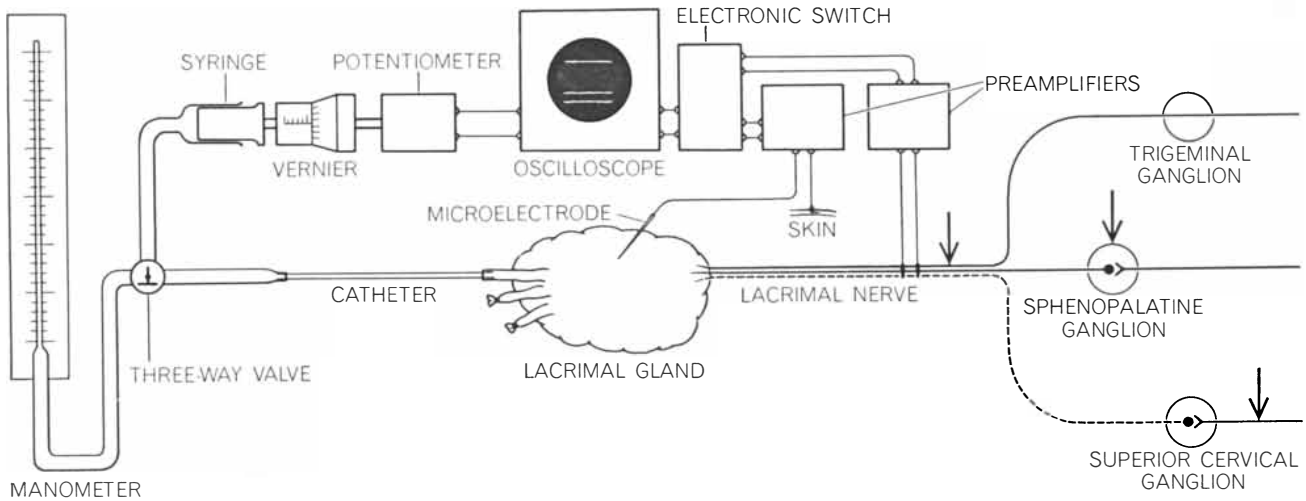

**NASOLACRIMAL DUCT is the downward continuation of the lacrimal sac and the region into which the collecting system of the eye empties through the lacrimal punctae.**



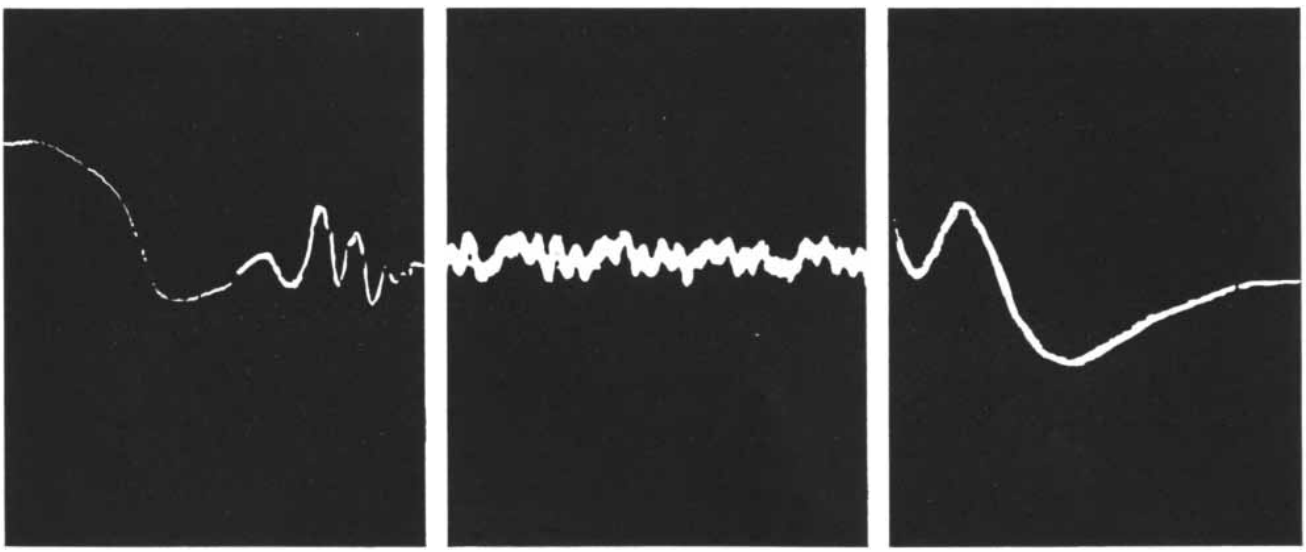

**ABSENT IN MAN are the nictitating membrane, nictitans gland and Harder's gland present in the eye of a rabbit (*left*). Man makes up part of the lack by having Meibomian glands on the inside of his eyelid as shown at right. These make the oily layer of tears.**

ing various nerves connected to it. When this was done to sympathetic fibers of the lacrimal gland, the flow of reflex or chemically induced tears increased, suggesting that nerve impulses traveling along sympathetic fibers inhibit the secretion of tears. Yet when sympathetic fibers were stimulated electrically, the results differed; decrease, increase and no change in the tear flow from the nasolacrimal duct have all been reported at various times.

This welter of bits of evidence was compiled by means that must all be considered indirect. Studies in which fluid from the nasolacrimal duct was used to evaluate tear flow or chemical composition are not directly applicable to the lacrimal gland because other glands contribute to tear formation (as may changes in the flow of blood or activity of muscles in the vicinity of the eye). During the past two years at the University of Pennsylvania Graduate School of Medicine, Mituhiko Hisada and I have performed a series of electrophysiological experiments to trace the connections of the lacrimal gland cells to the central nervous system and to determine the electrical properties of the membrane of the lacrimal cells. In this work we established a direct approach by recording the flow from the excretory duct of the lacrimal gland in the cat by means of a cannula, a thin tube .15 millimeter in external diameter, and a system capable of detecting when a single gland cell responded by recording tiny changes in the electric potential of the cell membrane. This system required a microelectrode that could be inserted through the membrane into the interior of the cell. We also recorded electrical activity of the lacrimal nerve, the main nerve to the gland. These three




**EXPERIMENTAL SCHEME to determine the nerve connections of cells of the lacrimal gland is depicted. The arrows at right show where stimulus was applied to the lacrimal nerve and parts of the sympathetic system (*trunk of the "Superior cervical ganglion"*) and the parasympathetic system (*"Sphenopalatine ganglion"*). Transmission came from a microelectrode placed in a lacrimal gland cell and connected to an oscilloscope recording the membrane potential. Flow from the excretory duct of the lacrimal gland via a catheter was recorded by a manometer and the associated equipment at top. The experiment was conducted with cats and rabbits.**

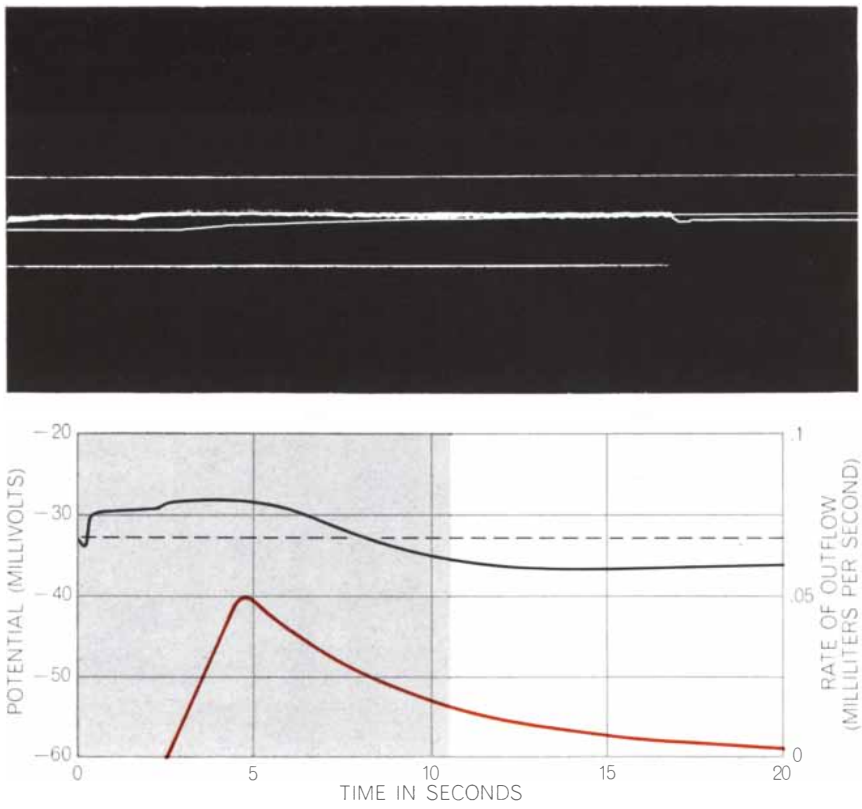


**ELECTRICAL ACTIVITY of the lacrimal nerve appears on the oscilloscope. The drop in the curve at left records action potential of the trunk of the superior cervical ganglion when the trunk itself was stimulated. As the curve in middle indicates, however, no potential was recorded from the lacrimal nerve when the trunk was stimulated. The drop in the curve at right shows the action potential recorded from the lacrimal nerve when part of the parasympathetic system, the sphenopalatine ganglion, was stimulated.**

measurements were made when we stimulated either sympathetic or parasympathetic fibers with electric pulses. We demonstrated that the lacrimal nerve became active when the source of parasympathetic fibers (the sphenopalatine ganglion) was stimulated but not when the source of sympathetic fibers (the superior cervical ganglion) was stimulated. We concluded that the lacrimal nerve contained parasympathetic fibers that carry nerve impulses directly to the lacrimal gland.

Next we demonstrated that the lacrimal cell-membrane potential fell from minus 28 millivolts to minus 23 millivolts when we stimulated the lacrimal nerve. Since we were also able to show that this drop was accompanied by an increase in flow from the excretory duct of the lacrimal gland, we concluded that the change in membrane potential produced by stimulation of the lacrimal nerve was genuinely associated with secretory activity. As we expected, we obtained the same results by stimulating the sphenopalatine ganglion, the source of parasympathetic fibers. When we stimulated the source of sympathetic fibers, however, we recorded no change in lacrimal cell-membrane potential or change in flow from the excretory duct. This does not eliminate the possibility that sympathetic nerve impulses may be responsible for the continuous secretion of tears either by stimulating other glands that contribute to the formation of tears or by regulating the flow of blood through the lacrimal gland. Since inhibitory phenomena are difficult to detect, it may be that sympathetic nerve impulses inhibit, not stimulate, the secretion of tears by the lacrimal gland. If this is the case, when we stimulated sympathetic fibers we should have found a change in the cell-membrane potential. We did not find such a change, but possibly our methods were not sensitive enough to detect the change or a decreased flow from the lacrimal excretory duct. In any case, if sympathetic nerve impulses do enhance or inhibit secretory activity by the cells of the lacrimal gland, these impulses do not reach the gland by means of the lacrimal nerve, because we recorded no activity in the lacrimal nerve when the superior cervical ganglion was stimulated [*see lower illustration on opposite page*].

If there is no inhibition by sympathetic fibers to cancel activation by parasympathetic fibers, how is the flow of tears regulated? Continuous tears, reflex tears and psychogenic tears can be regulated by activating few or many parasympathetic nerve fibers and thereby few or many secretory cells. Not only can the number of active cells be varied but also the activity of each cell can be altered by changing the frequency of the nerve impulses to the cell. Accordingly reflex and psychogenic tears would seem to be accompanied by activation of large numbers of fibers in the lacrimal nerve, and each nerve fiber would seem to carry many nerve impulses per second. We found that when we increased the strength of a single electric pulse, more fibers were activated; this was shown by the fact that the size of the potential recorded from the lacrimal nerve increased to a maximum. When we used a stimulus strong enough to activate all the fibers in the lacrimal nerve, the cell did not respond with a secretory potential unless repetitive stimuli were applied. Nevertheless, we could increase the response of a lacrimal cell (that is, the magnitude of its secretory potential) by changing the frequency of stimulation. In our laboratory the optimal frequency was found to be 20 stimuli per second.



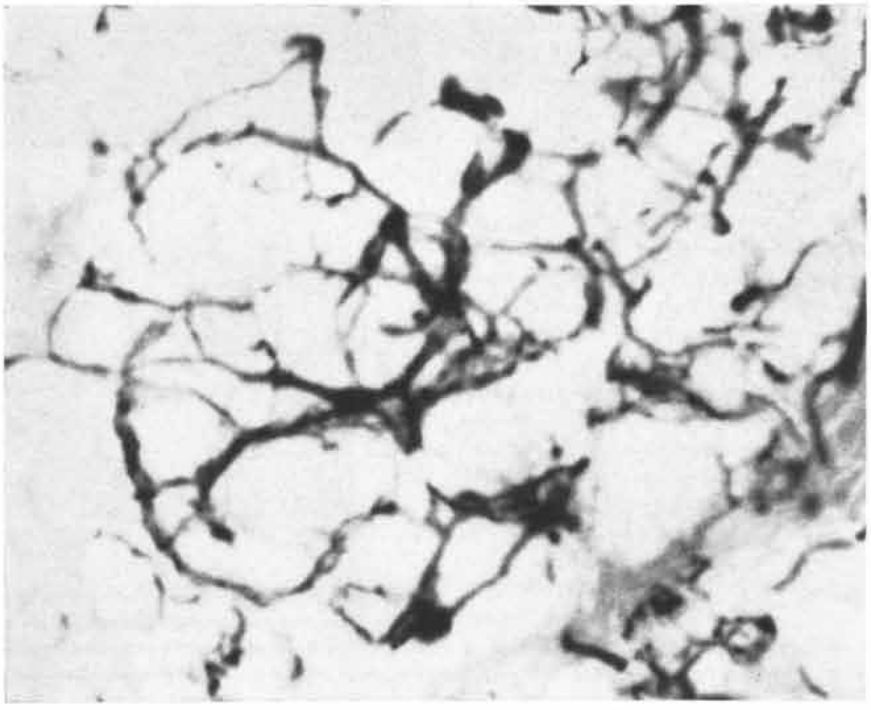

**MEMBRANE POTENTIAL recorded by a microelectrode in a lacrimal gland cell is transposed from the oscilloscope trace (*top*) to a graph (*bottom*) comparing potential and the rate of flow of fluid from the excretory duct of the gland (*colored curve*). The broken line on the graph represents reference potential; the gray background indicates duration of stimulus.**

Seeking evidence that one cell might be innervated by more than one fiber, we determined the change in the cell-membrane potential when we activated an increasing number of fibers of the lacrimal nerve with repetitive stimuli of varying strength but constant frequency. If multiple nerve fibers did innervate a single cell, the secretory potential would—theoretically—increase as we increased the number of active nerve fibers. We were unable to detect any such result. It should be pointed out, however, that it is difficult to maintain a microelectrode in a cell for longer than a minute and it was therefore extremely difficult to stimulate a given lacrimal gland cell often enough to provide a definite answer.

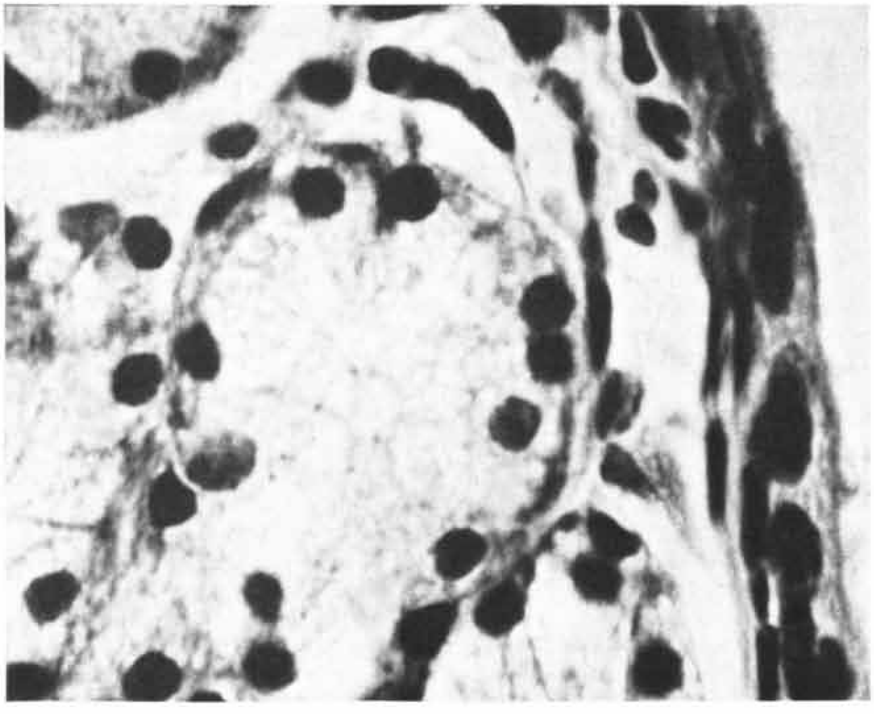
There are other mechanisms by which the continuous flow of tears may be regulated. The rate of flow could be controlled by the flow of blood through the gland, which in turn depends on such factors as the rate of evaporation from the surface of the eye. This system would necessitate receptors that respond when the surface becomes dry. Alternatively, the flow rate might be influenced by pressure within the ducts, and it is

possible that the fibers in the lacrimal nerve, which are believed to carry impulses toward the central nervous system, may signal changes of pressure within the duct. It has been suggested that when the pressure in the duct reaches a certain level, a contraction alters the size of the duct and thereby regulates the flow of tears.

Nerve systems may not be the only influences that regulate the flow of tears. The flow might be controlled as well (or perhaps instead) by substances in the blood that can change the meta-

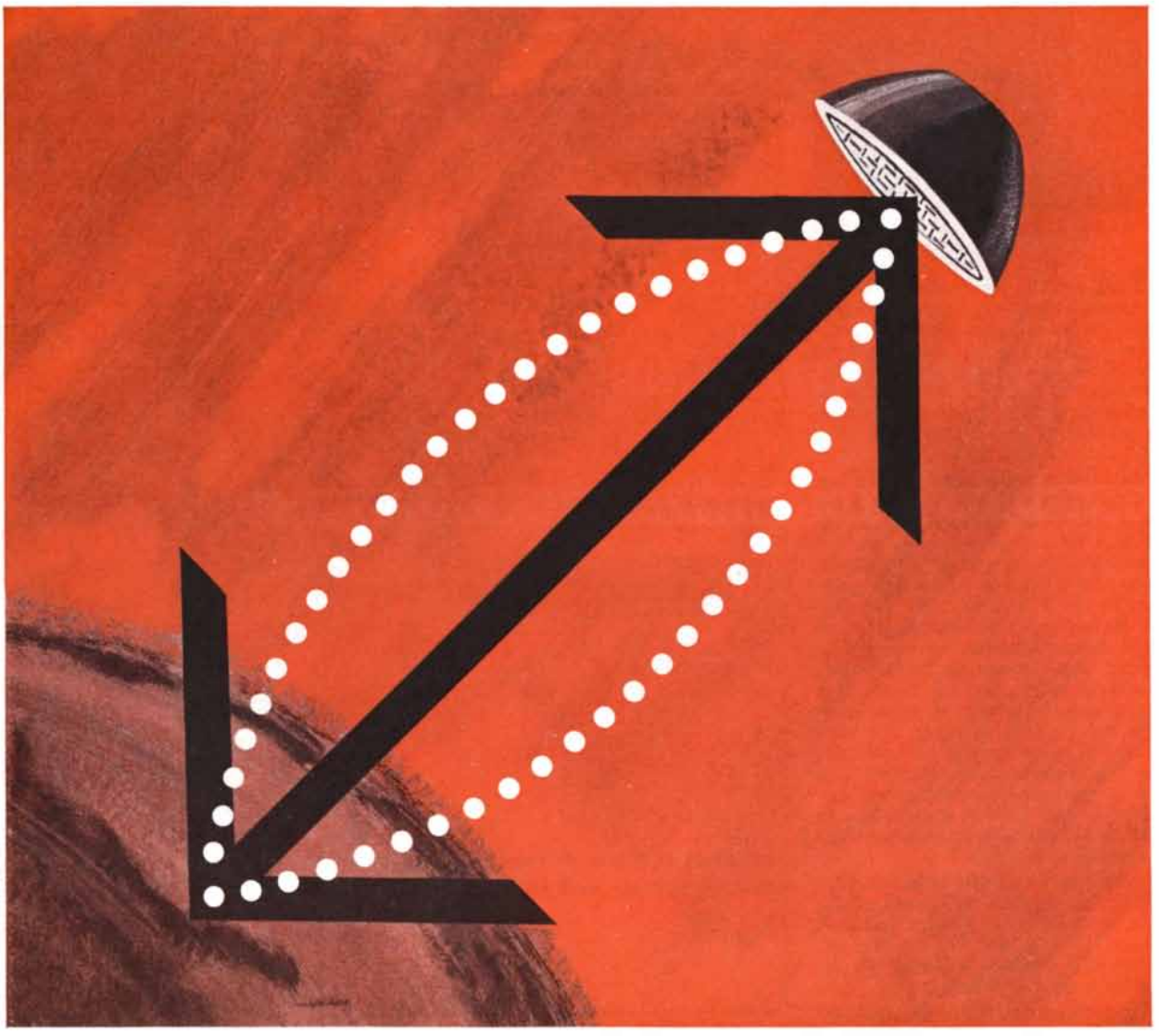


HISTOCHEMICAL TECHNIQUE entails staining cells of the lacrimal gland as shown. Dark lines reveal heavy concentrations of cholinesterase in nerve fibers surrounding the acini.



**ACINI WITH CENTRAL LUMEN appear in this cross section of the lacrimal gland of a rabbit. A cylindrical secretory cell is visible at top left. The photograph was made by Narendra Krishna of the Research Department of the Wills Eye Hospital in Philadelphia.**

# URGENT: Boost the flow of data from space– by steering it!



An "electronic boomerang" transmission system technique, developed by our Sylvania subsidiary for the Air Force, can potentially increase both the quantity and quality of data sent to earth from satellites.

How? A fixed set of antennas in the satellite electronically steers transmissions back to earth along the same path traveled by a signal transmitted from a ground station requesting data.

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It uses a flat disc, always facing earth, as a receiving and sending surface. Only 1/20 as many solar cells are required for power, and the tunnel diode transceivers are about 100 times more radiation-resistant than transistorized systems.

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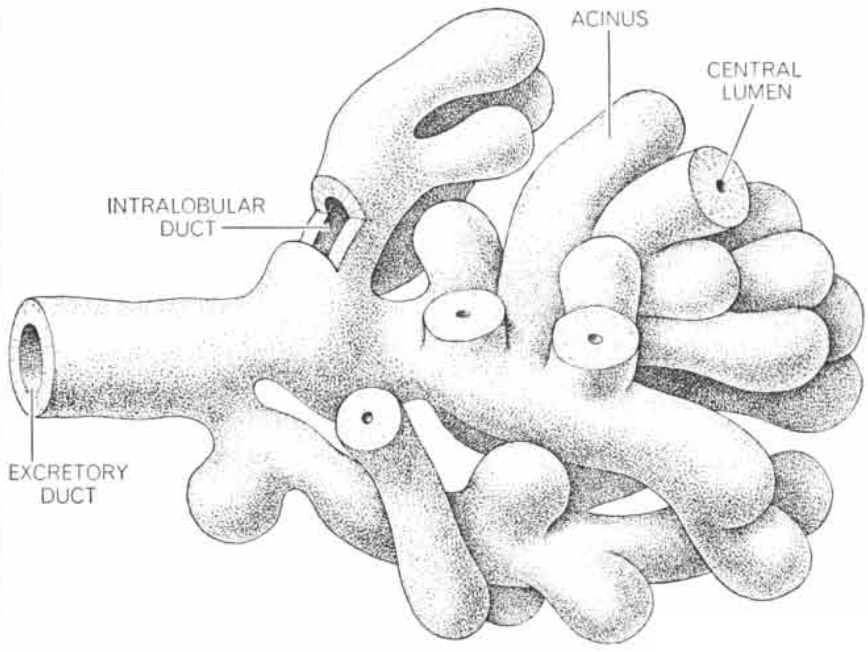
bolic rate of the secretory cells. A. Nover in Germany and M. Martinazzi in Italy have reported that hormones secreted by such endocrine glands as the thyroid, pituitary and gonads can influence the formation of tears. Although we have demonstrated that parasympathetic, but not sympathetic, nerve impulses can increase the secretory activity of cells in the lacrimal gland, many questions concerning the regulation of the flow of tears must still be answered.

Little is known about how the lacrimal cells actually secrete tears. It is not even known whether the way in which the lacrimal cell transports water and soluble substances from the blood to the duct is an active process requiring metabolism or a process of passive diffusion. Such problems are being studied by determining the flow of ions between cells and the extracellular fluid and measuring the electrical constants of the cell membrane in various secretory organs: the kidney, thyroid gland, salivary gland, nasal salt gland (in lizards and marine birds) and gastric mucosa. It is to be hoped that the results of our electrochemical studies of the lacrimal gland will help to answer more general questions of how cells secrete and how their secretory activity is regulated.




**HUMAN LACRIMAL GLAND** has a cluster of acini, or saclike lobules. The central lumen, clear spaces in the acini, empty into secretory ducts, then into the excretory duct at left.

| | | TEARS | SERUM |
|---|---|---|---|
| ELECTROLYTES | $HCO_3^-$ | 26 | 21–30 |
| | $Cl^-$ | 128 | 98–106 |
| | $K^+$ | 24.1 | 4.1–5.6 |
| | $Na^+$ | 145 | 136–145 |
| SOLIDS | TOTAL PROTEIN | .67 | 6–7.5 |
| | ALBUMIN | .39 | 3.5–5.5 |
| | GLOBULIN | .16 | 2.5–3 |

**CHEMICAL COMPOSITION** of reflex and chemically induced human tears is compared with that of serum, the liquid part of blood. The tears are from a conjunctival sac. Electrotypes are given in milliequivalents per liter; solids, in grams per 100 centimeters.

# *Where did life begin?*

The expanse of space invites conquest because it may provide new knowledge in answer to profound questions—such as that of the origin of life and of the earth. If extra-terrestrial life is discovered, conjectures about our own life must assume new dimensions.

If the moon, billions of years old, can provide a record uneroded by water or air, it may hold the clue to the origin of the earth. The first flights may show that the moon was formed by a rare collision—or that the moon and perhaps the earth were formed by condensation. If the latter is true, it increases the possibilities that life itself exists in other planetary systems throughout the universe. Thus, the work of Avco and other companies gains particular significance.

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# INDUSTRIAL MANIPULATORS

## Many tasks done by human hands cannot yet be taken up by automatic machines. Machines can, however, extend the capacities of the hand, and they suggest ways in which manipulation can be made automatic

by Ralph S. Mosher

In recent decades self-controlled machines and self-controlled industrial processes have evolved rapidly, but there are still many tasks that resist the elimination of the human operator. One task that will do so for a long time to come is ordinary manipulation.

An automatic machine can be almost entirely self-sufficient in a mass-production process. There the problem is to carry out programmed, repetitive operations under more or less fixed conditions. But consider the operations that must be performed by a power shovel or a crane. In digging an excavation or transporting objects from one location to another the machine is called on to make continual adjustments to changing conditions. For this it requires a human operator applying human information and control. There exists neither the technology nor the hardware to replace that control system with an artificial one, and if such hardware existed, it would be fantastically expensive.

On the other hand, the coupling of a machine to human control can be developed to far higher levels of refinement than the rudimentary and clumsy operations of power shovels, cranes or the like. There are forms of manipulation that require all the delicacy of a human operator but that cannot be carried out by man unless he is assisted by a machine. Among these are operations that call for superhuman strength and those that must be performed in a hostile environment such as the highly radioactive interior of a "hot chemistry" laboratory or a nuclear reactor. The need for handling radioactive materials by remote control has been mainly responsible for the invention and design of a variety of artificial manipulators.

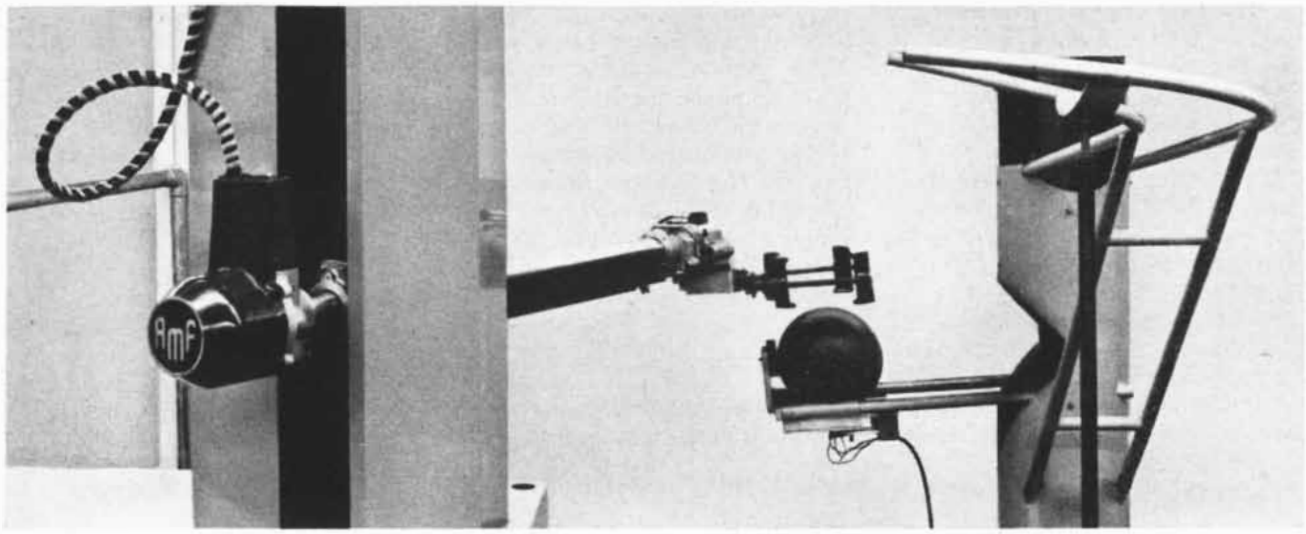
There are now manipulators for handling microscopic objects (micromanipulators), for handling explosive chemicals, for working underwater and for certain industrial operations. I shall discuss in this article a general type of manipulator that is capable of doing various kinds of jobs and seems to open the way to the development of new appendages for amplifying man's powers and performances.

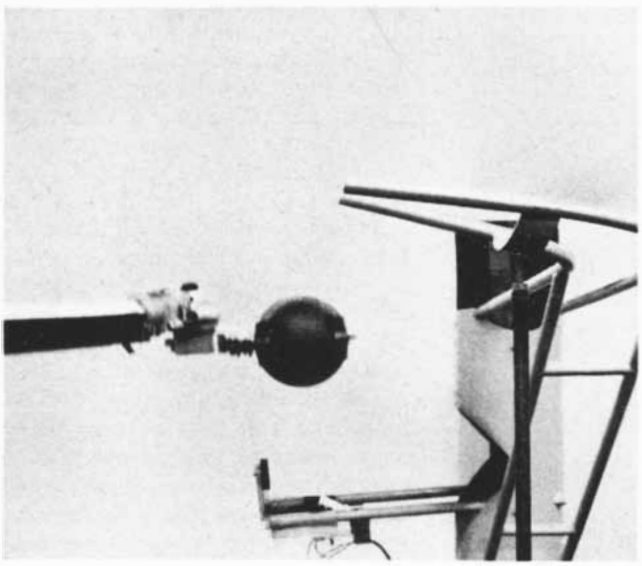
Manipulation is a much more complex activity than it appears to be. One must begin, therefore, with a detailed analysis of the elementary motions and factors involved in any sort of manipulative performance. Consider the seemingly simple operation of opening a door. One grasps the doorknob and swings the door in an arc of a circle with the hinge axis at its center. The hand pulling the door must follow an arc lying in a plane at the level of the knob parallel to the plane of the floor, and it must conform to the circumference of the circle defined by the distance from the knob to the hinge axis. In doing this the hand, assisted by the human nervous system, is guided by the door's resistance to being pulled along any other path. In other words, the human motor system responds to a feedback of forces that must be interpreted. A strong robot, lacking any means of such interpretation and free to pull in any direction, might easily pull the door off its hinges instead of swinging it open. Similarly, the same robot, given a chair to carry, might pull it to pieces because of inability to sense or interpret the resistance of the chair's structure to being pulled apart. Consider another example: the problem of sliding a rod into a tube into which it will just fit snugly. A man can do this even blindfolded by trying various angles of insertion until he finds the one at which he can push the rod in without forcing it. A robot, on the other hand, would simply push hard at any angle and bend or crumple the rod.

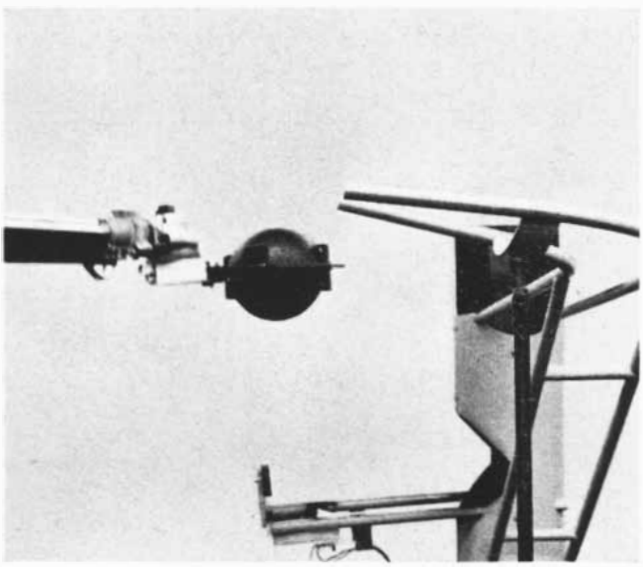
The factor involved here can be illustrated in another way. As everyone knows, it is virtually impossible to draw a perfect circle freehand. The senses of vision and touch are not sufficient guides to perform this operation accurately. Yet anyone who turns the handle of a pencil sharpener or an eggbeater describes a true circle in the air every time. The handle provides the guide, and the sense that is called into play is the kinesthetic one: the sensing of forces and positions by the body's skeletal and muscular system.

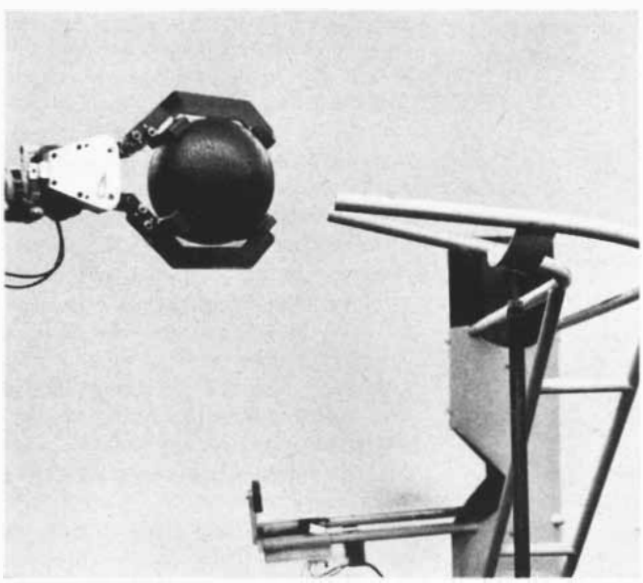
It follows, then, that one of the main requirements for a mechanical manipulator is that it must be equipped with a kinesthetic sense corresponding to the human one. It must be capable of detecting changes of force and position, large or small, and transmitting this information accurately to the human operator. Such a device, possessing the properties of feedback and kinesthesis, can be described as a cybernetic anthropomorphous machine, or, for short, CAM.

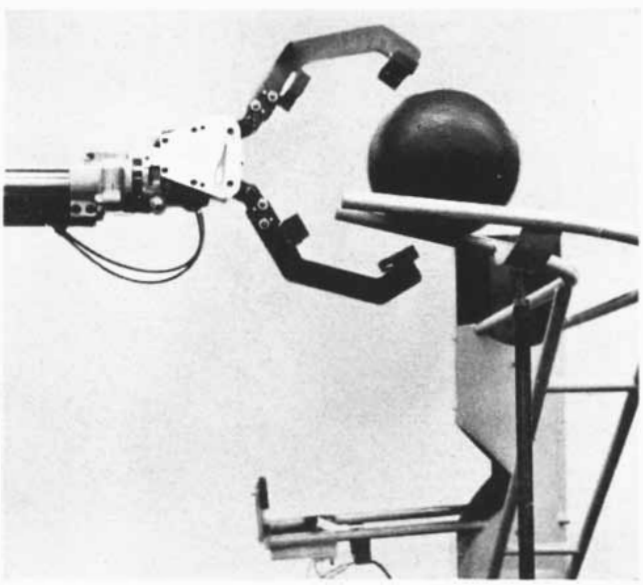
The next primary requirement for a manipulator is a quasi-human repertory of motions. In our essentially Euclidean world it takes six degrees of freedom of motion to position an object: three to place it in space (as defined by the three familiar coordinates $x$, $y$ and $z$) and three to orient the object itself (in the attitudes known as pitch, roll and yaw). A machine can easily be designed to carry out the various necessary movements, but if a system of levers, switches or buttons were used to control these motions, the human operator would have to operate six controls simultaneously. A man cannot accurately









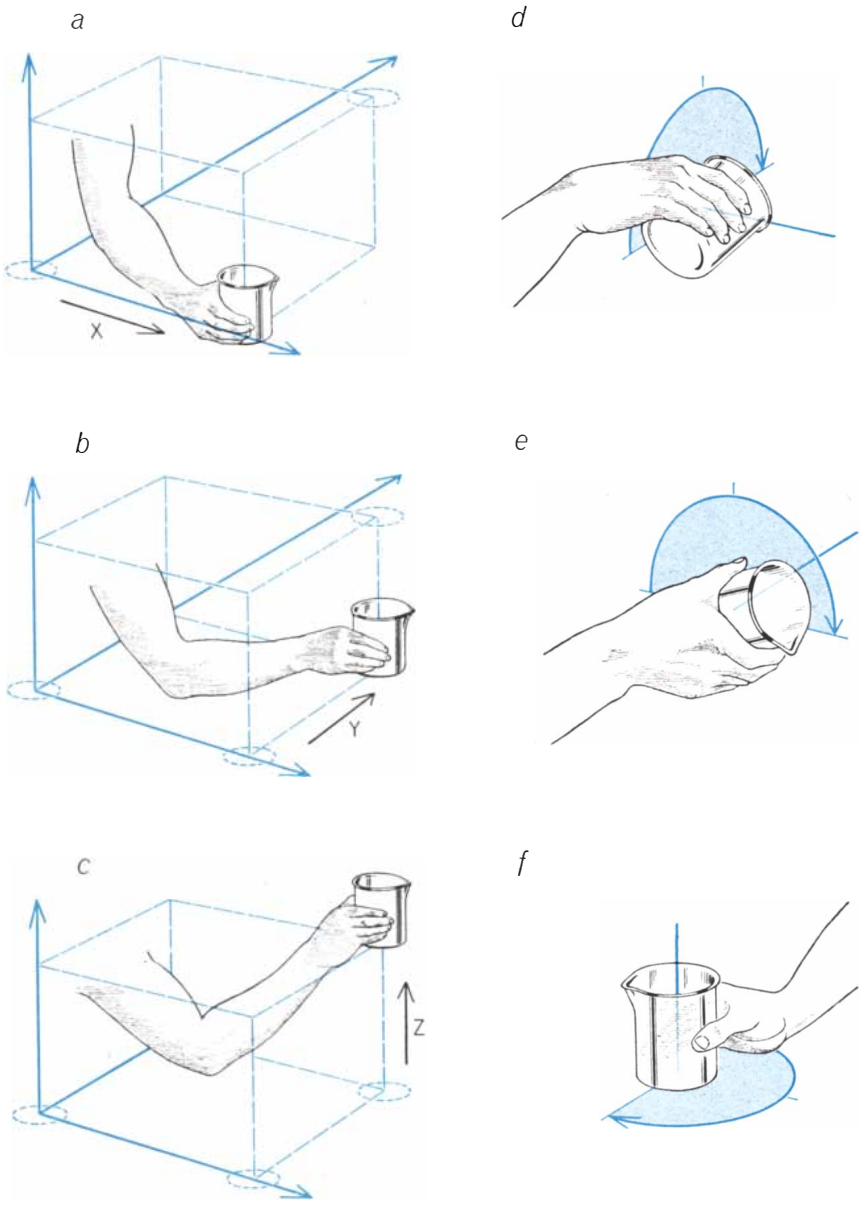
**PROGRAMMED MANIPULATOR** can repeat the same transfer operation indefinitely at a constant speed, and can be reprogrammed at will. Devices of this sort are adaptable to assembly-line tasks such as loading or unloading parts, shifting parts to and from a stamping or welding rig, or spray-painting irregular areas. The American Machine and Foundry Company's Versatran manipulator first reaches for, then grasps, lifts, rotates and ultimately releases a bowling ball (*left to right, lower four photographs*).

operate more than one, or at most two, such controls at a time. Therefore an effective manipulator must be coupled to the operator more directly than through devices such as levers or buttons.

In the Advanced Technology Laboratories of the General Electric Company we have developed a machine called Handyman that is based on a coupling system incorporating this objective [*see illustrations on pages 92 and 93*]. Essentially it consists of a pair of mechanical arms and hands in roughly human form that is connected electrically to a harness worn by the operator. The system causes the mechanical limbs to mimic the actions of the man's arms and hands (that is, to follow the human template), while the man, in turn, receives signals from the machine conveying information about force and position. That is to say, the machine is coupled to the man's sensory and motor system in such a way that the whole setup operates in a highly integrated manner through feedback loops.

Handyman has 10 motions in each arm, actuated hydraulically by means of electric signals that cause the arm and hand to carry out precisely the same motions as those made by the operator, as indicated by his finger and arm angles and other physical signs. The machine, in handling an object, registers the positions and forces associated with the manipulation; this information is translated into electric signals and sent back to actuators attached to the operator, which convey to him forces proportional to those experienced by the machine. The harness he wears is called a follower rack.

The coupling is so direct and detailed that the man does not have to think about operating the machine. He simply concentrates on the manipulation task itself, and he observes the actions of the mechanical arms and hands as if they were his own.

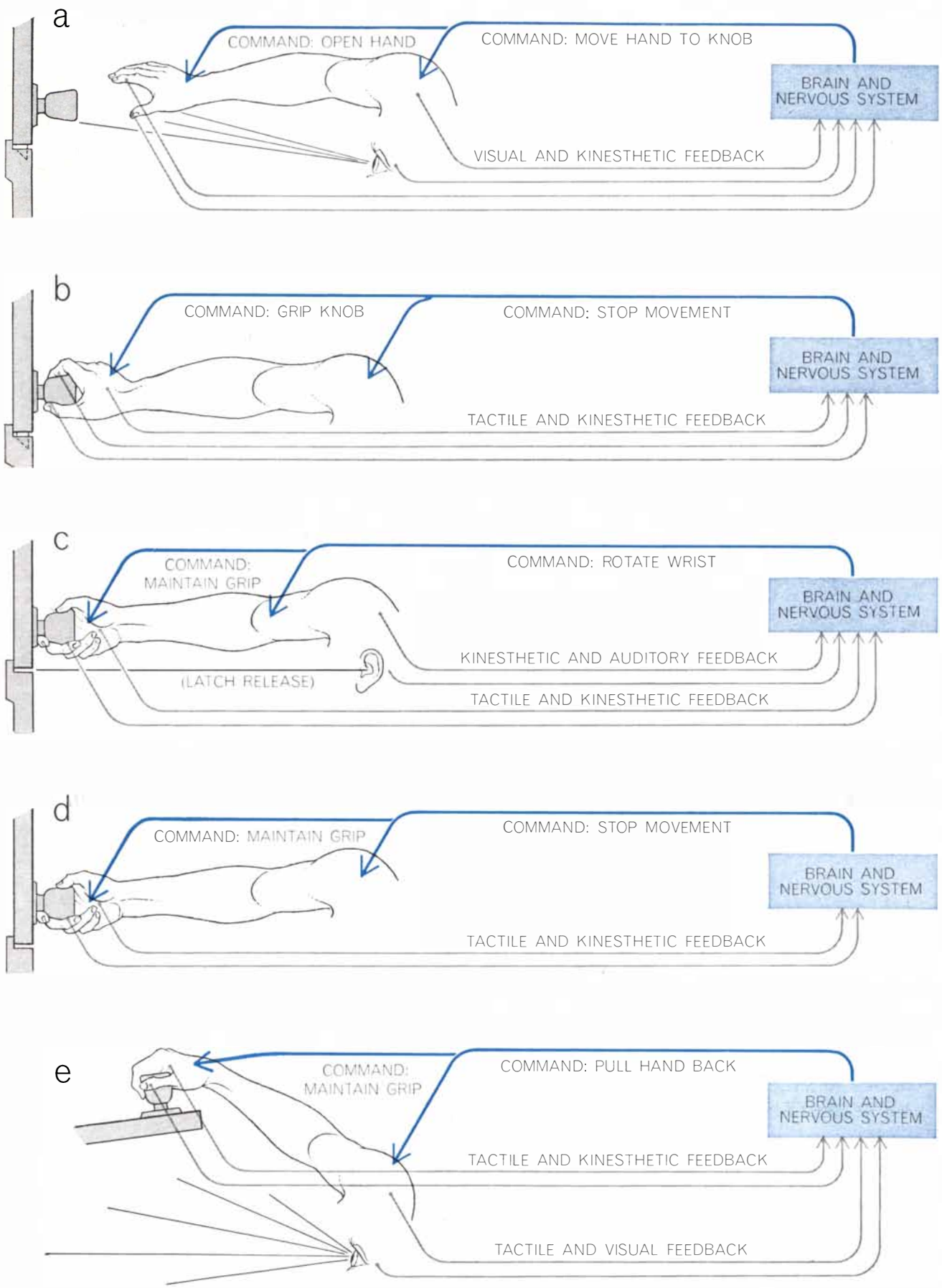



**TWO SETS OF MOTIONS constitute the six degrees of freedom for any object in space. Direct motion along three coordinates determines position: the beaker is moved forward (*a*), sideward (*b*) and upward (*c*). Three coordinates of rotation determine the object's orientation: pitch, or elevation (*d*); roll, or twist (*e*), and yaw, or azimuthal rotation (*f*). Any manipulator must make these six motions if it is to simulate human arm movements.**

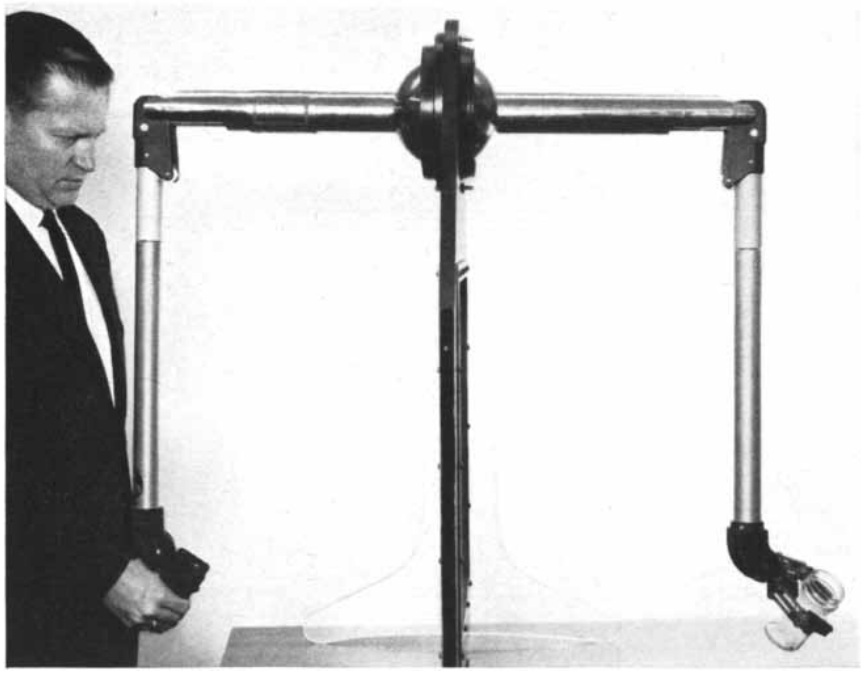
Our experience in the design and use of Handyman (which was created originally for remote-control work with radioactive materials) has shown that a wide range of variations on this prototype machine is feasible. The design can be varied in size (producing very large or very small Handymen) and in many details. The topological relations between the machine and the operator must, however, be kept the same, so that he does not lose mental contact with the mechanical arms that are supposed to mimic his behavior.

The Handyman experience has also brought to light several critical design requirements for such a machine. It must be free of any internal forces (such as friction, dead weight or the like) that would tend to tire the operator or mask the forces he is trying to measure. The machine's information about force and position must be reflected to him firmly and crisply so that he can work at the speed he desires, maintain smooth control of the velocity of the machine's movements and conduct those movements without overshooting or oscillation. The amount of force reflected back to the operator should be directly proportional to that experienced by the machine, and the proportion should be set at a level such that the force is strong enough to be detectable over interference but not so strong that it tires the operator when he has to work with the machine for any length of time. And the design should make the nature of the force unambiguous; for instance, when the robot hand grasps a ball, the signal coming back to the operator should tell him whether it is the ball or the fingers that are being compressed.

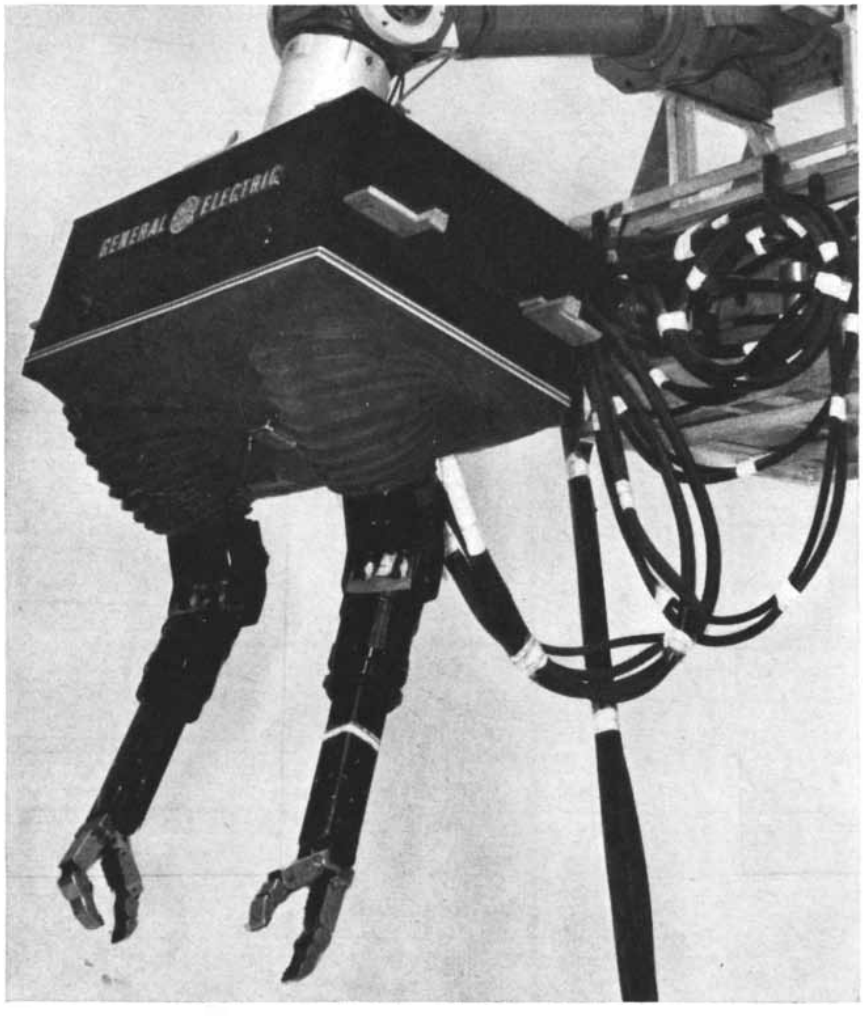
Let us now look at a few examples of manipulating machines made possible by application of the principle of a kinesthetic feedback of information




**OPENING A DOOR** is a seemingly simple task that involves the feedback of a complex series of sensory cues. Visual, tactile and auditory, as well as kinesthetic (or deep-muscle sensing) information is required merely for successful unlatching (*"a" through "d"*). Smooth performance thereafter depends on the kinesthetic sensing of the forces and positions involved in moving the hand at a fixed elevation parallel to the floor along a circular path (*e*) that is defined by the distance separating the doorknob from the hinge.



SIMPLE MASTER-SLAVE SYSTEM uses direct mechanical linkage and is limited to loads of five pounds or less. This is the American Machine and Foundry Company's Mini-Manip.



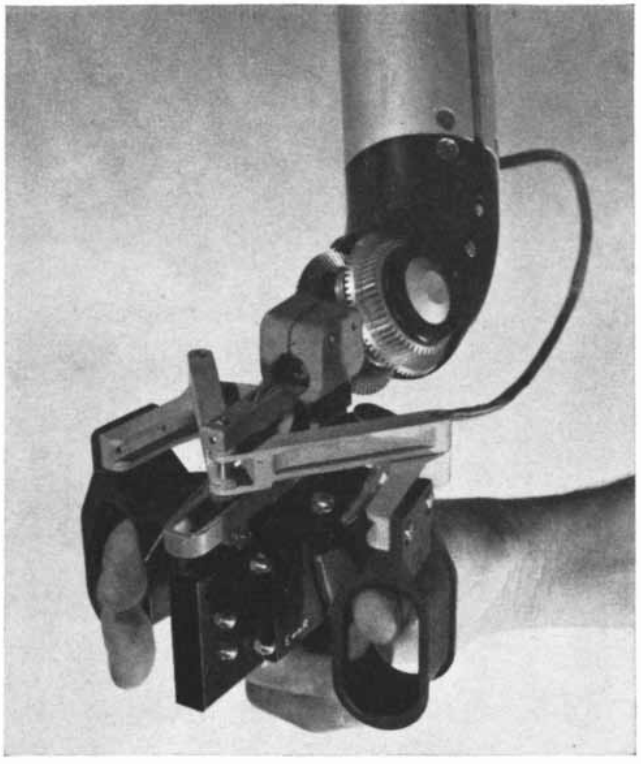

COMPLEX SLAVE has a pair of hydraulically operated arms that mimic human shoulder, elbow, wrist and finger-grip motions. This is the General Electric Company's Handyman.

about position and force to the operator. One example is a design for a liquid-delivery machine employing a siphon. The task is to deliver a fluid to many different stations in a plant from a vehicle that carries the liquid in a tank, a large siphon being necessary because for one reason or another pumping would be impracticable. If the siphon were held by an ordinary crane, one or more men would have to push and maneuver the nose of the heavy siphon to direct it into the opening where the fluid is to be delivered. A manipulator, however, handling a 1,000-pound siphon, could maneuver the siphon in and out of any station accurately and rapidly. The operator, guided by feedback through his controls, would place the siphon in the required position as readily as if he were handling a garden hose with his own hands.

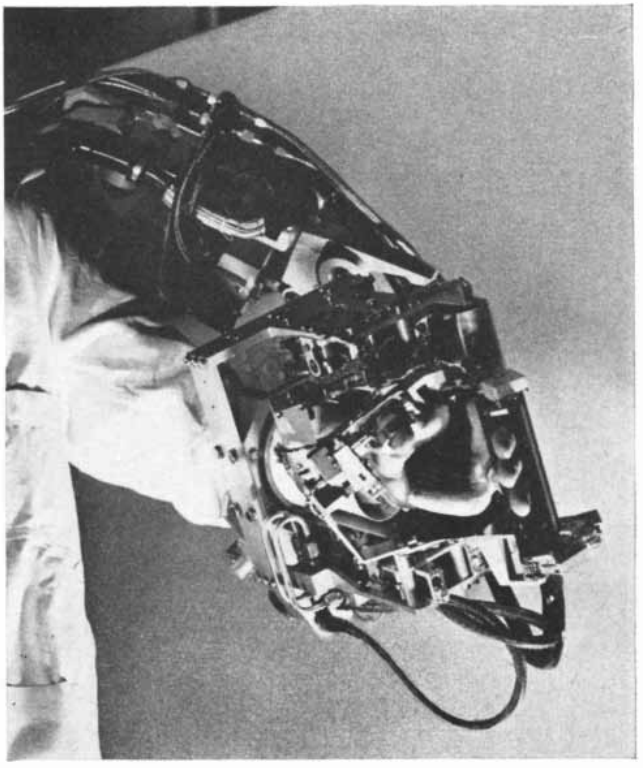
A somewhat similar arrangement is applied in a design for a boom system to be used on a ship. It could be used to fish large, heavy objects out of the sea, to transfer them from one ship to another or to load and unload them between ship and dock. The problem in this kind of operation is to pick up the load accurately and expeditiously when the ship is being rocked by the motions of the sea. With the boom system employing instant feedback an operator could make his moves with greater speed than the rate of the ship's tossing and handle the job almost as surely as if there were no interference.

On the same general plan one can build considerably more versatile machines. One such design outlines a manipulator with a single arm and hand that could do a large variety of jobs in a factory. This machine would not only serve for individual tasks under the control of an operator but could also be programmed for automatic performance, without an operator, of a job consisting of a cycle of specific repeated operations.

The delicate task of assembling closely fitting parts is well within the capacities of a manipulator using feedback. At the same time, the application of force feedback and spatial correspondence could also introduce a high degree of refinement to a job that is now performed comparatively crudely, namely, earth-moving. Equipment can be designed that would enable an operator to dig, lift and move earth around as precisely as the proverbially delicate handling of eggs. In such a machine a 16-inch movement of the operator's hand is translated into a 16-foot movement of



MASTER GRIP of an Argonne National Laboratory manipulator fits either hand loosely. This means a loss in feedback response.



MASTER DRIVE for Handyman is a complex "follower rack." This portion of it controls the slave's "wrist" rotation and "hand" grip.

TEST OF DEXTERITY for the controller of Handyman involves holding and swinging a hammer with the manipulator's right "hand" in order to drive a nail into a billet of wood steadied with the left "hand." The photograph shows a test nail being driven.

**UNILATERAL MANIPULATOR responds to commands from an operator who closes separate circuits for each motion. Such systems are controlled by vision only. This is Minotaur I, built by General Mills for maintenance of a reactor at Los Alamos Scientific Laboratory.**

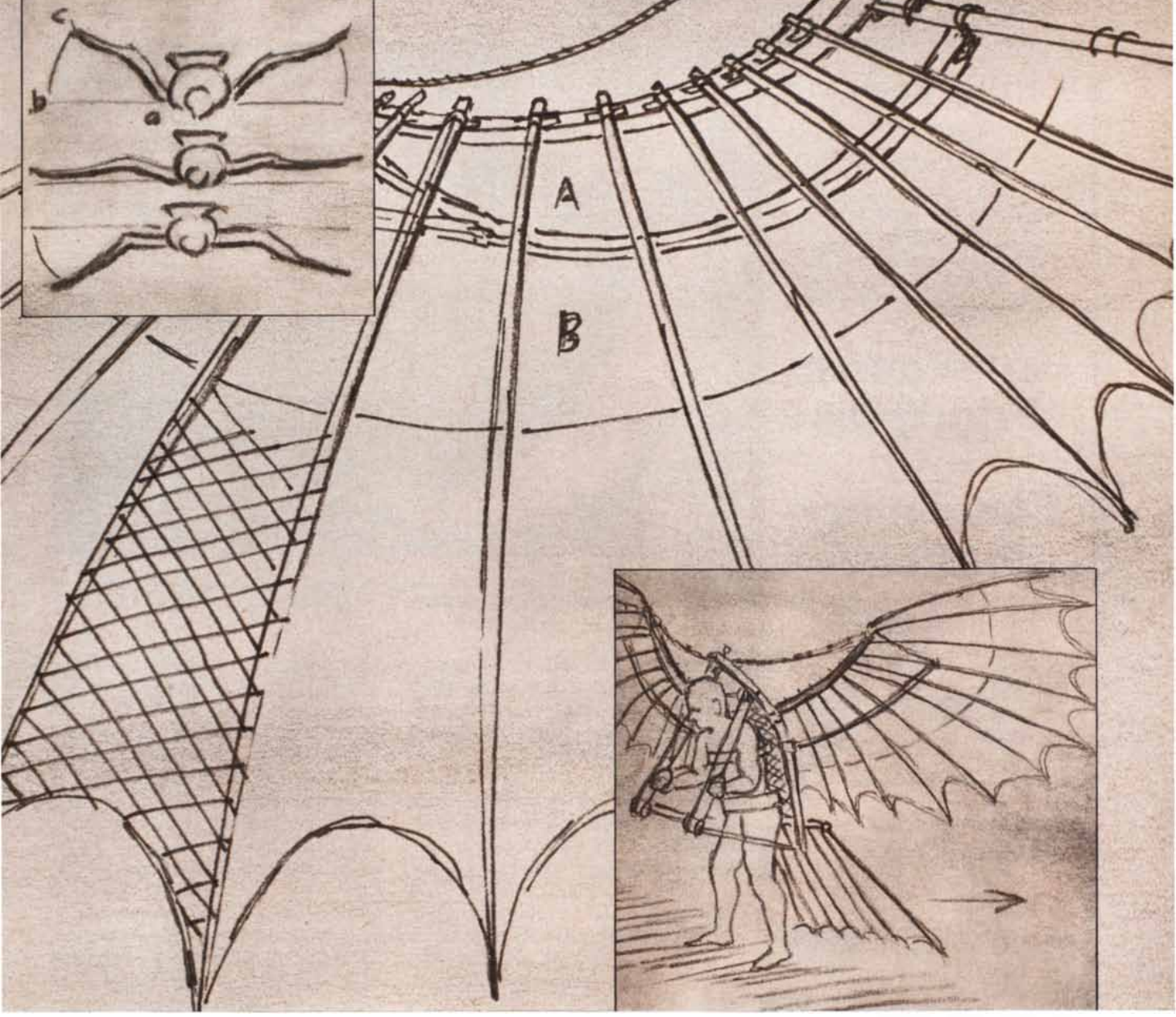


the shovel, but even this high ratio allows the operator a sufficient "feel of the road." He can operate surely and confidently without concern about stuttering or stalling his machine.

To illustrate the wide range of possible applications, I shall cite a manipulator developed in another field: medical prosthetics. It is a harness designed for a patient who has suffered paralysis or loss of the use of most of the arm muscles. Supported in this harness, the arm is weightless, and the patient can use the small muscle power still available to bend the arm. The weak motions thus made possible can be amplified electronically and converted into the performance of specific tasks, such as propelling a wheelchair. The machine also allows the patient to exercise and develop muscles that still function.

Working on designs for manipulators, one is naturally led to speculate on the possibility of building "pedipulators"—machines that would mimic the operations of the legs and feet. This presents a number of new problems, foremost among which is the difficulty of designing a system that would enable the man to maintain his balance on the foot-like appendages while standing still. The pedipulator, like its human operator, would of course have to be two-legged. We are building an experimental model with legs 12 feet long that will explore some of these problems.

The possible applications of such a machine are still rather uncertain, but a few inviting ideas come immediately to mind. A pedipulator with legs 18 feet long would move over the ground at the rate of about 35 miles per hour if its human operator moved his legs at a six-miles-per-hour gait. This speed can-




# We might have given Leonardo a lift

Da Vinci and his contemporaries envisioned winged marvels soaring birdlike across our skies. One of many reasons their "birdman" ideas never really got off the ground: *lack of efficient control.*

Today's airframe designers are not so handicapped. They employ highly efficient actuators using Saginaw Ball Bearing Screws:

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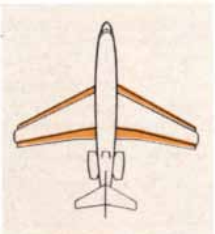

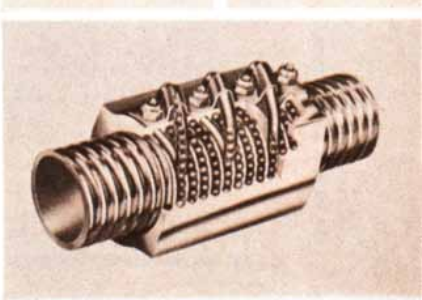

Saginaw ball bearing SCREWS and SPLINES

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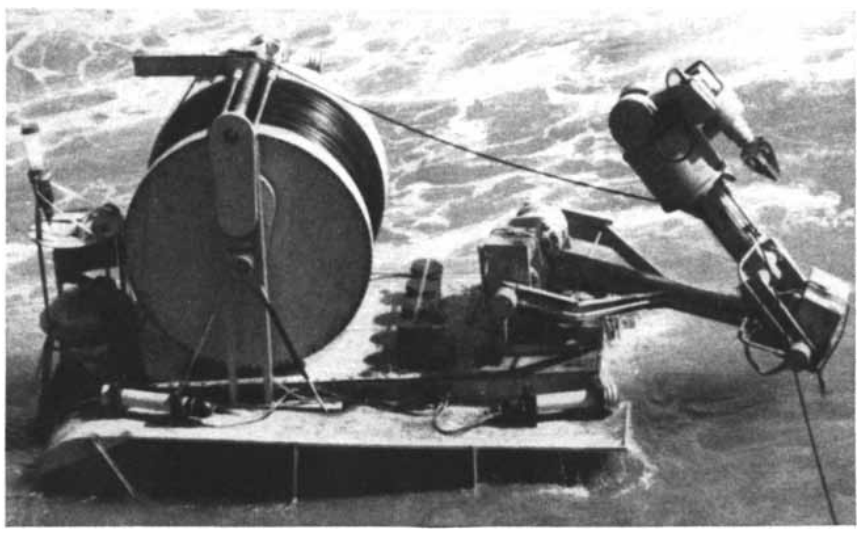
PROPELLANT STUDIES are conducted inside an armored cell with the aid of master-slave manipulators. This Mini-Manip installation is in Redstone Arsenal's Gorgas Laboratory.

not compete with that of the automobile, but a pedipulator could travel over terrain no vehicle can traverse. It might be extremely useful for purposes such as rescue operations.

Summing up the manipulator story, one can say that the development of the system of force feedback and position correspondence represents a highly promising technological advance. It enables the operator to achieve a mental transference that makes the machine an extension of himself. He does not need to learn how to operate the machine, or to condition himself to it or even to think about it. He and the machine respond to each other automatically, and in effect he is directly face to face with the job that both together are performing. As a result it has become possible to endow manipulators with great power under safe control and to move loads with higher speed and greater dexterity. With recent reductions in the cost of the servomechanisms required for these machines, the manipulators represent a considerable potential economy in handling materials. And it appears that they now offer the prospect of performing tasks in various fields that man has not been able to perform heretofore.



SUBMARINE MANIPULATOR, built for the U.S. Navy by General Mills, undergoes tests off the California coast. The Navy bathyscaphe *Trieste* is equipped with a similar grapple.


Glowing idea
for licking sticky
sorting problems

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Our new phosphors used for stamps won't help you find letters in the dark. But they do throw light on a new way to handle mail faster. ■ The United States Post Office Department had a need for a special kind of phosphor as fine as confectioner's sugar, yet able to luminesce brightly under ultraviolet. (Reduction of particle size generally dulls the glow.) Sylvania was able to successfully meet *both* requirements. ■ What is the purpose? To speed the processing of mail. Airmail stamps, now being tested, are coated with a red-glowing phosphor solution. Letters with these stamps are then passed through special electronic equipment—and these machines are able to read the color of the bright glow and sort the mail, automatically! ■ Sorting is only one job our phosphors can do. They can identify documents to fight counterfeiting, illuminate safety and marking devices, "code" pills and capsules—can be used in plastics to make objects glow without electricity. ■ How did we get to be experts in phosphors? Through years of solid experience and leadership, starting with phosphors for lamps and cathode-ray tubes. Sylvania is also a leader in tungsten and molybdenum, special chemicals, and semiconductor materials. We're hard at work on many advanced developments in all of these important areas. We offer our participation in your product developments. Chemical & Metallurgical Division, Sylvania Electric Products Inc., Towanda, Pennsylvania.

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# The Illusion of Movement

*Flashing two lights at certain rates of speed creates the illusion of a single light in motion. Experiments with the illusion assist in efforts to clarify the neural mechanisms of visual perception*

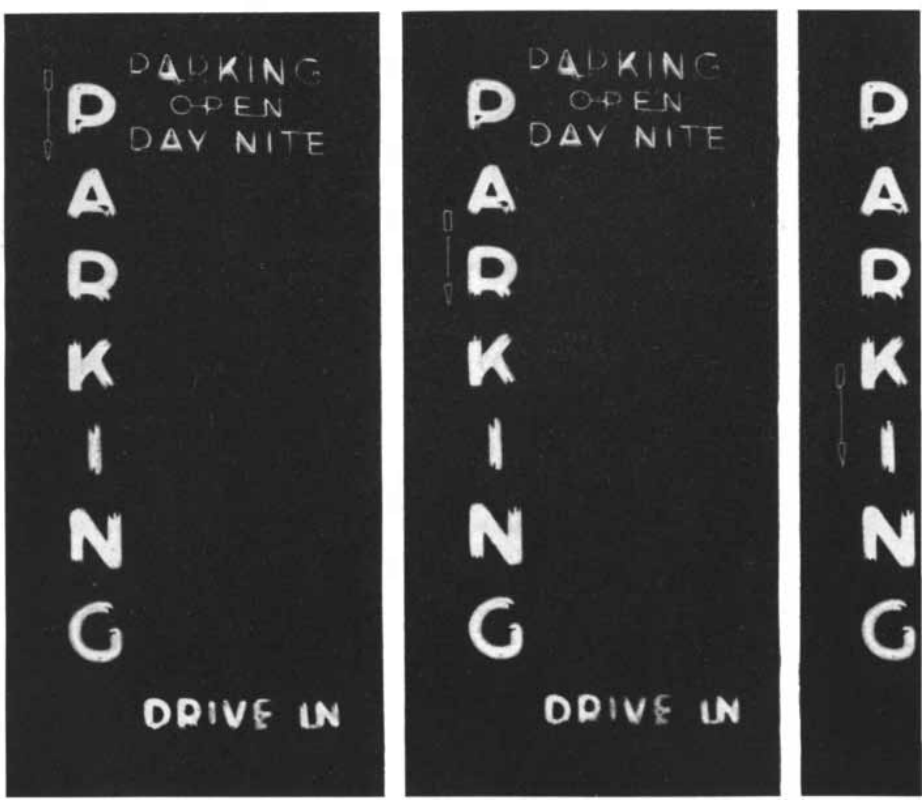
by Paul A. Kolers

The effort to explain how perceptions are formed by the nervous system has attracted investigators from many disciplines. An important and often elusive aspect of the problem is ascertaining how the physical stimulation of sensory organs is transformed into perceptual information: into objects seen, sounds heard and things touched. In the study of perceptions the examination of illusions has proved helpful. Illusions, in contrast with other perceptions, furnish erroneous reports about the environment. It is through these errors that illusions provide insight into the mechanism of perception. I shall discuss briefly the general subject of illusions and then concentrate on describing some experiments my colleagues and I have conducted with the illusion of movement that can be created under controlled conditions with a suitably timed flashing of lights. Finally, I shall set forth some of the conclusions suggested by the experiments.

Illusions have not always had good standing among the investigators of perception. When perceptual illusions were introduced as a topic of study in the 19th century, the prevailing attitude about them was that they were interesting parlor tricks—minor imperfections or errors in the working of man's perceptual apparatus. The German psychologist Oswald Külpe, writing near the end of the century, called them "subjective perversions of the contents of objective perception." The notion of error Külpe had in mind implied that there is some "real world" faithfully reported by the senses. Few contemporary investigators take this view. Instead of thinking of illusions as errors in perceiving they regard them as genuine perceptions that do not stand up when their implications are tested. Moreover, illusions are now regarded as putting in question any belief in "objective" perception.

The principal property of an illusion is that it is convincing. A person who experiences an illusion usually has had what seems to be a vivid perception. An illusion is illusory for this very reason: it looks or feels exactly like something else. It is only when the individual attempts to verify his experience by predicting what should follow from it that he can say wherein his experience was illusory. For example, if one sees an object that appears to be moving, placing another object in its path will quickly show whether the movement is real or illusory; no collision will occur with illusory movement.

Although the most familiar illusions are the perceptual ones, illusions are not restricted to perceptions. There are illusions of memory; one is *déjà vu*, in which a person has the compelling sense that he is experiencing something he has experienced before, although all objective checks indicate that he could not possibly have experienced it. There are illusions of insight: a person who goes to sleep with a problem on his mind sometimes awakes in the night with the




**TYPICAL ILLUSION OF MOVEMENT** is represented by the arrows in this electric sign. When one looks at the sign as it operates, one seems to see a stream of arrows in flight.

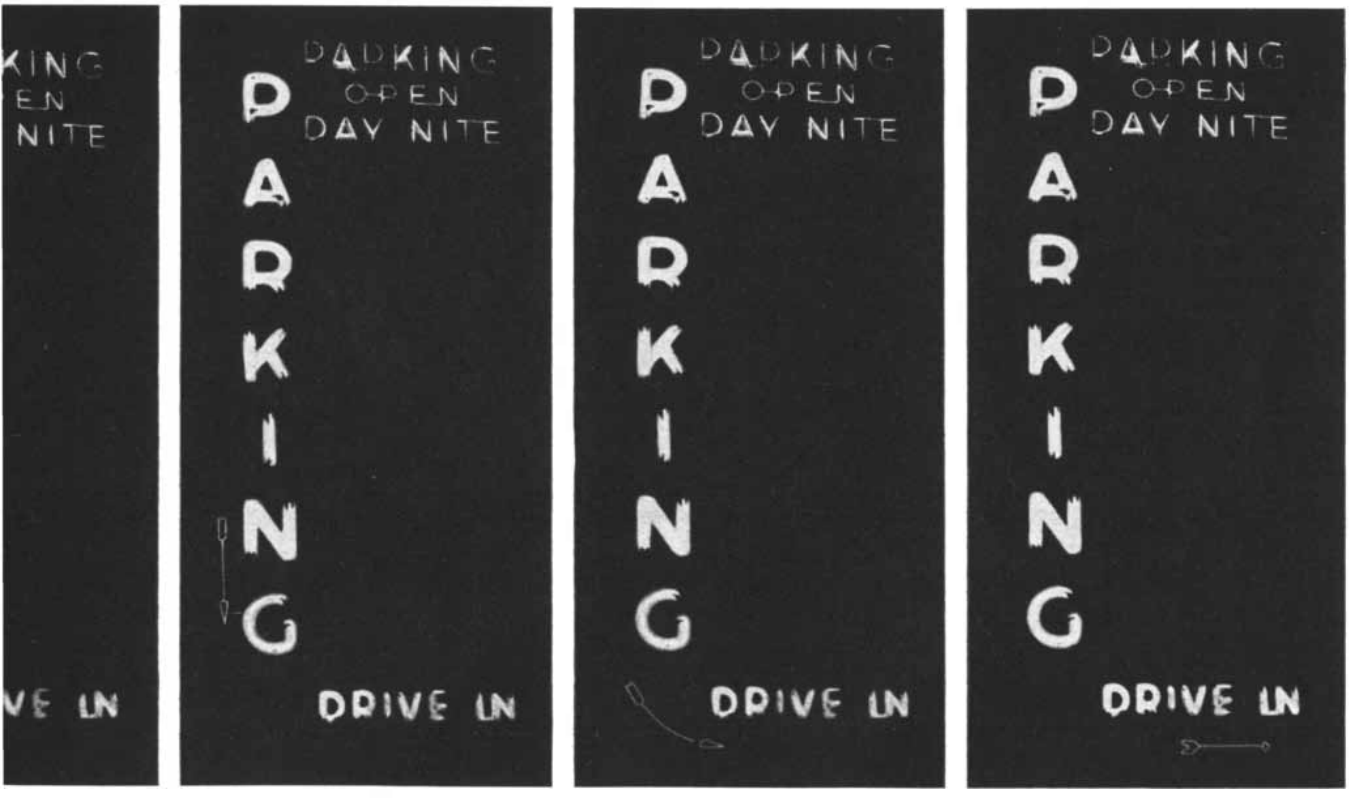
conviction that he has the answer, whereupon he goes happily to sleep again only to find himself confronted in the morning with a meaningless cliché or (if he has taken the trouble to write down his insight) with an unintelligible scrawl or words that have no relation to the problem. More than one of my colleagues has remarked that the elation attending a "brainstorm" is often a signal that the accompanying idea is likely to be fruitless. Similar illusions are occasionally experienced by people inhaling an anesthetic. Just before "going under" they have a profound experience of insight; it often takes the form of a sentence or two that seem to be the key to an understanding of the universe. On regaining consciousness, however, the patient is usually unable to recall his insight. William James told such a story about himself, and he remembered the sentence. It was: "The universe is permeated with the intense smell of kerosene."

There is another aspect of insight: a person may solve a problem without realizing that he has solved it, and so he continues long afterward to work on it. Some computer programmers have in their office a collection of wastebaskets, each labeled with the name of a day. Every day they put into the appropriate basket the rejected results of the day's work so that the material can be kept for a week, because the programmer may realize on Thursday that he solved the problem on Monday. The point to be made about such phenomena is that there is nothing in an experience that testifies to its correspondence with "reality," nothing in a perception that guarantees its truth. Judgments of reality and truth must come from sources other than the experience or the perception.

Even though illusions occur in a wide range of circumstances, they are not random events. They are certainly not results of an operational failure in perceiving. The little that is known about them indicates that they occur under particular conditions, which differ for different kinds of illusion. For example, in unsystematic investigations I have obtained many more reports of the *déjà vu* experience from adolescents and young adults than from children and older adults, and many of the illusions of insight and understanding seem to be associated with fatigue or the use of drugs.

Having indicated the broad range of illusions, I turn to the perceptual illusions, which have been the most thoroughly studied, and in particular to the visual illusions, among which are the illusions of movement. Several visual illusions, involving the effects of lines, are illustrated on the next page. Look at the drawings first, taking note of what you see. The figures are illusory because what you see does not reflect the physical relations described in the caption. These figures also provide further examples of the limited conditions under which illusions occur. Some of the illusions in the illustration can be explained by the functional anatomy of the eye, others cannot. Some of them can be presented piecemeal in time or to the two eyes without losing their illusory nature, others cannot. These observations suggest that visual illusions are not all processed in the same way or by the same part of the visual system [see "The Visual Cortex of the Brain," by David H. Hubel; SCIENTIFIC AMERICAN, November, 1963].

A visual illusion that has been extensively studied is the illusion of movement. This illusion has a special place in the history of psychology: the systematic account of it in 1912 by Max Wertheimer, who was then in Germany and later came to the U.S., was the manifesto of Gestalt psychology. Wertheimer's thesis was that students of the mind should look at wholes rather than at bits of data: at a melody, for example, rather than at its notes. To put the matter another way, his view was

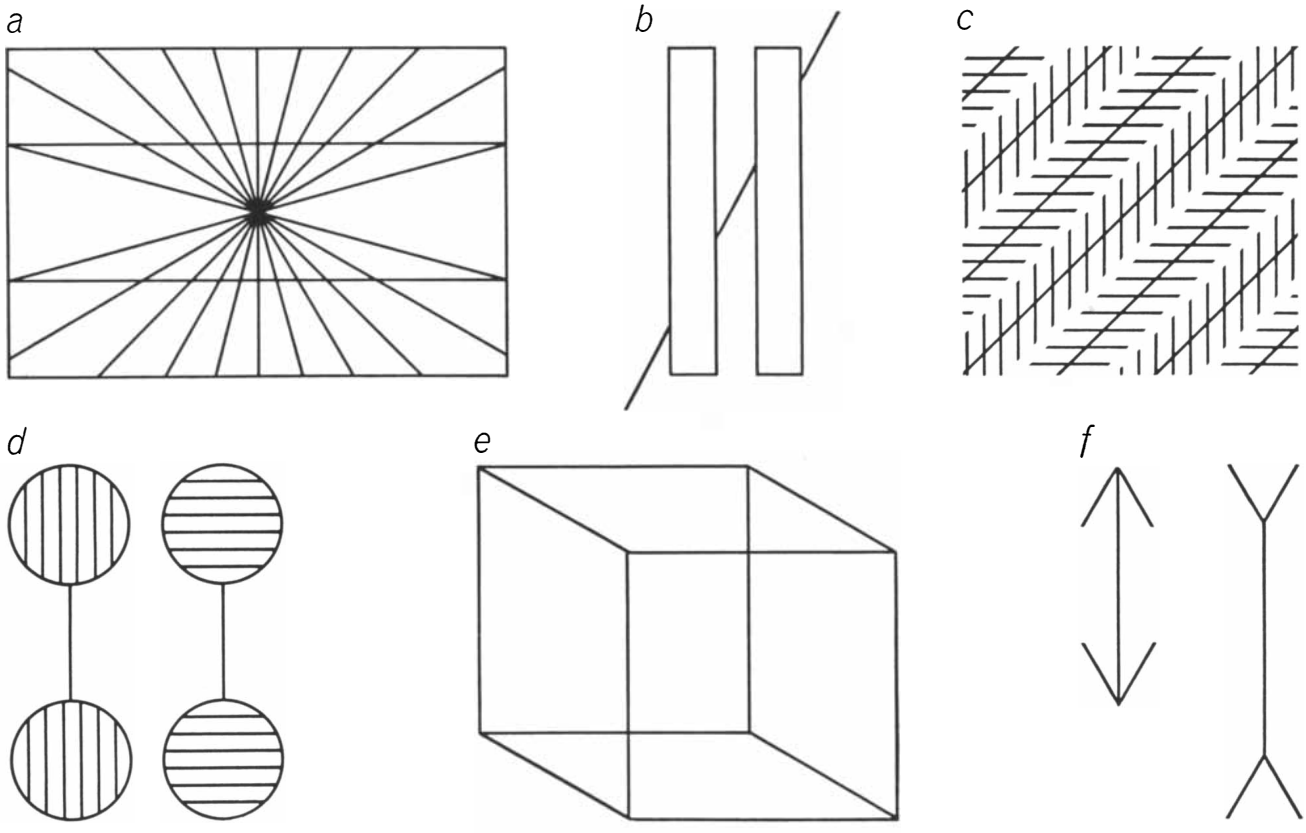



**The apparent motion is, of course, an illusion created by flashing individual arrows on and off sequentially. An even more vivid illusion of moving light can be created under controlled conditions and used for the study of the mechanisms of perception.**

that the central object of study should be the manner in which the nervous system organizes the stimulation presented to it. The illusion of movement that can be produced with two lights, he said, clearly went beyond the data presented to the eyes and so was an illustration of the organizational activities of the nervous system. The illusion is interesting both for its vividness (under proper laboratory conditions it is a striking, even amusing, thing to observe) and for the fact that it clearly identifies several fundamental and still unsolved problems about the way the human visual system works to deliver a representation of the outside world.

The illusion can be produced in several ways, of which the following is the easiest and best known. Two small gas-discharge lamps are placed a short distance apart and turned on and off in sequence. Each "on" time is about 50 milliseconds, but the interval of time between the turning off of one lamp and the turning on of the other is varied. When the interval is brief, say 10 milliseconds, most observers see the two lamps as being on simultaneously. When the interval is "long," say one second, most people see first one lamp and then the other come on and go off. The illusion occurs when the time interval is manipulated in the lower part of the range, between about 25 and 400 milliseconds. As the interval is increased gradually from 25 milliseconds, the appearance of simultaneity (itself an illusion, since the lamps are actually lighted in sequence) gives way to that of movement. The first lamp appears to move part of the distance toward the second and then disappears; then the second lamp appears, displaced toward the first, and moves toward its own actual location [*see top illustration on opposite page*]. With further increases in the time interval between the two flashes, the distance between the disappearance of the first lamp and the appearance of the second diminishes until the observer perceives what is called optimal movement: a single lamp moving smoothly and continuously across the space from its origin to its terminus. Many people report that the change from partial movements across the screen to optimal movement gives the appearance that the two lamps grow out from their respective locations until they join. So vivid is this appearance of growth and joining that Wertheimer, and subsequently many others, argued that it reflects an increase in excitation of neighboring areas in the brain to the point where they produce a "short circuit." This explanation did not find much favor among investigators not committed to the Gestalt theory.

As the time interval between flashes is increased still further, optimal movement continues to be seen, but its speed grows successively slower. Finally one no longer sees an object moving across the space. Instead most observers have a sense of movement itself: objectless, "pure" movement, which Wertheimer called "phi movement." (From this term came "phi phenomenon," the name sometimes used generically for the entire phenomenon of apparent movement.) The last stage of the perception is a slow sequence of flashes as first one and then the other lamp comes on and goes off. To sum up: Small variations in the interval of time between the two flashes produce five distinctly different perceptions—simultaneity, partial movement, optimal movement, phi movement and succession.

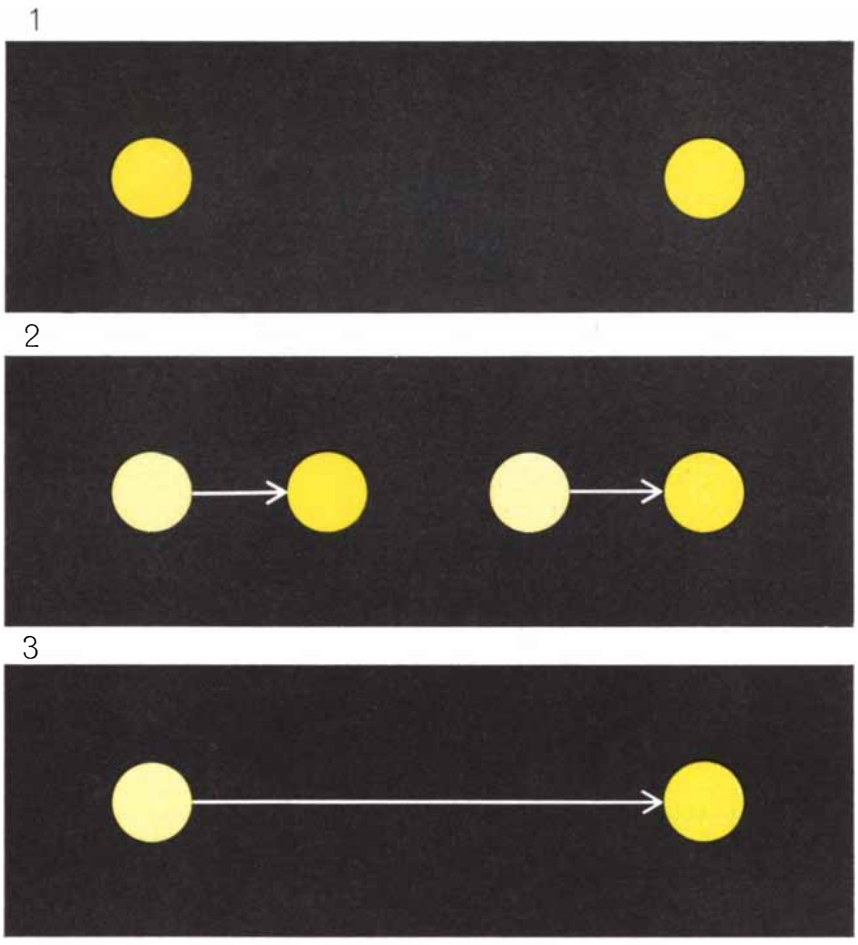



**VISUAL ILLUSIONS involve erroneous sensory reports. None of the figures is what it seems to be. In *a* the horizontal lines are parallel; in *b* the diagonal line is not staggered; in *c* the diagonal lines are parallel, and the appearance of a steplike arrangement is also illusory; in *d* the two pairs of circles are equally bright and the lines within them are equally sharp, as is evident if one turns the page 90 degrees; in *e* the cube changes perspective as one stares at it; in *f* the vertical lines are equal.**

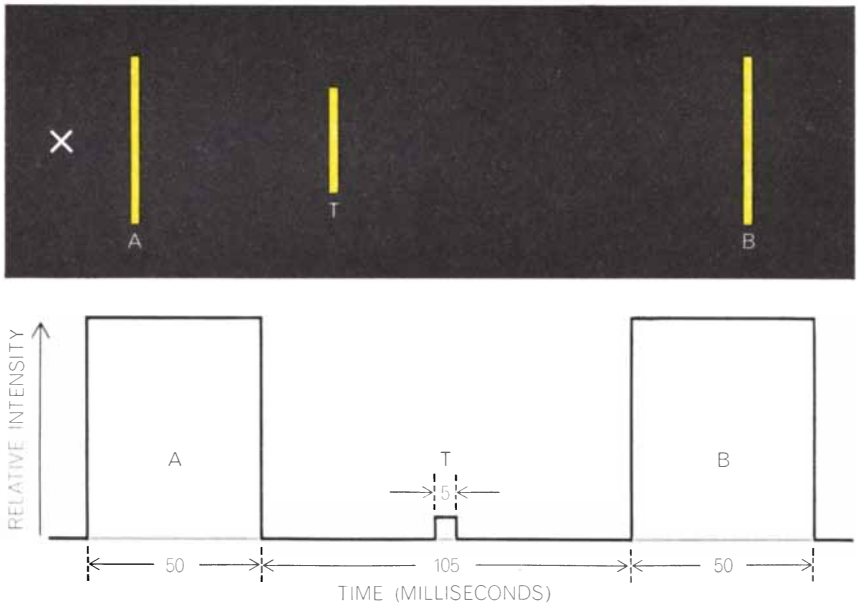
The phenomenon of apparent movement is frequently encountered in everyday life, in such forms as electric signs with arrows that appear to move and horses that appear to run. In some ways motion pictures incorporate this illusion; one perceives movement in them from a succession of still pictures flashed at certain optimal rates. There is in fact a story to the effect that it was while contemplating the physiological aspect of the motion picture that Wertheimer recognized the problems for psychology the phenomenon of apparent movement provides.

Although there has been no agreement on the cause of the illusion, most observers agree that optimal apparent movement cannot be distinguished in appearance from real movement. This correspondence led many psychologists to argue that the neural mechanisms that give rise to the two perceptions must themselves be identical. The argument further states that the only stimuli necessary to produce a perception of movement are the illumination and darkening of two separated regions of the retina with an appropriate time interval.

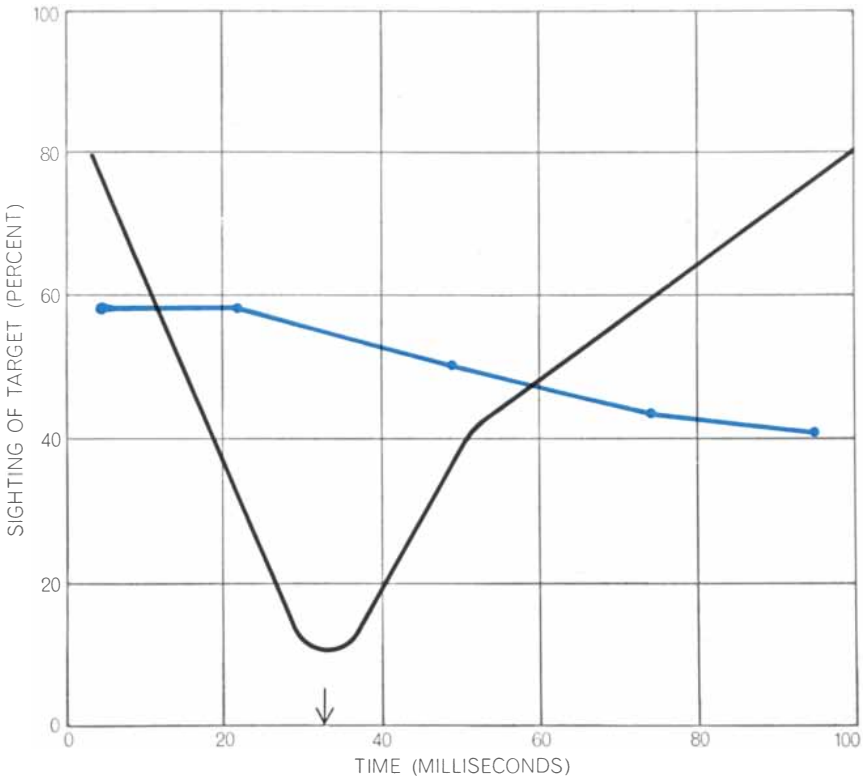
In rebuttal it must be said that the perception of movement depends on more than the speed of a target's displacement. Moreover, the conditions that produce real and illusory movement differ in several ways, four of which I shall enumerate. First, apparent movement occurs only at certain rates of stimulation, namely speeds that calculation reveals to be in the region of 15 to 25 degrees per second across the observer's visual field. That is far smaller than the range of real movement, where an object can be seen at speeds between about half a degree and 125 degrees per second. Second, the image of an object moves across the retina when the movement is real, but there is no motion across the retina in the illusion. A third difference is that real movement produces a blur when the movement is rapid, whereas the blurry appearance of phi movement (the illusory appearance of rapid movement) occurs under the opposite circumstances: when the time interval between the turning off of one light and the turning on of the next is made longer than that required for optimal movement. Finally, although an observer cannot distinguish between the appearance of real and illusory movement, apparent movement tends to be slower than real movement: the speed of an object in real movement has to be less than the calculated speed of an




**ILLUSION OF MOVEMENT** can be created with two lamps flashed sequentially. If the time interval between flashes is very short, the two lamps appear to be on continuously, as at *1;* with a longer interval one sees partial movement, as at *2;* as the interval is further lengthened one sees smooth, continuous movement of a single object, as at *3.*




**EXPERIMENT IN PERCEPTION** involves a line of light in illusory movement, created by sequential flashing of lines *A* and *B,* and a small target light *T* flashed briefly (*top*) as subject looks at point *X.* Typical characteristics of flashes are shown at bottom. The experiment determines the effect of illusory movement on perception of the target light.




**CONTRASTING EFFECTS of illusory and real movement on the perceptibility of a target are indicated. The colored curve shows the perceptibility of a target light presented as indicated by the dots; the light appeared in the "path" of an apparently moving line, which would have been closest to the target at the moment indicated by the arrow. The time scale refers to the intervals between flashes of the two lines used to create the illusion of movement. A line in real movement has a different effect, shown by black curve.**

object in illusory movement in order for the two speeds to appear the same.

Over the years these differences between the two types of perception have tended to be overlooked, neglected or gainsaid, with the result that most investigators have stressed the similarities of real and apparent movement. Accordingly many of them have adopted the view that the mechanisms of the two perceptions must be the same. Dissatisfaction with this argument from appearance to mechanism was the starting point for my own investigation, which has been conducted at the U.S. Naval Medical Research Laboratory and at the Harvard University Center for Cognitive Studies. The outcome of my studies was the finding that the neural mechanisms for the two types of perception must be quite different, because these identical perceptions seem to be constructed in the nervous system according to different rules. I shall discuss experiments that showed three such differences.

The experiments leading to the discovery of the first difference grew out of some earlier work in which my colleagues and I found that both the detectability and the brightness of a target form are drastically reduced when a different form is presented briefly within certain intervals of the appearance of the target. The nearer in time and space the different form is presented with respect to the target form, the more difficult it is to see the target form. This phenomenon goes by the name of visual masking. In one variation of it, called backward masking, the second presentation makes it harder to see the first even when the two are separated by as much as 250 milliseconds—an interval that is brief by many standards but in this instance is between 10 and 100 times longer than the duration of the flashes.

On the basis of these experiments we made a prediction about a masking flash that was moving. The prediction was that a small, stationary line of light in the path of a larger moving line should be harder to see the closer the two are, and that the brighter the moving line, the less able one should be to see the stationary one. This in fact is what happens and is our control experiment. Assuming that this result would occur, we asked what would happen to the stationary target if the line of light were in apparent rather than real motion. Would the target be affected by the "position" of the illusory line? The illusion of a moving line can be produced by a process similar to that described for the two flashes: the illusion will appear when two lines—an "origin" and a "terminus"—are turned on and off briefly, their onsets separated by an appropriate pause. Our apparatus presented the lines by means of photographic negatives that were between the light source and the observer's eye, so that the stimuli appeared as lines of light on a dark background [*see bottom illustration on preceding page*]. At various times during the dark interval between the offset of the origin and the onset of the terminus—in other words, at various points along the "path" of the apparently moving line—we presented a fixed target light.

In order to measure the effect of the apparently moving line on the stationary target, we first found the luminance at which the observer was able to detect the target about 90 percent of the time when it was presented without the line for about five milliseconds. Then we determined how often the observer reported seeing the target when the line in apparent movement was also present. Typical results are presented in the illustration on this page, together with the data that would have resulted if the moving line had been real rather than illusory. It is evident from the illustration that the trend of the data differs for the two kinds of line. When the line is in real movement, the probability that the observer will detect the target is least when the line and the target are closest. When the line is in illusory movement, the probability that the observer will see the target is least immediately before the terminus of apparent movement is flashed on—a time when the illusory movement puts the line well past the target. Checking this result with control experiments, in which only the origin or the terminus was presented, we found that the variation in seeing the target was caused by the backward-masking effect of the terminus.

By the series of experiments I have described we were led to our first finding of a difference between the neural mechanisms for the processing of real and apparent movement. A line in real movement affects the perceptibility of objects in its path; a line in illusory movement does not. In other words, real and illusory movement, notwithstanding their identical appearance, differ at least

in the way they affect other events going on in the visual nervous system.

Next we sought to ascertain whether other differences exist or whether the one just described was an isolated phenomenon. Brief, neighboring flashes of light are rather rare events in nature, and it might be that our experiments had led us to a finding of little relevance to the understanding of perception. Since the human mind was capable of inventing the phenomenon of illusory movement, however, it might have other criteria for distinguishing that phenomenon from real movement.

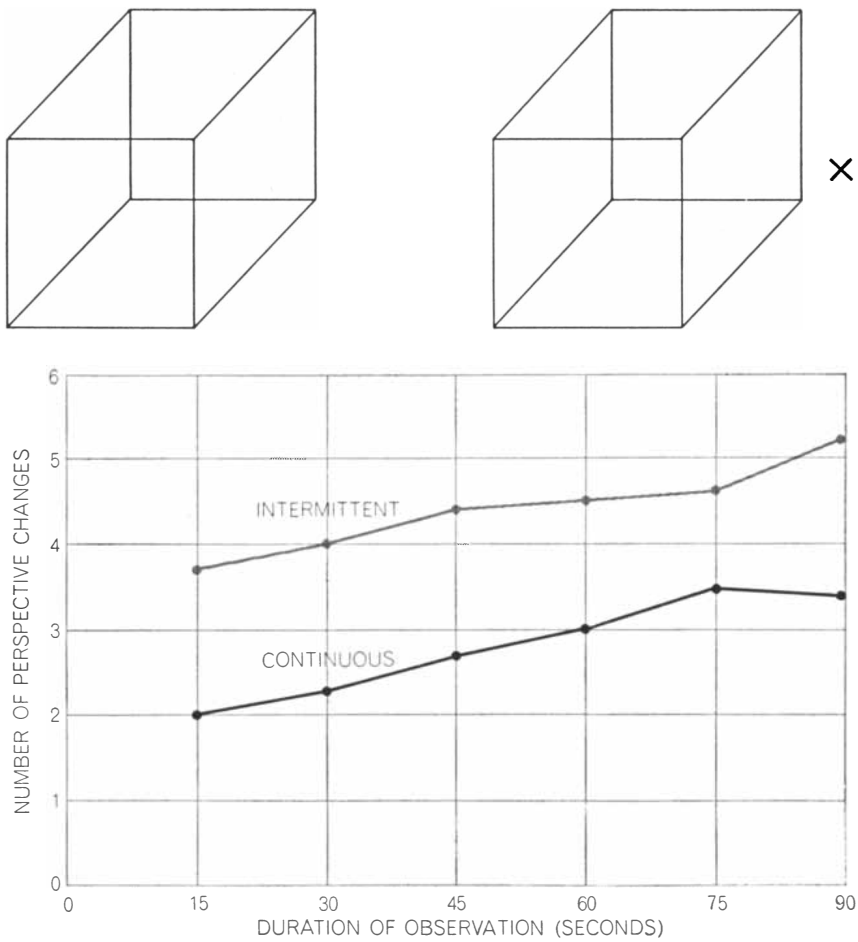
To test that possibility we conducted an experiment on the effect of extending the period of observation of illusory movement. We based the experiment on an observable fact about real movement: if you look fixedly at a point marking one end of a pendulum's swing while the pendulum oscillates at about three cycles per second, you may look for three or four minutes without ever losing the perception of a moving object. That is not the case with apparent movement, as we found in our experiment. Observers who looked fixedly at a point adjacent to the "path" of a line of light oscillating in apparent movement at about three cycles per second found that the perception of movement disappeared: they saw only the two terminal lines flash on and off. The perception of movement would return briefly from time to time and then disappear again. These alternations occurred between five and 10 times in two minutes of viewing, the number varying from person to person.

Our initial hypothesis about these alternations was that the threshold for the perception was changing slightly during observation—a not uncommon finding in visual experiments. When we tried to "track" the apparent movement by slightly varying the time interval that produces the effect, however, we found that small changes in the interval of time between the two lines never affected the number of alternations perceived, provided that we stayed within the bounds of optimal movement. Evidently it was not a change in threshold that was causing the alternation but some more complex perceptual function. Here, then, was a second difference in the treatment of real and illusory movement by the neural system of vision.

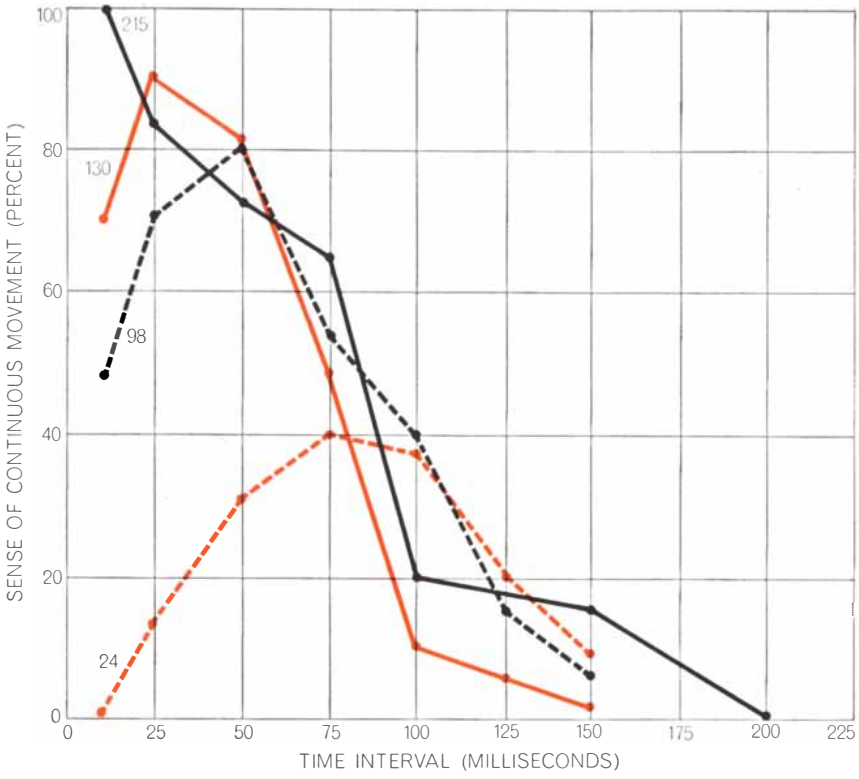
In further experiments varying the interval between origin and terminus we found a third criterion for distinguishing between real and illusory movement. When the origin and terminus are flashed for 50 milliseconds each and the intervals between them are 100 milliseconds, the observer usually sees a single form oscillating in a plane. If one of the intervals is reduced to about 75 milliseconds, however, the observer continues to see movement in the plane during the shorter interval, but during the longer interval he sees a bow-shaped movement. The object appears to come out in front of the plane of oscillation or to go behind it. If the object were in real movement, it would appear to change its speed rather than its distance from the observer.

Having thus established that the perceptual apparatus deals with illusory movement in at least three ways that differ from how it deals with real movement, we turned to the question of whether or not two illusions can affect each other. We studied this question with two illusions of spatial displacement. One was apparent movement. The other involved a phenomenon that can be seen when one stares at a drawing of a cubelike figure. The phenomenon can be observed in the illustration below, which presents a shape derived from a figure first described some 130 years ago by the Swiss naturalist L. A. Necker. Most people who stare at such a figure see it in three dimensions. As they continue to stare, say for about a minute, they find that the orientation of the cube changes repeatedly. These apparent changes vary in rate with the duration for which one stares. The rate slowly increases, reaches a plateau and then declines a little; the particular values depend on contrast, size, light intensity and other physical variables as well as on what psychologists call the observer's set, or attitude.

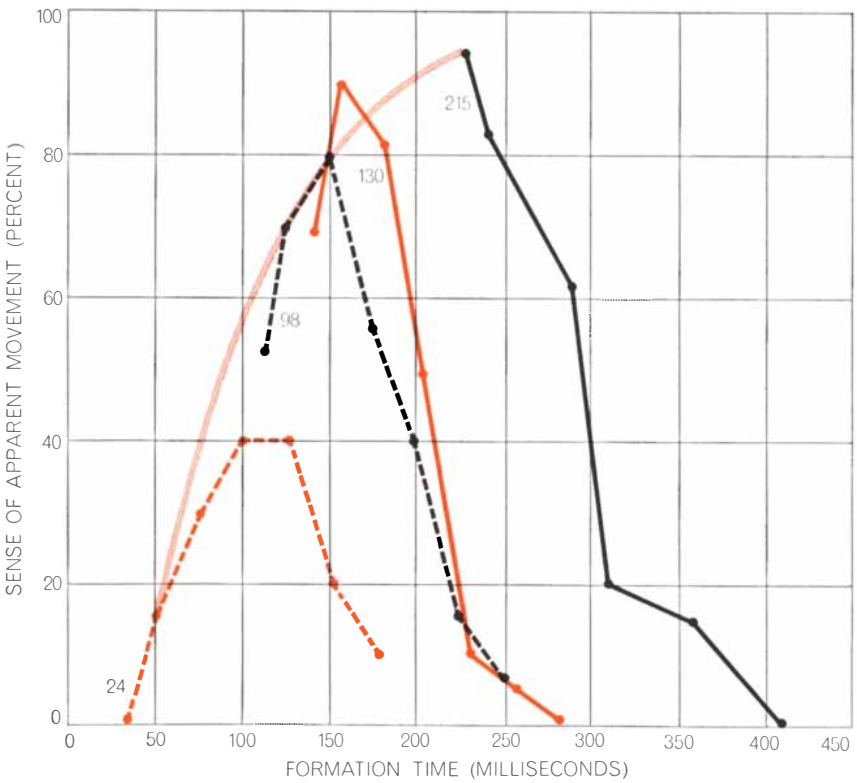
Our purpose, as I have said, was to find whether or not these two kinds of illusory spatial displacement—apparent movement and the alternation of a Necker cube—would affect each other. We began by presenting a Necker cube in apparent movement to see what effect this would have on the rate of alterna-




**PERSPECTIVE CHANGES were examined in an experiment with two cubes. The cubes were presented either continuously or intermittently, the latter method producing an illusion of a single cube in oscillation. Subject looked at point *X* and pressed a buzzer when the perspective of the right-hand cube seemed to change. Chart at bottom shows an average of the number of perspective changes seen in each 15-second interval by several subjects.**




**VARIATION OF CONDITIONS produced variations in the perception of illusory movement. Two lines of light were flashed at a constant intensity and spatial separation, but the duration of each flash and the time interval between flashes were varied. Numerals at the beginning of each curve show, in milliseconds, duration of individual flashes.**




**BASIC PROCESS of figure-forming in the visual system is suggested by the broad curve. The other curves replot the data shown in the top illustration on this page by summing the duration of the first flash and the time interval between flashes to give an image-formation time. Broad curve shows a hypothetical function tapped by individual curves.**

tion. The method of producing the apparent movement was similar to that described for lights and lines: we presented two cubes alternately, each for 50 milliseconds, with a pause of about 100 milliseconds between them. The entire cycle occurred at a rate of 3.3 cycles per second. For comparison we also had the observers look at a continuously presented cube.

The results were that the apparently moving cube changed perspective more than the continuously presented cube. On the other hand, a control experiment with a single cube presented for 50 milliseconds at a rate of 3.3 times per second produced an equally large number of perspective changes. The experiment demonstrated that the illusions themselves did not interact but that a rate of intermittency required to produce one illusion (apparent movement) was also a rate that increased the frequency of another (reversals of a Necker cube). It was evident that the rate of about three cycles per second plays an important role in the visual system. I shall return to this point, but first I wish to make a corollary observation and to discuss another experiment.

When two Necker cubes are exposed at a rate of about three cycles per second, most observers see a single cube moving back and forth between the termini. This apparent cube changes perspective not only at the two termini, where it is physically present, but also in the space between the termini, where it never "really" exists. These transformations of the illusory cube are consistent with what the observer would have seen if the cube had been physically present in that space. In other words, under certain conditions the observer performs an impletion, or filling in. By doing so he supplies himself with information that is not present in the stimulus array—information that acts to rationalize his perceptions, or make them coherent. What the observer sees is consistent with what he thinks he is seeing. He does not fill in these perceptions ad libitum, however: the impletions occur, for apparent movement, only at certain rates of stimulation. The importance of these rates emerged more fully from the next experiment.

The experiment grew out of interest in a set of relations discovered half a century ago for the intensity, spatial separation and temporal separation of flashes of light that produced apparent movement. Named for the German psychologist Adolf Korte, they have been recognized for some time as approxima-

tions rather than laws. Our interest was directed in particular to two of them.

The first was that in order to maintain optimal movement an increase in the spatial separation between flashes required that the time interval be increased if the intensity were held constant. The second was that if the spatial separation were held constant, an increase in the intensity of the flashes required a decrease in the time interval. We found, as had others, that the "law" for spatial separation does not hold for small distances, say .75 degree to 5.25 degrees. In fact, within that range we found no variations at all in the occurrence of apparent movement: the time interval and the intensity required for apparent movement to be seen remained identical over that range. The relation describing intensity and temporal interval, however, held good in the range we measured, up to certain interesting limiting values.

Holding distance and intensity constant, we found that the probability of the subject's reporting apparent movement varied as the duration of the flashes and the temporal interval between them were varied. We also confirmed an earlier finding that the properties of the second flash were practically irrelevant in establishing movement; as long as the second flash was visible, its intensity and duration seemed to be of no consequence. The important things that occurred were in the first flash.

The top illustration on the opposite page shows the proportion of positive responses an experienced subject gave when there was a fixed spatial separation between two flashes but their duration and the temporal interval between them were varied. When the flashes are weak, say 24 milliseconds long at the moderate luminance of about five millilamberts, apparent movement occurs only a limited number of times—at best somewhat less than half the time. Increasing the duration of the flashes increases the probability that apparent movement will be seen.

When the data are replotted to add the duration of the first flash and the time interval between the flashes, we obtain what we believe to be the basic curve describing the formation of the illusion of movement. The curve is shown in the bottom illustration on the opposite page; the thin lines indicate the proportion of times the observer saw apparent movement for each of several flash durations. The broad, tinted line represents a hypothetical function fitted

to the data; we believe it describes a single process in the visual system that is tapped by each of the separate curves. It rises steadily to a maximum where the flash duration is about 250 milliseconds. Subsequent checking experiments suggested that this "parent curve" reaches a plateau, at which it stays through flash durations of about 300 to 350 milliseconds and then descends rapidly.

This account of apparent movement, although still incomplete, relates the phenomenon to two mechanisms in human perception. One is the amount of time the visual system requires to form the perception of simple figures. The other is impletion.

From many experiments we know that the visual system takes about 300 milliseconds to form the perception of a simple object one is prepared to see. In other words, one can form certain visual perceptions at an optimum rate of about three per second—the rate I spoke of earlier as having particular significance. Many kinds of simple stimuli that occur within 300 milliseconds, which is to say at faster than the optimum rate, can interact so that the occurrence of each affects the appearance of the other. For example, sequences of letters presented at such a rate can be confused by the observer; he may detect the letters but confuse their sequence. Thus there is something special to the human visual system about rates in the region of three cycles per second. One of the results is the illusion of movement.

In sum, what our experiments reveal, in addition to several behavioral criteria that distinguish real and apparent movement, is that the "mechanism" for illusory movement has more in common with the "mechanism" controlling the formation of simple visual figures than it has with real movement. What one sees "moving" in an illusion is the result of an impletion, but the impletion occurs only at the rates of stimulation associated with forming the perception of simple visual figures. The more difficult problem remaining is to elaborate the rules that govern impletions.

Experiments of this kind also support a hypothesis that has been advanced tentatively in the past few years. It is that perceptions are constructed by means of a number of different operations occurring at different times and places in the nervous system. This could be called an "assembly line" model of visual perception. We look forward to learning if subsequent experiments bear out such a concept.

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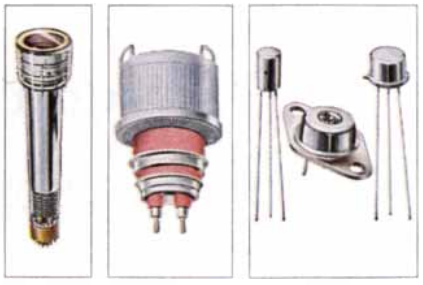

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# HABITAT SELECTION

## How does an animal choose its environment? Experiments with mice that live either in fields or in forests indicate that both heredity and learning have played a role in the evolution of this behavior

by Stanley C. Wecker

*Mid pleasures and palaces*
*'though we may roam,*
*Be it ever so humble,*
*there's no place like home.*

If animals were capable of understanding verse, this sentiment would doubtless have as much meaning for the denizens of a rotting log as it does for the inhabitants of the most fashionable suburb. One need only visit the countryside to perceive that the plants and animals in a natural community, like their human counterparts, are not scattered haphazardly over the landscape. Each organism tends to be restricted in distribution by its behavioral and physiological responses to the environment. It follows that living things must be able to locate favorable places in which to live. Their methods of doing so are so numerous and varied, however, that it is difficult to generalize about the selection of habitat.

On the one hand, many small organisms of otherwise low mobility have evolved means for utilizing air and water currents in the dispersion of members of their species. Spores, seeds, ballooning spiders and a surprisingly large number of insects drift in the upper reaches of the atmosphere, and a wide variety of planktonic forms ride the waves of the waters below. Occasionally terrestrial organisms accidentally cross long stretches of sea on pieces of driftwood, and live fish have been transported from pond to pond by hurricanes. The end result of this passive and essentially random dissemination of individuals is that a small number of them eventually reach areas conducive to continued survival and reproduction.

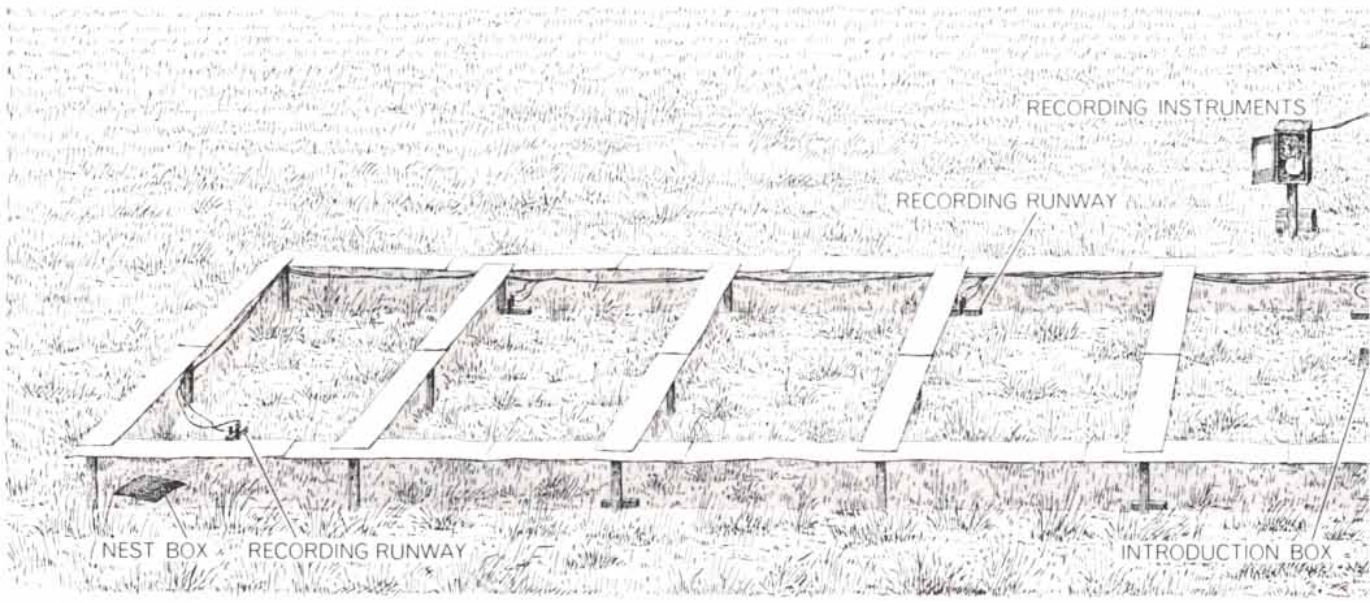
For the majority of animals, on the other hand, choosing a habitat is a more active process. This does not imply that most species can make a critical evaluation of the entire constellation of factors confronting them. More probably they react automatically to certain key aspects of their surroundings. For example, a wide variety of animals, ranging from single-celled protozoans to beetles and salamanders, often select their habitat at least in part by orientation along physicochemical gradients in the environment. These include such factors as temperature, moisture, light and salinity.

Another form of behavior that results in habitat selection is the choice of egg-laying sites by insects. Among certain beetles, butterflies and wasps the gravid female instinctively selects a plant or an animal host that will satisfy the requirements of the developing larva, whether or not the needs of the larva coincide with her own. Among the birds that live in shrubbery or forest the choice of habitat has been found to be associated with the height, spacing and form of the vegetation. Even when the overall character of the vegetation is appropriate for a species, a deficiency of specific environmental cues, such as song perches and nest sites, may exclude the species from an area within its range. The British ornithologist David Lack has called this phenomenon a "psychological factor" in habitat selection. Among the higher forms of life such factors may be fully as important as stimuli more directly related to physiological tolerances.

Although many ecologists have investigated the physical and biological factors that cause mammals to occupy certain habitats and avoid others, little is known about the role of psychological factors. One genus that is particularly well suited for the study of these factors is *Peromyscus,* the deer mouse. To this hardy little mammal almost every conceivable ecological situation, ranging from desert to tropical rain forest, from barren tundra to windblown mountaintops, is home. One species, *P. maniculatus,* is among the most variable of all North American rodents. It has 66 subspecies, which are found in so many habitats that a leading ecologist has remarked that probably no environmental change short of the inundation of the entire continent would eliminate all of them! In spite of this variability, however, in the sense of ecological adaptation the species has just two principal types: the long-tailed, long-eared forest forms, and the smaller short-tailed, short-eared grassland forms.

The prairie deer mouse of the Middle Western and Plains states (*Peromyscus maniculatus bairdi*) is a strictly field-dwelling subspecies that avoids all forested areas, even those with a grassy floor. Studies comparing the food preferences and the requirements for temperature and moisture of this subspecies and a closely related woodland form, *P. m. gracilis,* have not revealed any physiological differences of sufficient magnitude to account for the difference in their choice of habitat. It has therefore been concluded that the absence of the prairie deer mouse from forested areas within its geographic range is primarily a behavioral response to its environment.

The first experimental attempt to identify the environmental cues that cause these mice to choose a place to live was undertaken in 1950 by Van T. Harris, then working with Lee R. Dice at the University of Michigan Laboratory of Vertebrate Biology. Harris presented individual prairie and woodland deer mice with a choice between a laboratory "field" and a laboratory "woods." Each type of mouse exhibited a clear preference for the artificial habitat more closely resembling its natural en-



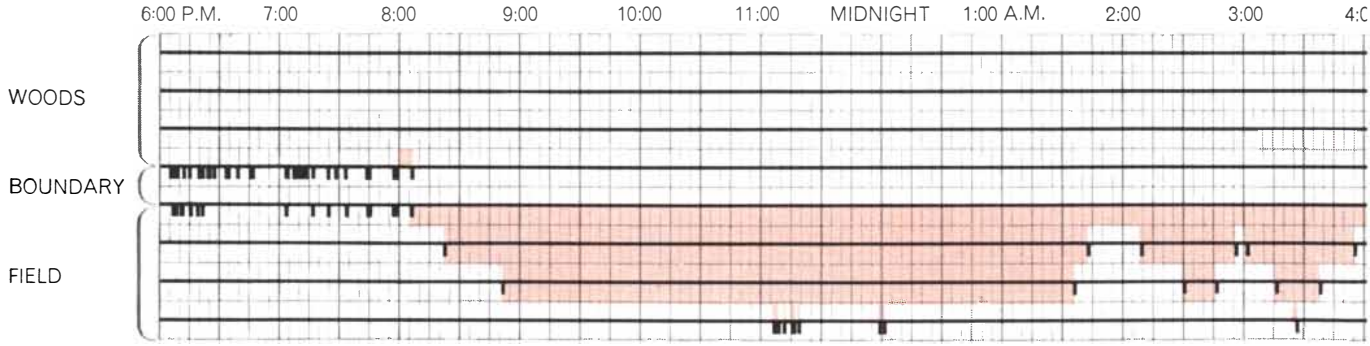

**EXPERIMENTAL ENCLOSURE for testing habitat preference of prairie deer mice is 100 feet long and 16 feet wide. Five of its 10 compartments are in a field (*left*) and five are in an oak-hickory woodlot. For testing, each mouse is placed in the introduction box near the middle. It can go from there into either the field half or the woods half of the enclosure. Each partition has a run-**

vironment. Since the physical conditions throughout the experimental room were uniform, Harris concluded that the mice were reacting to the character of the artificial vegetation. Moreover, laboratory-reared animals with no outdoor experience chose the "correct" artificial habitat as readily as the wild mice did. Harris therefore decided that this behavior was innate.

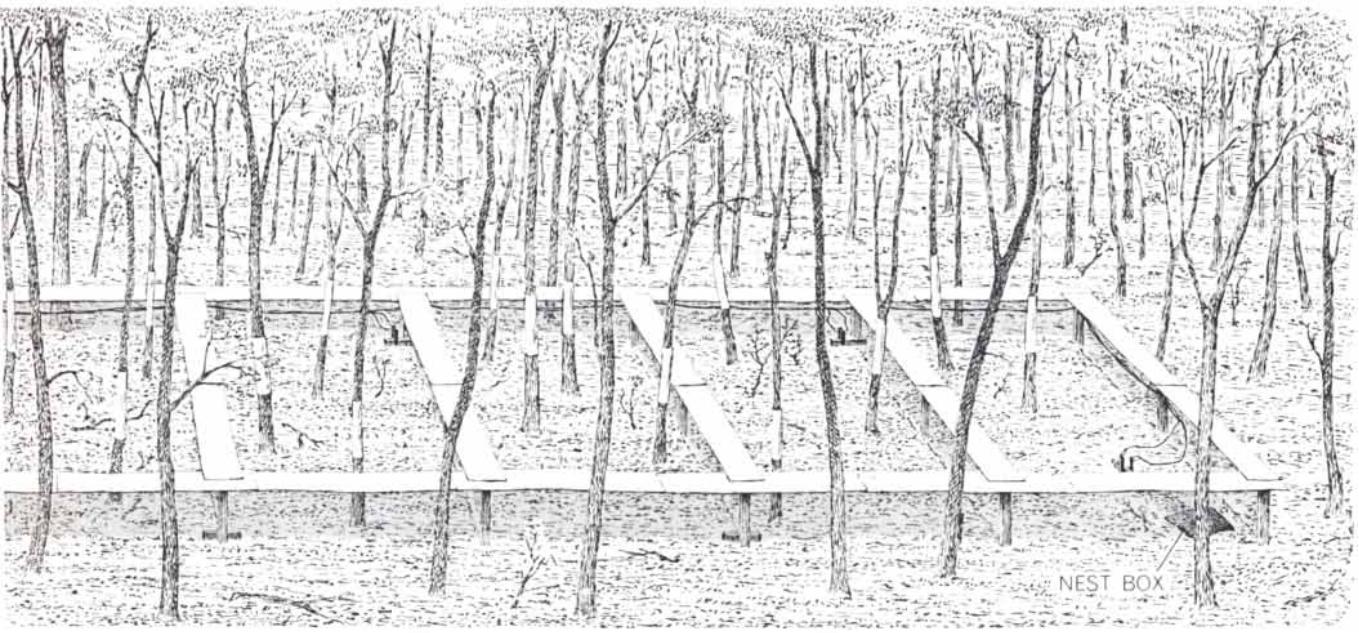
These experiments were not, however, designed to test the possibility that learning might also be involved. It has recently been established that early experience is of greater importance in the development of adult behavior than had once been thought [see "Early Experience and Emotional Development," by Victor H. Denenberg; SCIENTIFIC AMERICAN, June, 1963]. Since young prairie deer mice are normally born and reared in open fields, one would expect their early experience to reinforce any innate preference for this habitat.

These considerations raise two questions: (1) Does learning actually play a role in habitat selection by *Peromyscus*? (2) Can an innate preference for field conditions be overridden by early experience in a different environment? In order to investigate these problems I constructed a 100-foot-long outdoor pen on the University of Michigan's Edwin S. George Reserve, 26 miles northwest of Ann Arbor. The project was initiated with the support of the Department of Zoology and the Museum of Zoology and was carried out under the auspices of the Laboratory of Vertebrate Biology and its director, Francis C. Evans.

The long axis of the experimental pen crosses a relatively sharp boundary between an open field and an oak-hickory woodlot. The enclosure is divided into 10 compartments, five of which are in the field and five in the woods. There are two underground nest boxes, one at the end that extends farthest into the woods, the other at the end that extends farthest into the field. A third underground box in the middle of the enclosure serves as a chamber for introducing mice. Small metal runways leading from one compartment to another allow the animals to go anywhere with-




**RECORD MADE BY MOUSE in two nights shows preference for field. The mouse, from laboratory stock, was in the field for 10 days when quite young, then lived in laboratory for 56 days before test. Daylight hours are omitted here because the mouse was quiet in the field nest box. The eight horizontal lines (*black*) were traced by pens connected with the various treadles in the enclosure, ranging in order from the woods nest box at top to field nest box at bottom. Short vertical lines along the tracings are "blips" made when mouse crossed treadle. Just after 6:00 P.M. (*far left*) mouse leaves introduction box, runs back and forth across treadles at**



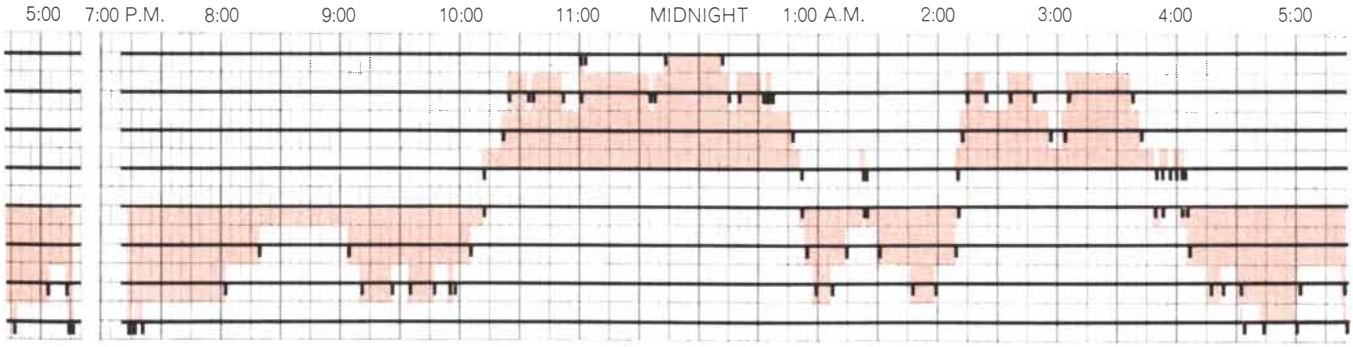

**way at one end that enables the mouse to go from one compartment to the next. Two of the seven runways with recording treadles are labeled. Nest boxes, both of which have treadles, are in the last compartments at left and right. The instruments that make permanent records of movements of each mouse (*see bottom of these two pages*) are in box at top, just to left of center.**

in the entire fenced area. A centrally located electric device records the time at which a mouse passes through the runways and enters the nest boxes. I place each mouse in the experimental enclosure alone and leave it there until it has nested in the same habitat for two consecutive days.

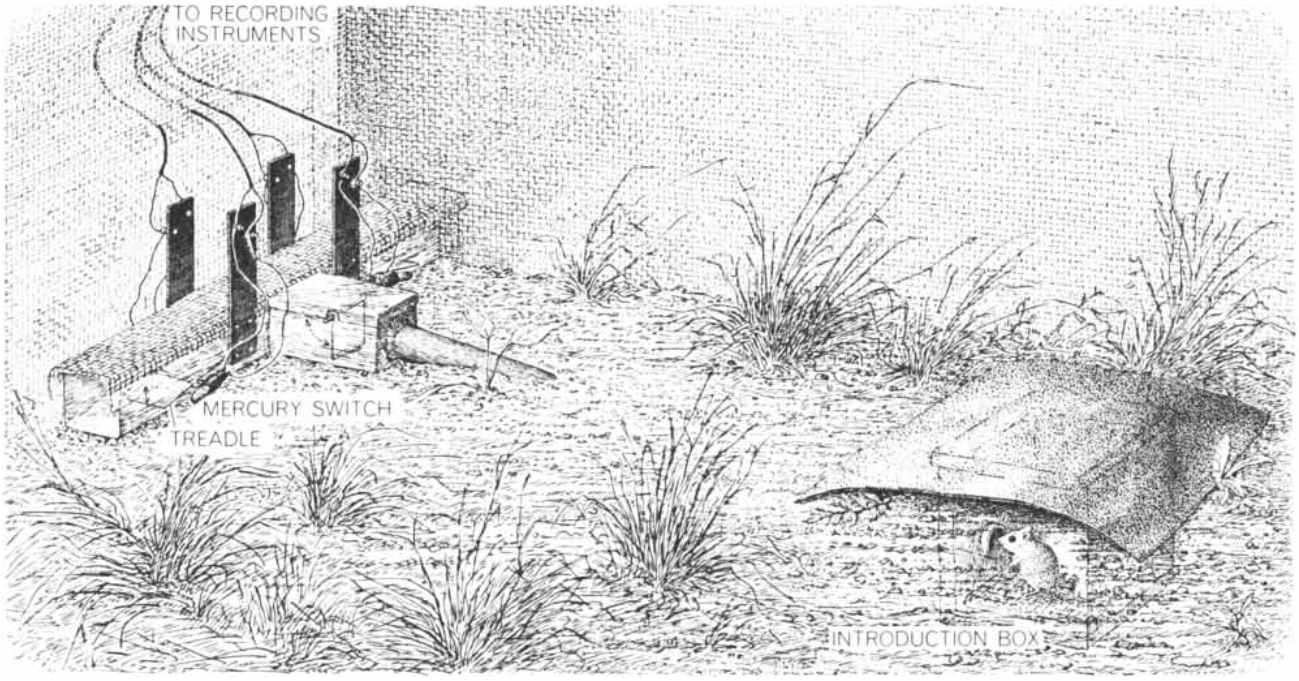
Prairie deer mice are nocturnal and are inactive during the day. I decided, therefore, that it would be most meaningful to consider the length of an animal's active and inactive periods in each environment (woods and field) as separate measures of habitat selection. Three other categories of measurement provide further data for comparing an animal's response to the woods with its response to the field. The five categories used in this study, then, are (A) *time active*, or time spent outside the nest boxes in woods and field respectively; (B) *time inactive*, or time spent nesting in woods or field; (C) *rate of travel*, or the speed at which a mouse moves about in each of the two habitats; (D) *activity*, or the frequency with which a mouse changes compartments or enters nest boxes in woods or field; and (E) *average penetration* (in feet) into either of the two habitats each time a mouse crosses the boundary between them. In all categories except rate of travel the higher score for woods or field is taken to indicate habitat preference. In the case of rate of travel it was assumed that a mouse travels more slowly in the preferred habitat; presumably the animal is less subject to stress in its normal environment.

In the course of the study I tested six groups of prairie deer mice, one mouse at a time, in the enclosure. Observing the 132 mice occupied the spring, summer and fall of two successive years. The two control and four experimental groups were each characterized by a different combination of two variables: hereditary background and pretest experience. The hereditary distinction was between field-caught mice (and their immediate offspring) and individuals selected from a laboratory stock. The experience was provided in the field, in the woods and in the laboratory.

The first group to be tested consisted




**habitat boundary. After brief foray into woods (7:58 P.M.) it returns to field and gradually moves all the way to the nest box (11:07 P.M.). It goes in and out, then moves back several times toward habitat boundary but never crosses it. At 5:16 A.M. it enters field nest box (*end of first night's record*) and remains throughout the day. Record for second night shows two long periods in the woods, including two entries into the woods nest box. It was usually assumed that the mouse went at least halfway to the next treadle after crossing a treadle, as shown by colored shading. Actually the mouse could have been anywhere between the two treadles.**




**INTRODUCTION BOX opens into the runway (*left*) that crosses the habitat boundary. The two recording treadles for the boundary can be seen in this runway. Tiny door at end of exit tube opens outward only. The two nest boxes resemble the introduction chamber.**

of individuals recently caught in old fields of the Edwin S. George Reserve, where earlier studies had clearly demonstrated the strong affinity of prairie deer mice for the field environment. My assumption was that the reactions of these adult animals would provide a basis for evaluating any unnatural effects of the enclosure itself. Accordingly I designated the eight males and four females in the group as Control Series I. At the end of the test it was obvious from all five measurements that the mice much preferred the field half of the enclosure [*see upper illustration on opposite page*]. From this I concluded that the testing situation permitted the animals to exercise their normal habitat preference.

If this preference is innate, field mice reared in the laboratory should also choose the field environment. In order to evaluate this hypothesis I tested seven males and six females from the prairie deer mouse colony of the University of Michigan Mammalian Genetics Center. These were Control Series II. The entire laboratory stock, designated *Peromyscus maniculatus bairdi* Washtenaw (for Washtenaw County), was descended from 10 pairs of animals trapped in the vicinity of Ann Arbor by Harris in 1946. According to the records the 13 individuals of Control Series II were 12 to 20 generations removed from any field experience. Their performance in the enclosure contrasted sharply with that of Control Series I [*see lower illustration on opposite page*]. In three of the five categories more Control Series II individuals preferred the woods to the field! The most that can be said of the group as a whole, however, is that it did not demonstrate a well-defined preference for either habitat.

In its laboratory environment the *bairdi* Washtenaw stock has been subjected to different selective pressures from those encountered in fields. Combinations of genes that are advantageous to prairie deer mice in nature, such as those affecting response to the environment, would in the laboratory probably not be selected for and might even be selected against. One can therefore assume that the field and laboratory populations used in my experiments had genetically diverged. Since other investigators have shown that such divergence in laboratory stocks can lead to morphological changes, it seems reasonable to assume that behavioral modifications will arise also. I suggest that these contributed to the highly variable habitat response of the mice in Control Series II. It is of considerable interest that the marked preference for fields displayed by their ancestors has been lost in only 12 to 20 generations.

Thus the data from Control Series II neither support nor refute Harris' contention that the habitat preference of prairie deer mice is normally determined by heredity. The next experiment provided a more rigorous evaluation. For this test I caught more wild field mice and bred them in the laboratory. The offspring, which were separated from their parents shortly after weaning, lived in laboratory cages for an average of about two months. Then I tested eight males and four females in the enclosure as Experimental Series I. None had had any previous outdoor experience.

Among these mice there was no reason to anticipate hereditary modifications of the type postulated for the laboratory stock. Thus if habitat preference is genetically determined, the behavior of the mice in Experimental Series I should approximate that of Control Series I. As the records indicate [*see top illustration on page 114*] these animals did display a pronounced affinity for the field half of the enclosure. Obviously prior experience in this environment is not a necessary prerequisite for habitat selection.

Since the animals were reared by field-caught parents, however, it is possible that some form of noninherited social interaction brought about the results. Unfortunately I have had no opportunity to evaluate this possibility, but other investigators have failed to find evidence in prairie deer mice for transfer of behavioral traits from generation to generation through learning. Litters reared by foster parents do not reveal any consistent indication of maternal, paternal or joint parental influ-

ence. It seems likely that, as Harris concluded, the habitat preference of wild populations of prairie deer mice is an expression of an innate pattern of behavior. The pattern may be elicited by certain key environmental stimuli, but it apparently does not depend on a period of habituation to the environment for its expression. This does not mean, however, that early experience has no effect on the selection of habitat by an adult animal. It seems reasonable to assume that a young deer mouse's normal association with open fields will reinforce its innate preference for this environment.

In order to ascertain the role such experience plays, I allowed pairs of laboratory animals to rear litters in a 10-by-10-foot pen constructed in the field. Located a short distance from the main enclosure, this area was divided into two compartments, each of which contained a number of nest boxes. Mice that had mated in the laboratory were moved into the nest boxes soon after they had borne litters and before the eyes of the young had opened. After an average of 31 days in the field pen 13 of the offspring were tested in the main enclosure. I labeled this group Experimental Series II.

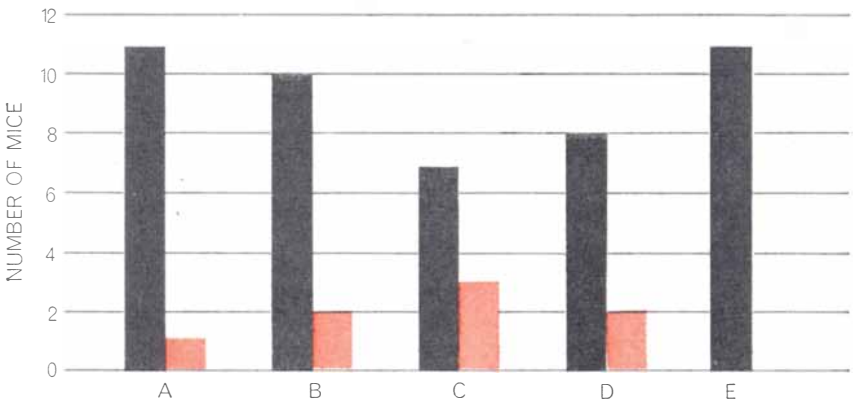
These 13 mice—eight males and five females—displayed a well-defined preference for the field habitat. Since the laboratory stock of Control Series II had not particularly preferred the field, the highly contrasting behavior of the offspring of such stock can only be explained by their field experience. Although the laboratory animals have apparently lost the innate preference of the subspecies for fields, they have retained a capacity for learning that enables them to exercise habitat selection if they are exposed to the field environment at an early age. Whether or not early experience in a different environment would reverse normal habitat affinities, however, remained to be determined.

Accordingly field-caught prairie deer mice were allowed to raise litters in a 10-by-10-foot pen in the woods. Subsequently I tested seven of the woods-reared offspring in the large enclosure. These mice—six males and one female—constituted Experimental Series III. The two weeks of woods experience did not noticeably influence their selection of habitat. In all five categories of measurement a majority of the mice exhibited the normal field preference. It thus appears that early experience in the "wrong" environment is not enough to override the innate habitat response. Since learning assumes a more important role in the development of a well-defined habitat preference by laboratory animals, it seemed possible that early experience in the woods might lead mice from laboratory stock to prefer the woods habitat.

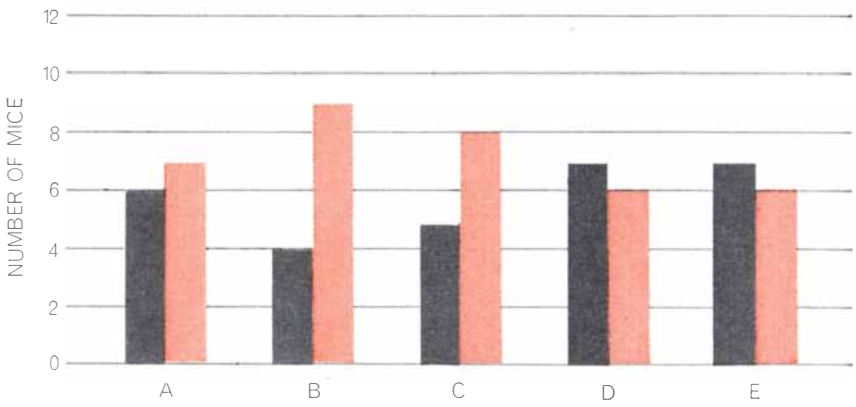
In order to determine if this was the case I transferred to the woods pen litters born to *bairdi* Washtenaw females. Nine of these offspring, six males and three females, were subsequently tested in the main enclosure as Experimental Series IV. As a whole, in spite of their 24 days of woods experience, these animals did not demonstrate a pronounced tendency to select the woods half of the enclosure. On the other hand, neither did they display any special preference for the field half. One must therefore conclude that prairie deer mice can only learn to respond to environmental cues associated with the field habitat.

To summarize the six experiments, four groups (Control Series I and Experimental Series I, II and III) consistently selected the field half of the enclosure, whereas the other two (Control Series II and Experimental Series IV) did not exhibit a well-defined habitat preference. All the individuals in the four groups that preferred the field environment had either field-caught parents or field experience or both. The other two groups were offspring of laboratory animals and had had no contact with the natural field environment prior to testing in the enclosure.

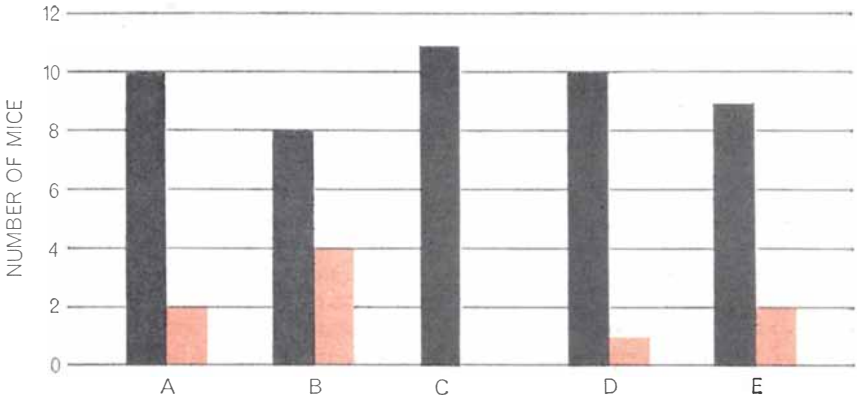
The data warrant the following conclusions: (1) The choice of the field environment by *P. m. bairdi* is normally



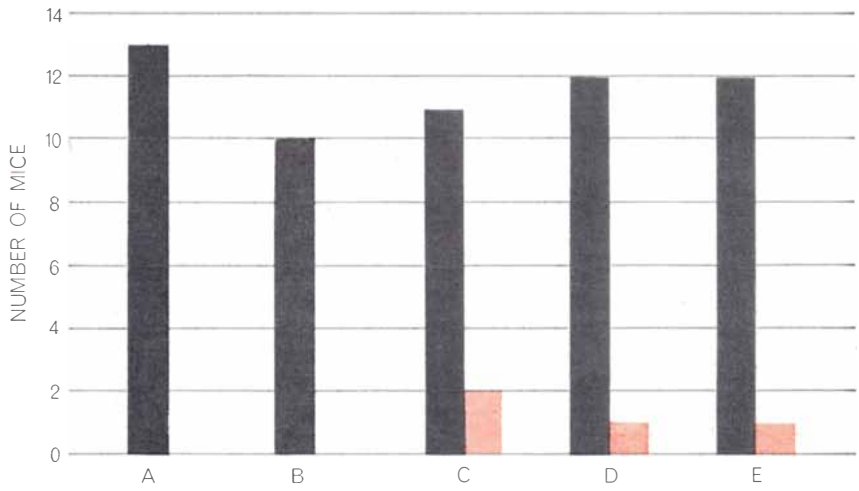

**CONTROL SERIES I, consisting of 12 adult mice trapped in an open field, showed a clear preference for the field. Gray bars indicate choice of field for each criterion of measurement (*A* through *E*); colored bars denote a preference for the woods. In this and the five bar graphs that follow, a pair of bars for some criteria does not add up to the total number of mice in the group. This results from a failure in the recording apparatus, or from the fact that an animal's score was the same for both woods and field, or because the mouse spent all its time in one habitat, making the comparisons in categories C, D and E impossible.**




**CONTROL SERIES II, consisting of 13 animals of laboratory stock, 12 to 20 generations away from the field, preferred the woods according to three categories of measurement. As a whole, however, this group cannot be said to have selected either half of the enclosure. Categories of measurement are (*A*) percent of time active in woods or field, (*B*) percent of time inactive, (*C*) rate of travel in woods or field, (*D*) activity in field or woods and (*E*) average penetration in feet by a mouse into woods or field from the habitat boundary.**




**EXPERIMENTAL SERIES I, 12 mice, were first-generation offspring of field stock, reared in the laboratory. In all five measurements of habitat selection, they chose the field.**




**EXPERIMENTAL SERIES II, 13 animals, were laboratory stock reared in a pen in the field. By all five criteria of measurement they displayed a strong preference for the field.**

determined by heredity. (2) Early field experience can reinforce this innate preference, but it is not a prerequisite for subsequent habitat selection. (3) Early experience in other environments (woods or laboratory) cannot override the normal affinity of field stock for the field habitat. (4) Confinement of the *bairdi* Washtenaw stock in the laboratory for 12 to 20 generations has apparently reduced hereditary control over the habitat response. This genetic change has markedly increased the behavioral variability of these animals when tested in the enclosure. (5) The laboratory stock did retain an innate capacity for learning from early field experience to respond positively to stimuli associated with this environment. Experience in the woods, however, did not cause them, on the whole, to select the woods habitat.

These results indicate that both heredity and experience can play a role in determining the preference of the prairie deer mouse for the field habitat, which raises an interesting question. Since the same affinity for fields can be learned by each generation, why has natural selection produced an apparently parallel, genetically determined response?

According to the British zoologist C. H. Waddington, evolutionary changes that increase hereditary control are advantageous because they tend to limit the number of possible ways an organism can respond to a particular environmental stimulus. This is beneficial because natural selection favors only those responses conducive to survival. Therefore, as long as the environment remains relatively stable, the population as a whole will eventually become genetically adjusted to the ecological situation it is most likely to encounter and best able to exploit. The innate preference of prairie deer mice for the field environment represents such an adjustment. Why, then, does the mouse retain what appears to be an independent mechanism for habitat selection based on learning? Furthermore, if we are dealing with two independent mechanisms, why should relaxation of natural selection under laboratory conditions remove one and not the other?

I would suggest that the innate pattern of habitat selection is not independent of the learned pattern but rather is really an extension of the learned pattern. This idea derives support from the observations on *bairdi* Washtenaw stock: the laboratory animals have not lost any innate habitat preference but learn to select the "correct," or field, half of the enclosure after being reared in a pen in the field. Presumably a certain number (*X*) of "field-adapting" genes would give the prairie deer mouse the ability to learn to respond positively to the field environment; a larger number of such genes (*X* plus *Y*) could make this behavior innate. After 12 to 20 generations in the laboratory the mouse reverts from the *X*-plus-*Y* genotype back to the *X* genotype.

The behavioral evolution from learned to innate response can be explained as an example of the "Baldwin effect," originally called organic selection when postulated in 1896 by J. M. Baldwin of Princeton University. Recently George Gaylord Simpson of Harvard University has redefined the process to explain how individually acquired, nongenetic adaptations may, under the influence of natural selection, be replaced in a population by similar hereditary characteristics.

As an alternative to accepting the old Lamarckian doctrine that acquired characteristics can be directly inherited, one might apply Simpson's interpretation of the Baldwin effect to the prairie deer mouse situation as follows: As the mice became physiologically and morphologically adapted to existence in the grasslands, patterns of behavior based on some form of learning (homing, for example) tended to confine individuals to the field environment. These patterns, although not exclusively hereditary as such, were still advantageous in that they restricted the animals to the habitat best suited for their survival and reproduction. Then chance mutation created genetic factors that facilitated the development of behavior patterns whose effects resembled those acquired through learning. Finally, since natural selection favored these factors, they spread through the population.

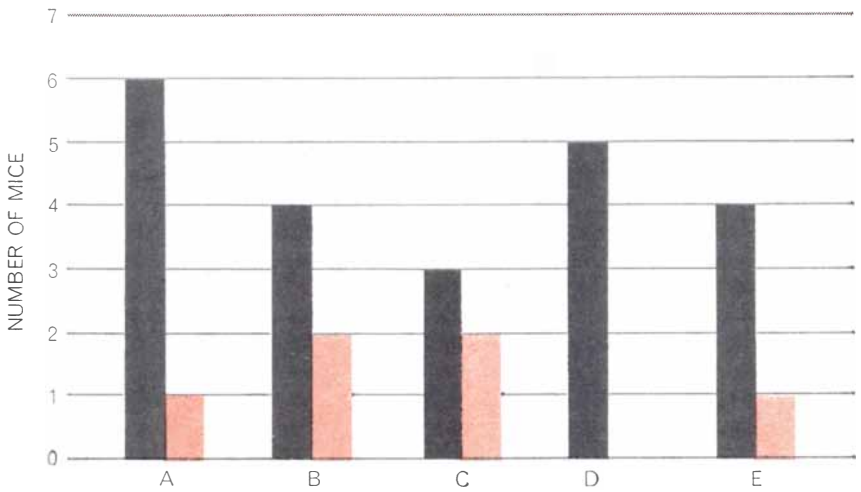
Waddington believes, however, that the Baldwin effect, with its emphasis on chance mutation, involves an oversimplification that ignores the role of the environment in determining the manner in

which particular combinations of genes will be expressed. For example, climate or some other aspect of the environment may determine what color certain animals will be, the animals themselves having a genetic potential for more than one color. Waddington maintains that natural selection operates not in favor of genes whose effects happen *by chance* to parallel acquired (nongenetic) adaptations but in favor of factors that control the capacity of an individual to respond to its surroundings. The interaction of organism and environment has the effect of reducing the number of different pathways for genetic expression, thus facilitating the production of better-adapted individuals. The more thorough this "canalization" of developmental possibilities is, the more likely it will be that favorable combinations of genes already present in the population in low frequency will find expression. Once expressed, these combinations of genes can be acted on by natural selection. Since they are favorable, the number of individuals bearing them will ultimately increase. Waddington terms this process the "genetic assimilation" of a character that is initially acquired, or nongenetic.

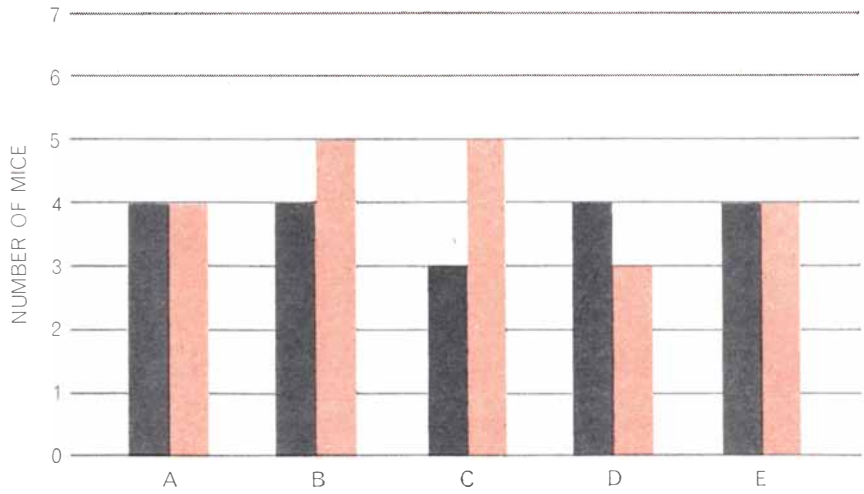
The results of experiments I am now conducting suggest that the *bairdi* Washtenaw stock learns to respond to the field environment very quickly and may indeed exhibit what the British zoologist W. H. Thorpe has called habitat imprinting. If imprinting is actually operating, one would expect the adult habitat response to be determined during a critical period early in the life of the animal, probably shortly after the young mouse first leaves the nest. It is significant, therefore, that young laboratory animals receiving only 10 days of early field experience still have a marked preference for that environment when they are tested in the enclosure, even after two months of confinement in laboratory cages! On the other hand, exposure of adult laboratory animals to the field environment for as long as 59 days does not cause them to develop a well-defined habitat preference.

In view of the above, it appears that one result of selection for an increased number of "field-adapting" genes has been to shift the development of the behavior patterns involved in habitat selection to earlier and earlier periods in the life of the individual. Obviously survival is enhanced by recognition of a favorable environment over successive generations through learning. It would be even more advantageous to restrict learning capacity to include only those cues associated with the favorable environment and to reduce to an absolute minimum the time required for such learning. Finally, the necessity for learning could be eliminated altogether by selection for sets of genes that endow an individual with the capacity for making an adaptive response to the critical stimuli as soon as the stimuli are encountered. In this context a hypothetical imprinting stage may have been an important preliminary to the ultimate genetic assimilation of the habitat response of the prairie deer mouse. Indeed, the behavioral differences among the various groups of mice tested during my investigation could be taken to reflect different steps in an evolutionary sequence leading from behavior largely dependent on learning to the development of an innate pattern of control. This sequence might have occurred as follows: (1) habitat restriction through social factors and homing, (2) recognition of the field environment through learning, (3) learning capacity reduced to cues associated with the field habitat, (4) imprinting to the field environment through exposure very early in life, (5) innate determination of the habitat response.

So far no one has identified the specific cues by which a prairie deer mouse recognizes the field environment. Fortunately the results of my investigations suggest a unique approach to this problem. Young laboratory animals do not develop a well-defined habitat preference in the absence of early field experience. It should therefore be meaningful to expose them in the laboratory to single stimuli designed to simulate different aspects of the natural field en-




**EXPERIMENTAL SERIES III, seven mice, offspring of adults trapped in the field, were conditioned by rearing in a pen in the woods. They tended to choose the field habitat.**

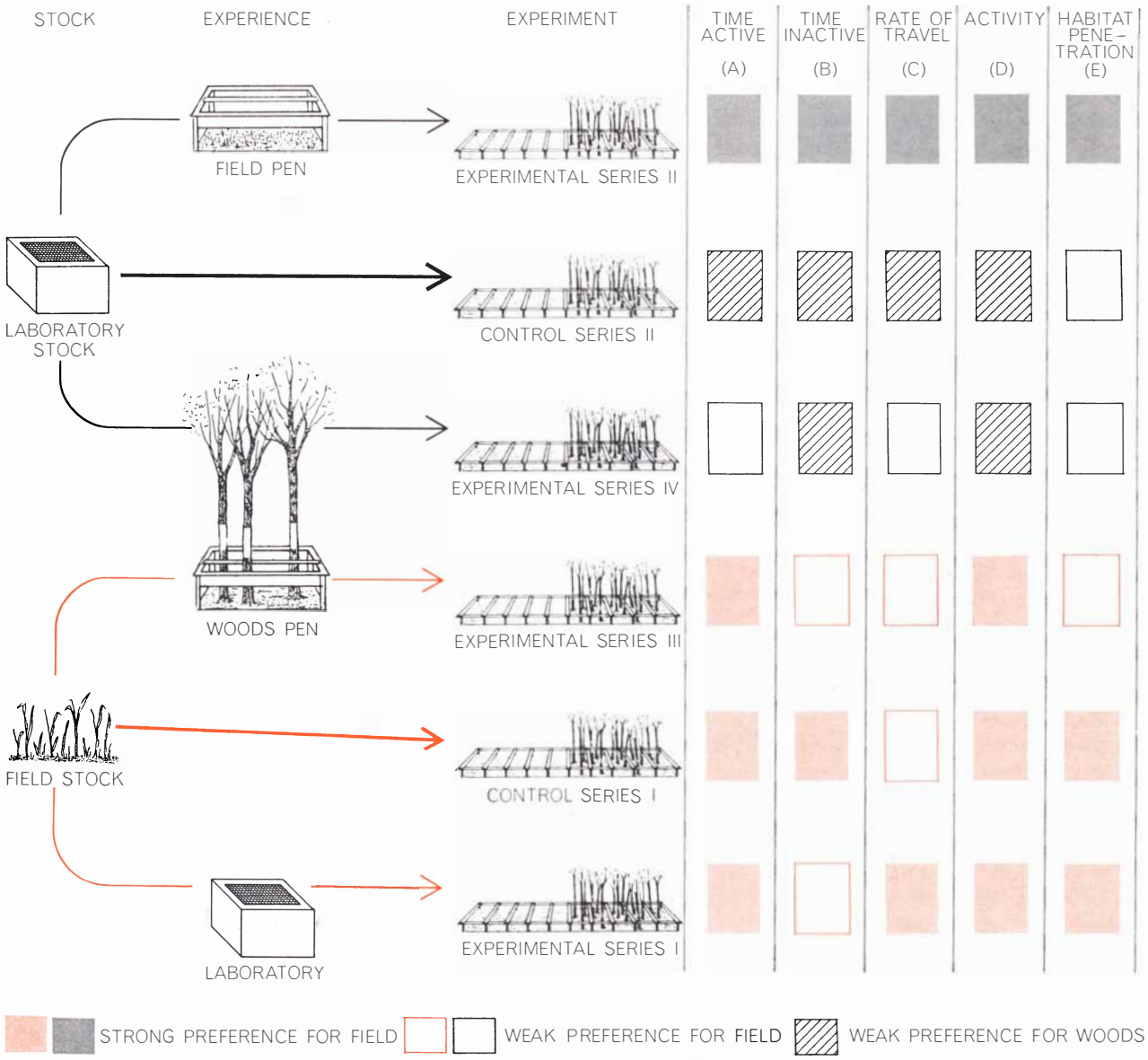



**EXPERIMENTAL SERIES IV, nine animals, were laboratory stock reared in the pen in the woods. Overall they appeared to have no particular preference for either of the habitats.**

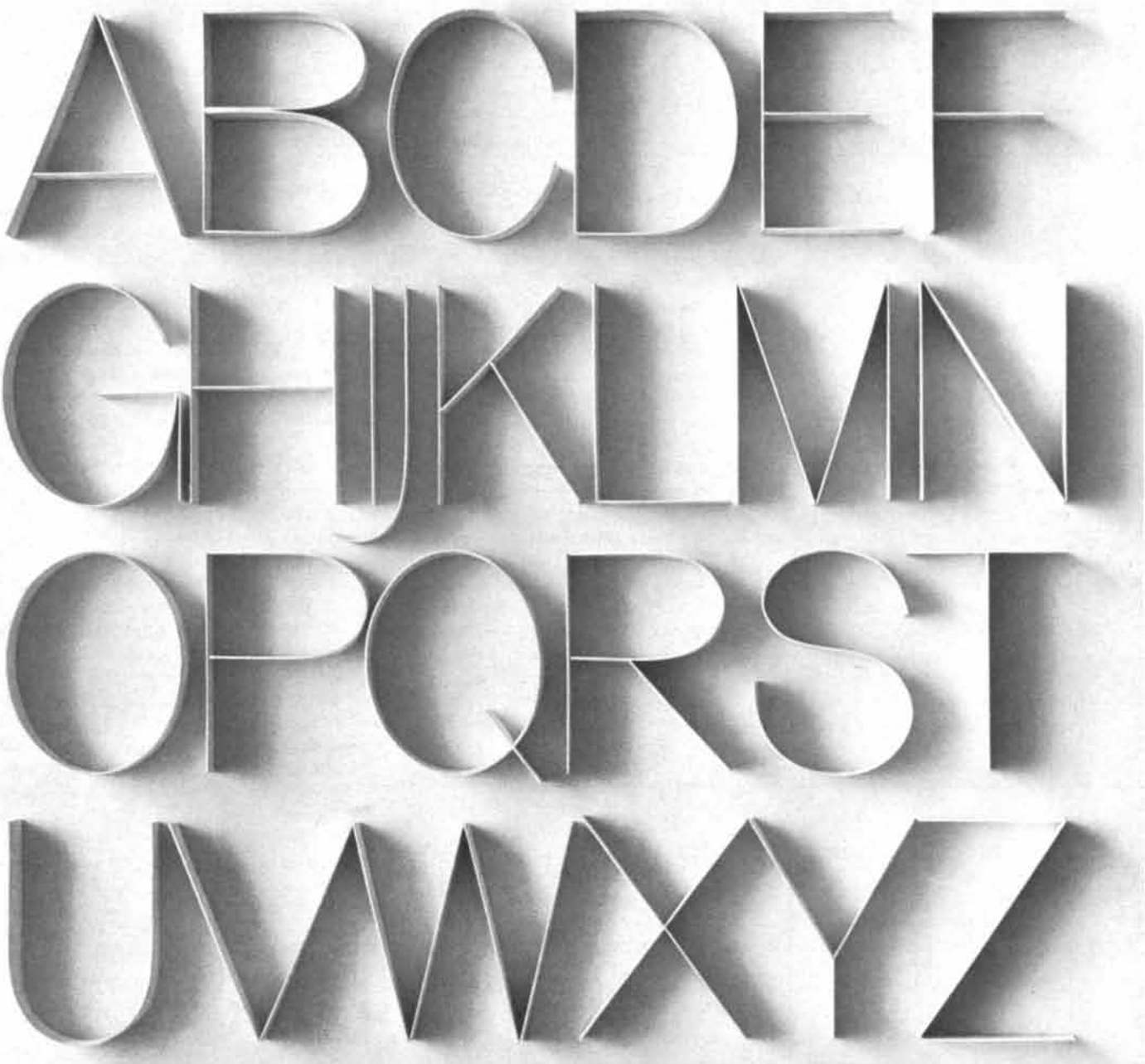
vironment. These stimuli include the sight, odor and touch of field vegetation, with artificial grass as the touch stimulus. Groups of animals, each group exposed to only one such factor, could then be tested in the experimental enclosure. In fact, I am now conducting such tests, but the data are not yet extensive enough to warrant any conclusions.

Having considered the role of evolution in habitat selection, I should like to discuss briefly the part that habitat selection plays in the evolutionary process. A diversity of habitat preferences within a species favors survival by making the species more adaptable to environmental change. Such a diversity, however, might be expected to lead to genetic divergence by selective processes similar to those already described. Nevertheless, most biologists do not believe that new species can arise in this way unless some form of geographical isolation occurs. In Michigan the ranges of the prairie deer mouse and the woodland deer mouse overlap, but there is no evidence of intergradation, or interbreeding, between the two types. It is known, however, that these subspecies did not develop side by side, because they were formerly isolated geographically. Indeed, the two forms came into close contact only during the past century, when the clearing of forests by man enabled the prairie field mouse to extend its range northward.

Both Harris' experiments and mine provide evidence that the observed difference in habitat preference of these subspecies forms the basis for their continued segregation. As Ernst Mayr of Harvard University points out, ecological differences between two such overlapping forms are to be expected, since competition would otherwise prevent both from coexisting in the same area.




**SUMMARY OF OBSERVATIONS** reveals preferences of prairie deer mice from various backgrounds. Mice captured in the field were placed in the experimental pen as "Control Series I" (*thick colored arrow*). Offspring of field-caught mice were given conditioning in laboratory cages or in a pen in the woods before testing (*thin colored arrows*). Laboratory stock were tested in the experimental enclosure as "Control Series II" (*thick black arrow*), and their offspring were conditioned in woods or field pens before testing (*thin black arrows*). Results of the tests on the six groups are given in right half of the diagram. The five categories of measurement are explained in the text. Degree of preference is indicated. Results are based on mean response of each group.

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# MATHEMATICAL GAMES

## *Simple proofs of the Pythagorean theorem, and sundry other matters*

by Martin Gardner

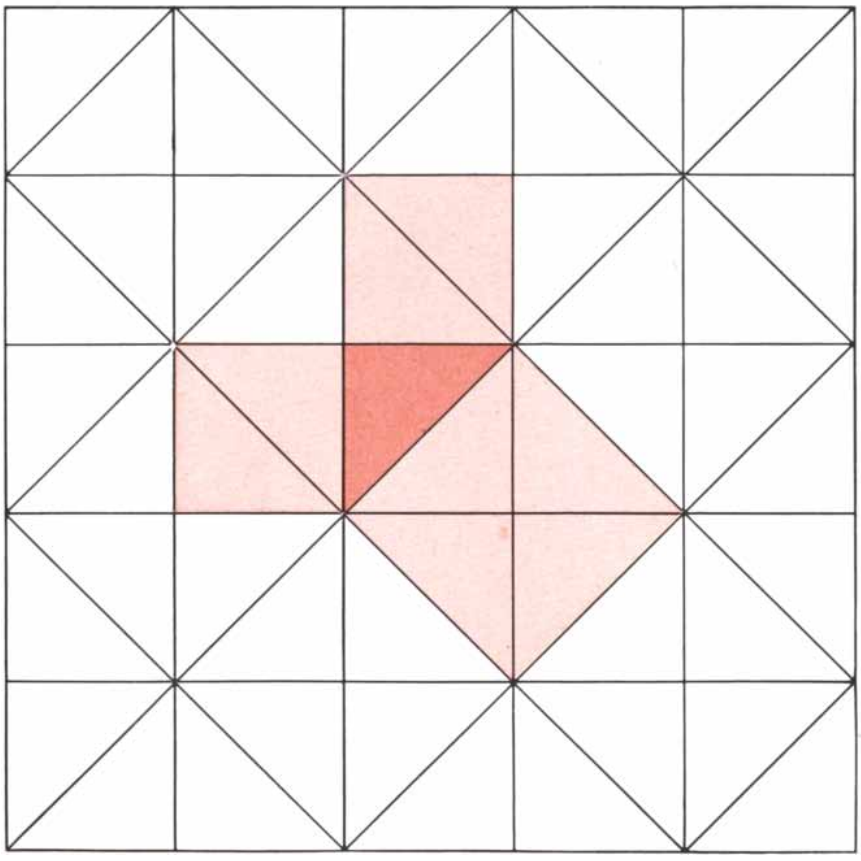
The first chapter of Arthur Schopenhauer's great philosophical work *The World as Will and Idea* contains a harsh attack on Euclid's method of proving propositions, and on the famous 47th proposition in particular. This is the familiar theorem, usually called the Pythagorean theorem, that states that the square on the hypotenuse of a right triangle has an area equal to the combined areas of the squares on the other two sides. It is, of course, one of the oldest and most indispensable theorems in the whole of mathematics.

Euclid's proof, as many readers will recall from high school geometry textbooks, is rather complicated. Construction lines are drawn here and there, says Schopenhauer, for no apparent reason; then we are dragged through a long chain of deductive steps until suddenly the proof snaps shut on us like a mousetrap. We are compelled to admit that the conclusion is true, but we feel somehow cheated. We do not "see" its truth. According to Schopenhauer we are like a doctor who knows both a disease and its cure but has no understanding of why the cure works. The proof is a "brilliant piece of perversity." It sneaks its truth in by a back door instead of giving it to us forthrightly, as a direct intuition of spatial relations.

A much better understanding of the theorem is obtained, Schopenhauer continues, by contemplating a diagram such as the one on this page. We see at once that the squares on the two legs of the shaded triangle are composed of four congruent triangles that fit together to form the square on the hypotenuse. Essentially the same diagram is used by Socrates (in Plato's *Meno*) to convince a slave boy of the truth of the theorem. How foolish, Schopenhauer says, to toil over Euclid's rough terrain when we can get there directly by such a "bright, firm road."

Schopenhauer's arguments are naïve: the proof he recommends concerns only a special case, the isosceles right triangle, and does not prove the theorem at all. Nevertheless, there is something to be said for the pedagogic value of simple proofs that give a maximum of intuitive insight. Consider the figure at left in the top illustration on the opposite page. Clearly *any* type of right triangle can be duplicated four times and arranged in this pattern. The tilted white square in the center—the square on the hypotenuse—has an area equal to that of the large square minus the combined areas of the four shaded triangles. Now we rearrange the four triangles inside the same large square in the manner shown in the figure at right in the illustration. The two white squares are the squares on the two legs. Since their combined area also is that of the large square minus the four triangles, we know it must equal the area of the tilted white square in the figure at left in the illustration.

No one knows who first thought of this beautiful proof, but it may predate Pythagoras himself. The figure at the left in the illustration appears in the *Chou Pei*, a Chinese manuscript that goes back to the Han period (202 B.C. to A.D. 220) but is believed to contain much older mathematical material. Although the manuscript gives no actual proof, it does mention the right triangle with integral sides of 3, 4 and 5, and many scholars think that the figure played a part in a proof similar to the one just explained. Pythagoras, who lived about 500 B.C., is believed to have proved the theorem (legend has it that he sacrificed an ox when he first discovered the theorem), but no actual proof by him has survived. Recent research has disclosed that the ancient Babylonians, more than 1,000 years before the time of Pythagoras, knew the theorem as well as many different kinds of right triangle with integral sides. There is *no* evidence that the Egyptians knew either the theorem or the 3, 4, 5 triangle. The myth that they did goes



*Ancient Greek proof of Pythagorean theorem for the isosceles right triangle*

back to 1900, when Moritz Cantor, a German historian of mathematics, knowing that Egyptian temple builders used ropes in laying foundations, suggested that *perhaps* they obtained accurate right angles by using marked ropes that could be stretched around stakes to form a 3, 4, 5 triangle. Perhaps they did, but there is not a single known document to support this guess.

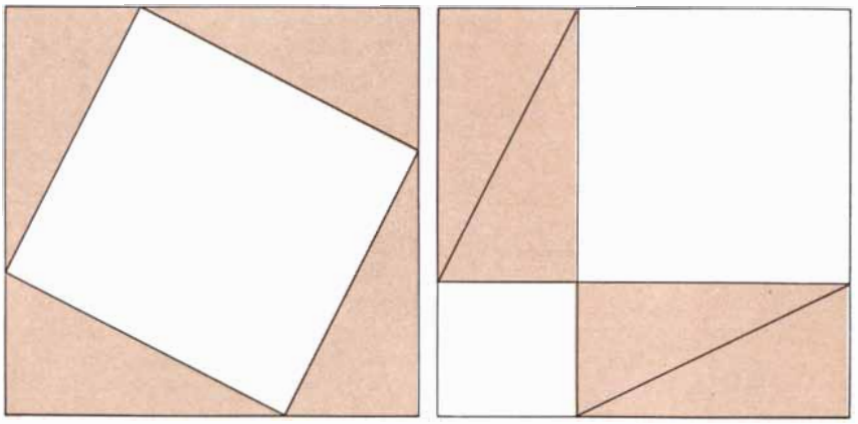
A delightful, dynamic proof of the theorem, devised by a New York mathematician, Hermann Baravalle, was published in 1945. Its five steps are shown in the illustration on the next page. Only the fourth step calls for comment. If a parallelogram is altered by a shearing motion that preserves its base and altitude, its area remains constant.

I know of no more intuitively satisfying proofs of the theorem than these, but by applying some elementary algebra still simpler proofs are possible. Surely the simplest is obtained by resting the triangle on its hypotenuse, as shown in the bottom illustration on this page, then dropping a vertical line from the top corner. The small shaded right triangle is similar to the large triangle *ABC* because both have the angle *A* in common. Similar triangles have sides in the same ratio, therefore $b : x = c : b$, or $b^2 = cx$. The small unshaded right triangle is similar to *ABC* (they have angle *B* in common), therefore $a : c - x = c : a$, or $a^2 = c^2 - cx$. We add the two equations

$$\begin{aligned} b^2 &= cx \\ a^2 &= c^2 - cx \\ \hline a^2 + b^2 &= c^2 \end{aligned}$$

and obtain the theorem.

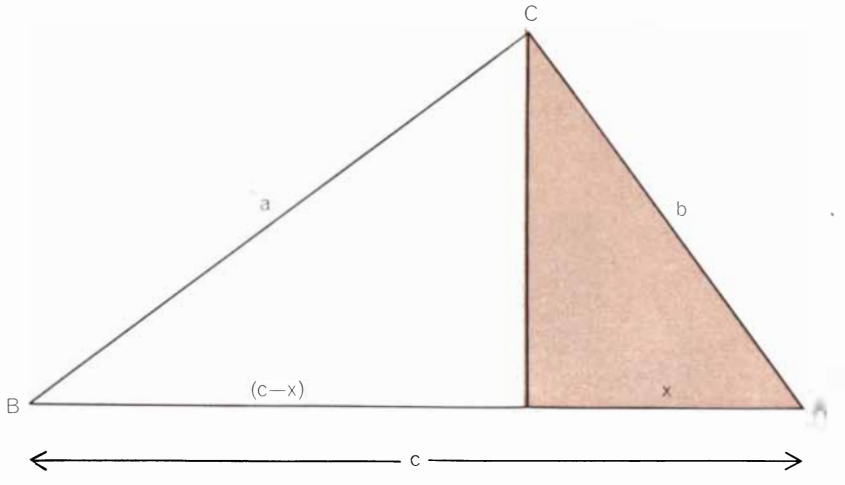
Hundreds of ingenious ways to prove the theorem have been published. The second (1940) edition of *The Pythagorean Proposition,* by Elisha S. Loomis, gives 367 different proofs, neatly classified by types. (This curious volume of 285 pages, privately printed, can still be obtained for $2.15 postpaid from Elatus G. Loomis, 1319 West 111 Street, Cleveland, Ohio 44102.) Of special interest—it is the only contribution to mathematics ever made by a president of the United States!—is an algebraic proof based on the construction shown in the top illustration on page 125. The proof first appeared in a Boston weekly called *The New England Journal of Education* on April 1, 1876, with a note by the editor saying it had been given to him by James A. Garfield, then a Republican congressman from Ohio. Garfield had hit on it, says the note, during "some mathematical amusements" with other congressmen, and "we think it something on which the members of both houses can unite without distinction of party." The basic right triangle is shown shaded. On its hypotenuse is drawn the right isosceles triangle *CBE*. Line *AC* is extended, then from point *E* a perpendicular is drawn to the extended line, meeting it at *D*. The shaded triangle is congruent with triangle *DCE*, therefore $AB = DC$ and $AC = DE$. I leave the proof (to be detailed next month) as a puzzle for the reader.



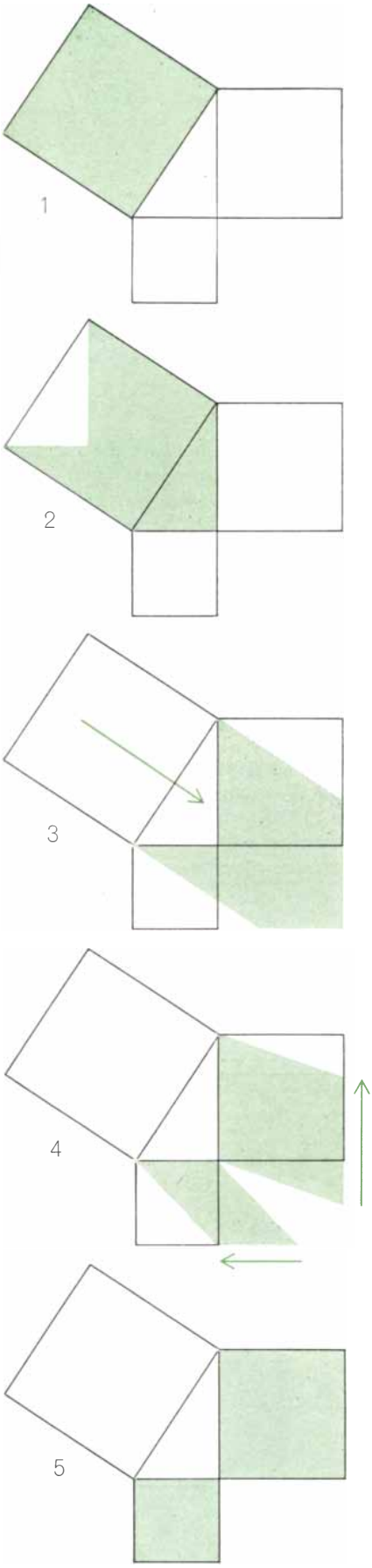
*A "look-see" proof of the theorem for any type of right triangle*

The theorem can be generalized in scores of interesting ways. For instance, any figure whatever can be drawn on the three sides—semicircles, hexagons, triangles and so on. As long as the three figures are similar, with corresponding sides on the triangle, the area of the figure on the hypotenuse must equal the sum of the areas of the other two. Pappus of Alexandria, a Greek geometer who lived about A.D. 300, proved a much more remarkable generalization. One starts with any triangle whatever [*ABC in the bottom illustration on page 125*]. On its legs one draws two parallelograms [*shown shaded*] of any size or shape. Sides of these two parallelograms are extended to meet at point *P*. We next draw a line through *P* and *C*, extending it downward until *QR* is equal to *PC*. If a parallelogram is drawn on the hypotenuse of the triangle, its sides equal to and parallel with *PR*, its area will be the sum of the areas of the other two parallelograms.

The proof is ridiculously easy. The shaded parallelogram at left in the illustration is equal in area to parallelogram *WPCA* (for the reason given in connection with Baravalle's proof) and also (for the same reason) equal to parallelogram *AQRX*. At right, the same argument shows that the shaded parallelogram has an area equal to parallelogram *QBYR*. Since the large parallelogram on the hypotenuse is made up of *AQRX* and *QBYR*, its area is the sum of the areas of the two shaded parallelograms. It is easy to see that the Pythagorean theorem is a special case of




*Simplest algebraic proof of the theorem*




*Baravalle's five-step dynamic proof*

Pappus' theorem. It obtains when angle $C$ is a right angle and the two shaded parallelograms are squares. In this special case the proof just outlined is essentially the same as Baravalle's proof.

The simplest right triangle with integral sides is the 3, 4, 5 triangle. Of course we can get an infinity of other "Pythagorean triples," as these three numbers are called, simply by multiplying each number by the same integer. If we multiply by 2, we get the Pythagorean triple 6, 8, 10. This is not very exciting, because a triangle with such sides is merely an enlarged version of the 3, 4, 5. Much more interesting are the Pythagorean triples that have no common factor, that is, that have integers that are "coprime." Such triples are called "primitive Pythagorean triples," which we abbreviate to PP triples. Obviously no two PP triangles will have the same shape.

Every Pythagorean triple, primitive or not, is an integral solution of the equation $x^2 + y^2 = z^2$. There is an infinite number of *primitive* solutions. (If the exponent of the three terms is any integer greater than 2, there are believed to be *no* integral solutions. This is Pierre de Fermat's famous "last theorem," not yet proved true.) The formula for finding primitive solutions goes back to the Greeks and probably back to ancient Babylonia:

$$x = a^2 - b^2$$
$$y = 2ab$$
$$z = a^2 + b^2$$

The letters $x$ and $y$ are the triangle's legs, $z$ is the hypotenuse. Letters $a$ and $b$ stand for integers called "generators." They can be any pair of positive integers, with the restrictions that they be coprime (have no common divisor), of opposite parity (one even, one odd) and that $a$ be greater than $b$. For example, if $b$ is 1 and $a$ is 2 (the smallest possible generators), we obtain the 3, 4, 5 triangle. Generators of 3 and 2 (for $a$ and $b$ respectively) give the next simplest PP triple: 5, 12, 13. In this way the formula generates all PP triples. There are 16 PP triangles with sides less than 100 and exactly 100 such Pythagorean triangles (including the primitives) if we count mirror images as being different.

The study of Pythagorean triples has long been a vigorous branch of recreational number theory, with a literature that has reached awesome proportions. It is not hard to prove that $x$ and $z$ must be odd and that $y$ is "doubly even" (divisible by 4). Either $x$ or $y$ is sure to be a multiple of 3, and one of the three numbers must be a multiple of 5. Since the factors 3, 4, 5 occur somewhere in the triple, the product of all three numbers must be a multiple of 60. The area of a PP triangle must be a multiple of 6 and cannot be a perfect square.

Taking off from such simple properties, students of Pythagorean triples have set themselves an endless variety of bizarre problems. How many PP triangles have a certain integer as a leg? As a hypotenuse? Find PP triangles with a perimeter that is a square, or an area that equals the hypotenuse, or legs that differ by 1, or an area that contains each of the nine digits once and only once, and so on. It is difficult to invent a problem along such lines that has not been industriously worked on.

It is easy to prove, for instance, that only two Pythagorean triangles—6, 8, 10 and 5, 12, 13—have perimeters that equal their areas. Is there a PP triangle whose hypotenuse is a perfect square, and with legs such that their difference is also a square? Yes; the smallest such triangle is 119, 120, 169. Is there a PP triangle with a square hypotenuse and legs that *sum* to a square? Yes; but now the smallest answer is 4,565,486,027,761, 1,061,652,293,520 and 4,687,298,610,289. (This last problem was posed and solved by Fermat in 1643.) The PP triangle with sides 693, 1,924, 2,045 has an area of 666,666. One leg of the PP triangle 88,209, 90,288, 126,225 has the same digits as the other leg, but in reverse order.

No isosceles right triangle can be Pythagorean (its hypotenuse is incommensurable with a leg), but one can get as close to isosceles as one pleases. Albert H. Beiler, in his fascinating paperback *Recreations in the Theory of Numbers,* gives a PP triangle so nearly isosceles that if the sides of one of its acute angles were extended 100 billion light-years, the divergence from a 45-degree angle would still be (as Beiler points out) an inconceivably small fraction of the radius of a proton! One leg in this mammoth Pythagorean triangle is 21,669,693,148,613,788,330,547,979,729,286,307,164,015,202,768,699,465,346,081,691,992,338,845,992,696. The other leg is that number plus 1.

Some of the most challenging problems in the field concern PP triangles that have the same area. Fermat showed how to find a set of as many equiareal nonprimitive Pythagorean triangles as desired. Some 20 years ago William P. Whitlock, Jr., worked out a number of

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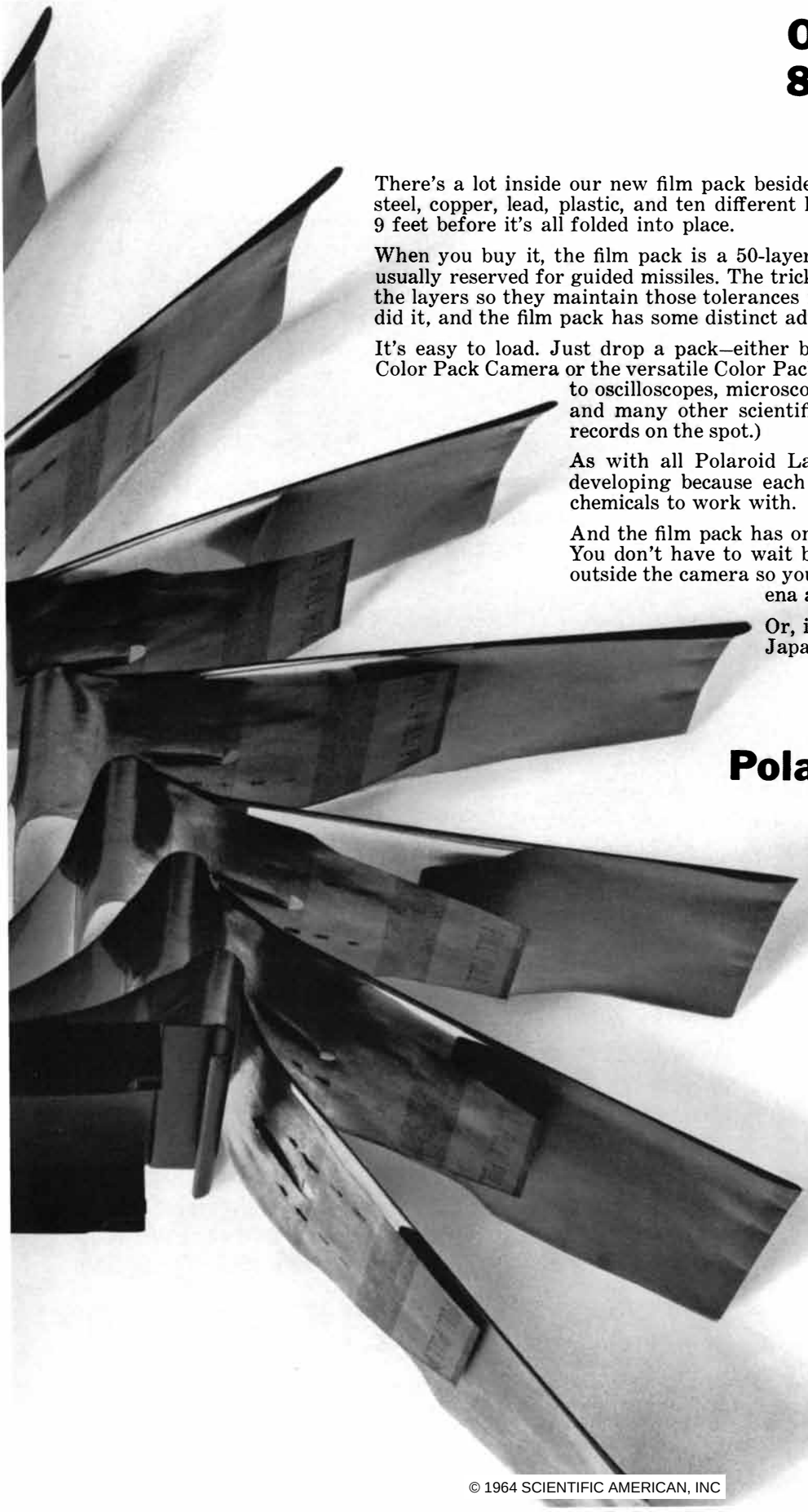

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ingenious formulas for finding pairs of equiareal *primitive* Pythagorean triangles. So far, however, only one example has been found of *three* equiareal PP triangles: 1,380, 19,019, 19,069; 3,059, 8,580, 9,109; 4,485, 5,852, 7,373. Their common area is 13,123,110. (This triplet was discovered in 1945 by Charles L. Shedd of Arlington, Mass.) Is there another triplet? Are there *four* equiareal PP triangles? No one knows.

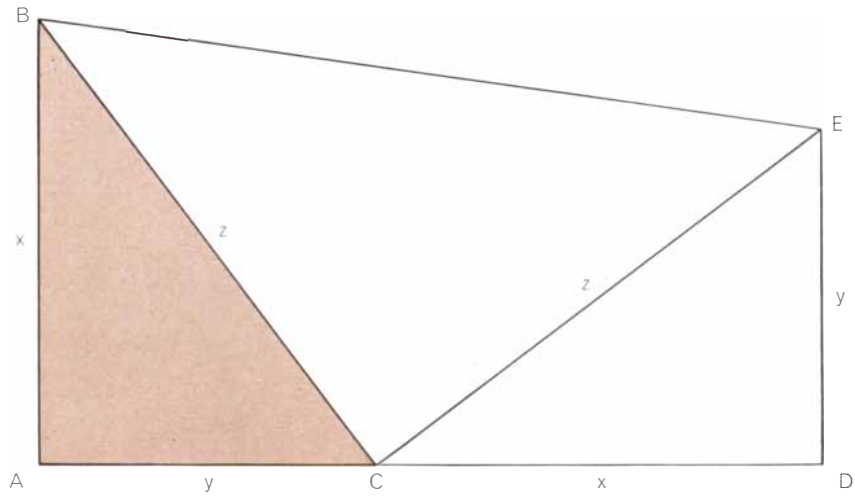
The reader had better leave these difficult questions to the experts. Here are four easy, although in some ways tricky, Pythagorean triangle problems, all to be answered in this department next month.

1. Which has the larger area, a triangle with sides 5, 5, 6 or one with sides 5, 5, 8?

2. A 30, 40, 50 Pythagorean triangle has a perimeter of 120. Find two other Pythagorean triangles with the same perimeter.

3. What is the smallest number of matches needed to form simultaneously, on a plane, two different (noncongruent) Pythagorean triangles? The matches represent units of length and must not be broken or split in any way.

4. For all Pythagorean triangles the diameters of inscribed and circumscribed circles are integral. The diameter of the inscribed circle is obtained by adding the legs and then subtracting the hypotenuse (e.g., the diameter of the circle inscribed in the 3, 4, 5 triangle is 2). Find a formula for the diameter of the circumscribed circle.



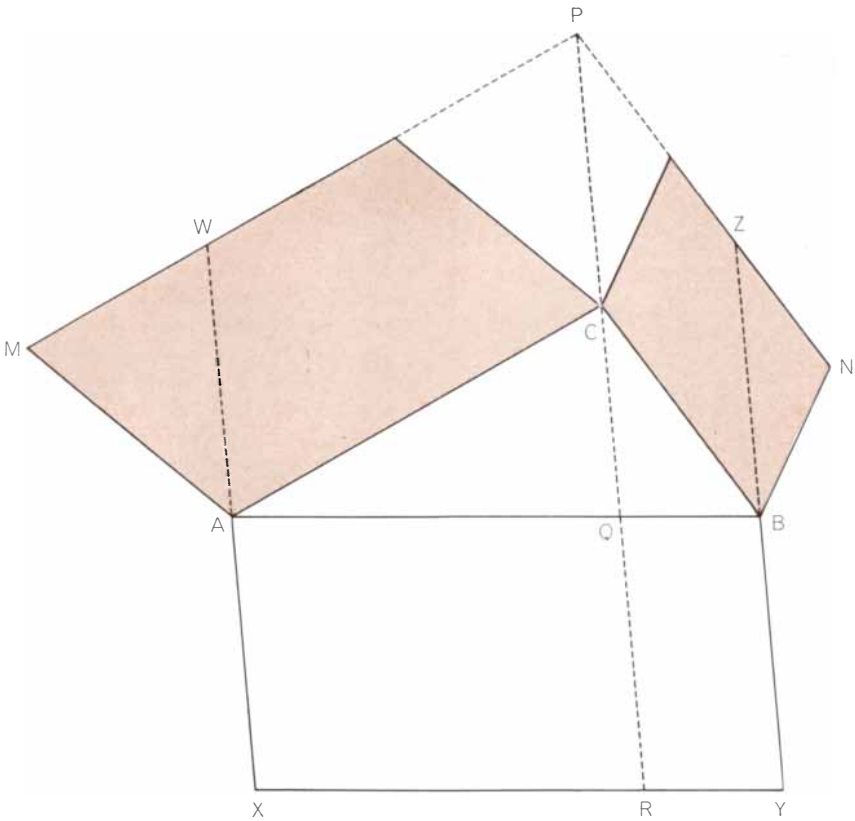

*President Garfield's proof*

The first of last month's rhymed riddles is answered by the word "caress," the second by the word "seven." The six words in the closing quiz are "strengths," "absconder," "typewriter," "gymnoplast," "understudy," "unoriental," "facetiously" and "verisimilitudes."

A summary of letters received about the June problem of the order-3 word square was promised for last month but has been held over until now. The problem was to get a maximum number of different dictionary words reading in both directions along all orthogonals and main diagonals. By August 1 some 50 readers had sent in 12-word squares, most of them superior to the 12-worder published in July. Many readers showed how 12 words could be obtained from a cross of *A*'s in the center of the square, as shown in the square numbered 1 in the top illustration on the next page. Twenty-six readers sent in 13-word squares, in most cases with words that could all be found in *Webster's New Collegiate Dictionary*. The typical square numbered 2 in the illustration was independently discovered by Vaughn Baker, Mrs. Frank H. Driggs, William Knowles and Alfred Vasko.

Vaughn Baker, David Grannis, Horace Levinson, H. P. Luhn, Stephen C. Root, Hugh Rose, Frank Tysver, C. Brooke Worth and George Zinsmeister all produced 14-word squares. Baker's square (*numbered 3 in the illustration*) has only one word—"wey"—that is not usually found in short dictionaries. Frederick Chait, James Garrels, B. W. Le Tourneau, Marvin Weingast and Arnold Zeiske devised 15-worders, but none with more than 12 short dictionary words.

Five readers hit the jackpot with 16 words: Dmitri Borgmann, L. E. Card, Mrs. D. Harold Johnson, Peter Kugel and Wylie Wilson. There is no way to decide which square is best, since all




*Pappus' generalization of the Pythagorean theorem*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M | A | R | P | I | G | S | T | Y | A | T | E |
| A | A | A | E | A | U | U | A | E | R | A | E |
| P | A | T | R | O | T | P | O | W | T | O | R |
| | 1 | | | 2 | | | 3 | | | 4 | |
| E | R | A | A | T | S | S | E | R | E | E | L |
| L | E | E | R | I | A | T | A | O | T | A | O |
| S | A | N | T | A | D | A | R | D | A | R | T |
| | 5 | | | 6 | | | 7 | | | 8 | |

***Solutions to June's word-square puzzle:*** (1) *12-word,* (2) *13-word,* (3) *14-word,* (4–8) *16-word*

exploit obscure words and even the meaning of "word" is hazy. The five squares, numbered 4 through 8, are reproduced in the order in which the alphabetized names appear above. I regret that space does not permit explaining the unusual words in these remarkable squares.

I have received a strange letter from Dr. Matrix, the numerologist. It opens by summarizing the now widely recognized pattern that links the lives of Abraham Lincoln and John Fitzgerald Kennedy. Lincoln was elected president in 1860, Kennedy in 1960. Both were deeply involved in civil rights for Negroes. Both were assassinated on a Friday and in the presence of their wives. Kennedy, when he met his death, was riding in a Lincoln convertible. Both presidents had successors named Johnson who were southern Democrats and former senators. Andrew Johnson was born in 1808, Lyndon Johnson in 1908. John Wilkes Booth was born in 1839, Lee Harvey Oswald in 1939. Both assassins were Southerners holding extremist views and both were killed before they could be tried. The first name of Lincoln's private secretary was John; the last name of Kennedy's private secretary was Lincoln. Booth shot Lincoln in a theater and fled to a warehouse. Oswald shot from a warehouse and fled to a theater. "Lincoln" and "Kennedy" each have seven letters, "Andrew Johnson" and "Lyndon Johnson" each have 13 letters, "John Wilkes Booth" and "Lee Harvey Oswald" each have 15 letters.

What bearing does all this have, Dr. Matrix asks, on the coming election? The next president to be elected after Lincoln was General Grant, a Republican. Goldwater's name also begins with "G" and he is a major general in the Air Force. On the other hand, both "Ulysses Simpson Grant" and "Lyndon Baines Johnson" contain 19 letters, as against 20 in "Barry Morris Goldwater."

After a careful analysis of all the numerological aspects of this remarkable pattern Dr. Matrix has constructed a number—13,212—that he says conceals an absolutely infallible prediction of the name of the next president of the United States. So certain is he of this that he promises to send $100 to every *Scientific American* subscriber if his prediction fails. I have no notion of how the number is to be interpreted, but Dr. Matrix, fearful of influencing the election by disclosing his prediction before November 3, promises to send a full explanation in time for publication in the December issue.


*A 1955 Pythagorean postage stamp*

# THE AMATEUR SCIENTIST

## *Experiments in phototaxis: the response of organisms to changes in illumination*

Conducted by C. L. Stong

Why does a moth fly into the flame of a candle, a cricket scurry for dark cover when exposed to light by the overturning of a rock? Such behavior, known as phototaxis, is observed in many organisms, plants as well as animals. Although a century of investigation has failed to explain the complex mechanism of phototaxis, the work has produced a number of interesting experimental techniques useful in the more general study of how living things react to their environment. Techniques of this kind have been particularly useful in the study of the single-celled organisms that exhibit marked response to changes in illumination [see "Purple Bacteria," by Roderick K. Clayton and Max Delbrück; SCIENTIFIC AMERICAN, November, 1951]. During the past year Werner C. Baum, associate professor of biology at the State University of New York at Albany, developed a series of experiments for investigating phototaxis; amateurs can easily adapt them for demonstrating how variations in age, nutrition, temperature and light intensity may alter the response of single-celled organisms to light of various colors.

"Light," Baum writes, "is an immediate environmental factor in the life of most organisms. In the case of plants one thinks chiefly of photosynthesis, but the less overt processes of phototropism (plants turning toward light) and photoperiodism (the response of plants and animals to variations in the relative duration of day and night) are also controlled by light. The common denominator of these varied effects of light is the absorption of light energy in one or more photochemical, temperature-independent reactions and the conversion thereby of light energy into the energy of chemical bonds.

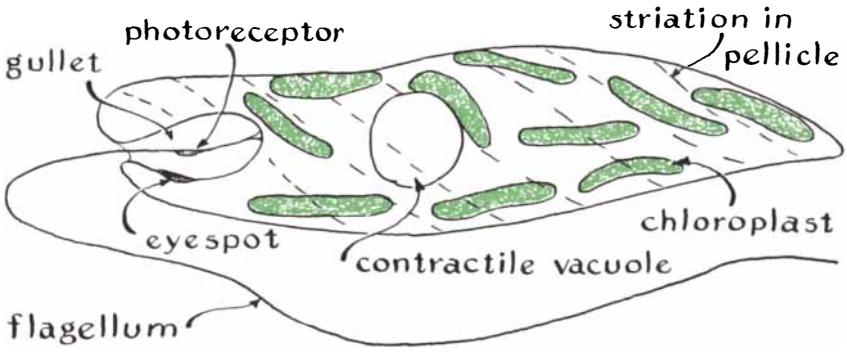
"In the case of phototaxis, the entire organism moves in response to light. Positive phototaxis is exhibited by the flight of insects toward a light source at night and by such behavior patterns as the vertical layering of zooplankton in surface waters during the day. Negative phototaxis is exhibited by darkling beetles and their larvae burrowing under the oatmeal on which they are being cultured and by the myriad of arthropods living under a log or rock.

"My interest in phototaxis was stimulated by the microscopic, single-celled organism called *Euglena,* which propels itself through water with a whiplike flagellum. *Euglena* has chloroplasts and can carry on photosynthesis, so that it qualifies in this respect as a plant. It also is capable of growing on appropriate media in the dark, so that it qualifies in this respect as an animal. Its high degree of motility, anterior gullet, contractile vacuoles, and its external, probably noncellulosic pellicle, or exoskeleton, are 'rule of thumb' animal characteristics [*see illustration on this page*].

"It is likely that generations of biology teachers have plagued or stimulated their students by asking them if *Euglena* is a plant or an animal in the hope that they will perceive from this loaded question the arbitrary nature of biological classification at certain levels and the continuity of morphological and physiological features in various organisms. The characteristics of *Euglena* combine to make it not only an interesting and instructive organism but also an excellent experimental subject.

"One of the more conspicuous features of most species of *Euglena* as observed under the microscope is an orange-red body called the stigma, or eyespot. In the electron microscope it appears as a loose aggregation of about 50 granules. The color of the eyespot is due to one or more carotene derivatives, the exact identities of which are still in doubt. As a group these pigments are involved in a number of photochemical processes in both plants and animals. Evidence suggests that the eyespot is closely related to phototactic responses in *Euglena* as well as in other organisms, although phototactic responses occur in organisms without eyespots.

"In addition to the eyespot a dense nodule near the base of the flagellum on the side facing the eyespot is variously designated as the photoreceptor and the paraflagellar body. Some investigators consider it of major importance in the mechanism of the phototactic response. According to one concept, positive phototaxis is related to a periodic darkening of the photoreceptor by the eyespot as the *Euglena* moves forward in its spiral path. This active orientation and swimming of *Euglena* in relation to the light source is designated as topophototaxis. It is distinguished from the phobophototaxis of certain bacteria: a spontaneous return to a region of greater light intensity whenever the light intensity else-



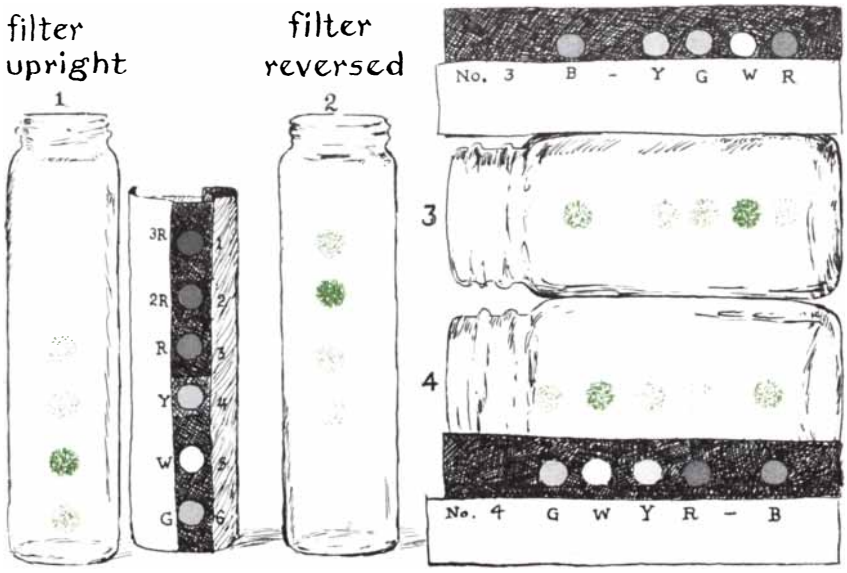

*Structure of the organism* **Euglena**

where diminishes. Thus the organism is 'trapped' in the light spot. The phototaxis of some organisms may involve both mechanisms.

"Although experiments on phototaxis using *Euglena* predate the work of the German biologist T. W. Englemann, it was he who in the 1880's carried out classical experiments on both photosynthesis and phototaxis. His experiments have served subsequent investigators as models of ingenuity and experimental design. Englemann worked with a purple sulfur bacterium, with *Paramecium bursaria* and with *Euglena* as well as with other organisms. He correlated the phototaxis of *Euglena* with the eyespot. In the purple sulfur bacteria he demonstrated both phototaxis and a correlation of phototaxis with photosynthesis in the near-infrared portion of the spectrum. He made an inference, subsequently confirmed, that in photosynthetic bacteria light of a color that most strongly attracts the organism also promotes photosynthesis most effectively. The energy involved in both processes is absorbed by the same pigment system.

"Investigators since Englemann have concentrated on pinpointing the absorption and action spectra and on elucidating the mechanism of the phototactic response, particularly the functions of the eyespot and the photoreceptor in organisms that have those parts. The work also includes studies of phototaxis in organisms that lack eyespots, such as the purple sulfur bacteria, desmids and blue-green algae, and of other organisms that possess eyespots, such as *Chlamydomonas* and *Volvox*. Comparative studies of phototaxis have been made on strains of *Euglena* with chloroplasts, eyespots and photoreceptors; on strains without chloroplasts but with eyespots and receptors, and on strains with chloroplasts and photoreceptors but without eyespots. Chlorophyll-free *Euglena* can be prepared by the bleaching action of certain chemicals such as streptomycin. Strains without eyespots have been obtained by subjecting specimens to ultraviolet radiation.

"Phototaxis in *Euglena* is frequently illustrated by exposing a culture in a transparent container to a beam of light. The active organisms promptly move to the side of the container nearest the light source, where, even though individually microscopic in size, they congregate in such numbers as to be readily apparent to the naked eye. It occurred to me that the effect might be emphasized by completely darkening the culture except for a small spot on the side wall of the container. I covered a culture contained in a 100-milliliter glass jar with a mask made of black paper. A single 1/4-inch opening was punched in the paper mask. When the culture was exposed to light, a dense aggregation of *Euglena* collected near the opening in less than an hour.



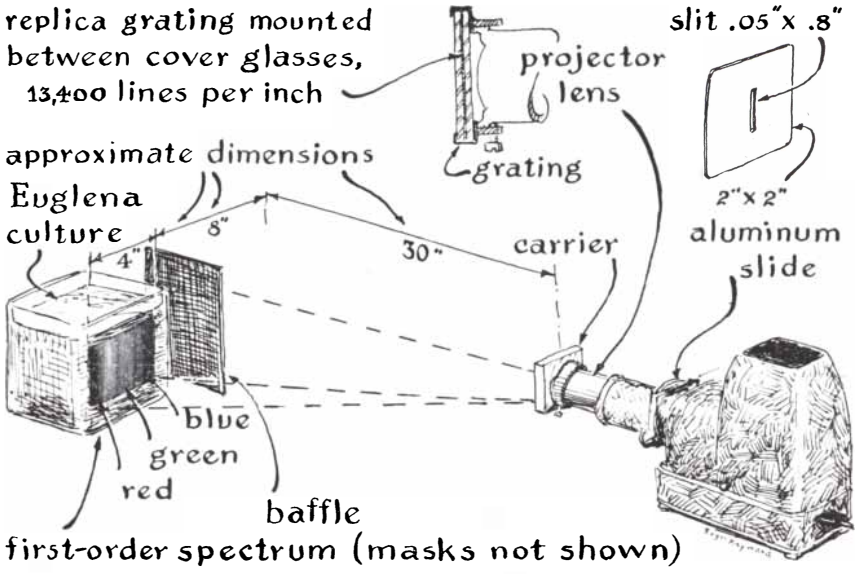

*Effect of various color filters*

"To demonstrate the influence of color I next made a black paper sleeve with windows covered by transparent plastic of various colors. A series of six 1/4-inch holes 3/8 inch apart was punched in a piece of black construction paper with an ordinary paper punch. A small strip of clear or colored cellophane was placed over each hole and secured with cellophane tape [*see illustration above*]. Dennison-packaged Du Pont cellophanes, available in different colors, were used as crude filters.

"The assembled device was carefully fitted to a glass vial so that the interior was completely darkened with the exception of the colored windows. The vials were about 3½ inches high and about an inch in outside diameter; both round and rectangular types were used. The fitted paper sleeve was assembled with masking tape so that it could be slid from the vial without agitating the culture.

"A *Euglena* culture was placed in a vial, the vial was stoppered and the window side of the fitted sleeve was exposed to a beam of white light. Almost


*Evolution of an experiment with color filters*




*Apparatus for splitting white light into the spectrum*

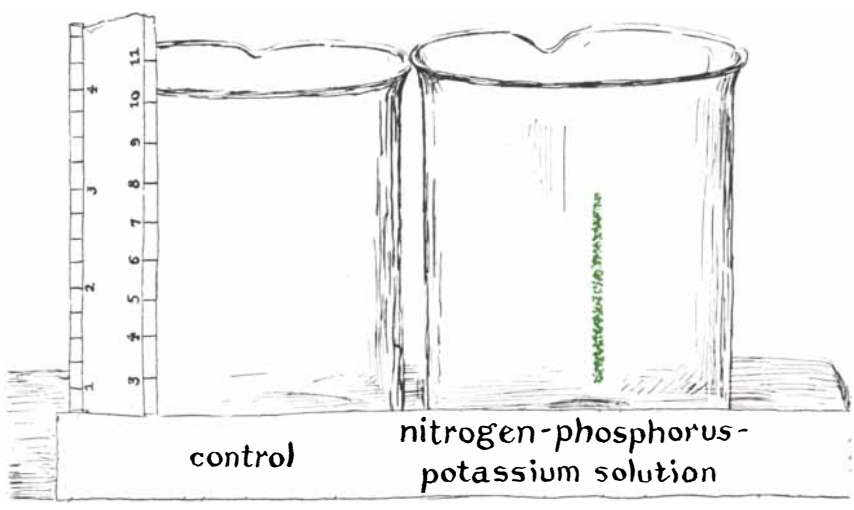
any light source was found to be satisfactory. A fluorescent lamp is weak in red wavelengths. When one uses a tungsten lamp, one should take care to assure uniform distribution over the exposed side of the culture vessel, and the lamp should not be so close that it heats the vial. Light intensity can be controlled in part, and the effect of intensity differences can be studied, by placing cultures at various distances from the light source.

"The approximate intensity of the light passing through the color filters at the distances involved (and presumably reaching the organisms in the vial) was measured by a light meter. Meters of the type used for determining photographic exposures can be used. The clear filter transmitted the most intense beam, followed by blue, then yellow, green and red in order of decreasing intensity. The approximate corresponding range of wavelengths was determined by measuring sample strips of the colored plastic in a colorimeter that indicated the percentage of light transmitted. The light turned out to be far from monochromatic. For example, the blue plastic transmitted blue light as follows: at a colorimeter setting of 400 to 450 millimicrons (blue), 90 percent; at 550 millimicrons (green), 60 percent; at 650 millimicrons (red), 23 percent. For a given range of wavelengths the intensity was varied by using two or more thicknesses of the filtering material. Complete data on the light-transmission characteristics of the plastic material are usually available from the manufacturer.

"Active *Euglena* cultures moved to the colored windows in less than 15 minutes. White light produced the quickest response, followed by blue, green, yellow and red. The number of organisms that assembled at each window was also greatest in the case of white light and declined in the same sequence: blue after white, then green, yellow and red. The sequence was the same whether the culture was lighted for only a few hours or overnight. The maximum phototactic response in blue light coincides with the maximum absorption of blue light by the eyespot. If aggregation of the organisms is allowed to continue for periods of more than 30 minutes, the *Euglena* adhere to the walls of the glass vials even when the culture is mildly agitated. The cultures can then be carefully poured off and the vials inverted on a paper towel for drying. After drying, the *Euglena* aggregates can be fixed to the glass by placing the vial next to a low heat source for a few minutes.

"A more versatile color filter was next constructed in which different-colored plastic strips 5/8 inch wide were placed across rectangular slots, measuring about two inches by 1/4 inch, cut in a black paper cylinder. The strips were arranged horizontally and overlapped about 1/16 inch. They were held in place by strips of gummed paper placed along the overlapped edges. Still a third variation of the filter assembly was prepared by securing narrow strips of colored plastic across a wide slot (about 1¼ inches) cut in a three-by-five-inch card. This proved to be a very flexible device, easy to place over slots in opaque sleeves that fit a variety of containers in assorted shapes and sizes.

"The results of experiments made with the color filters were so encouraging that I decided to subject cultures to an actual spectrum in the hope of observing the sharpest possible differentiation of phototactic response with respect to the wavelength of light. A simple apparatus for dispersing the light was improvised from materials that were at hand. The rays of a 60-watt incandescent lamp were refracted into a beam of parallel rays by means of the lens from a reading glass and were dispersed into the spectral colors by a glass prism that measured 1½ inches by two inches. The colors were then projected onto a culture of *Euglena*. A pronounced differential response was immediately apparent. Maximum aggregation occurred in the red area of the culture! This was contrary both to the results previously observed and to the literature. The puzzle was resolved by measuring intensity across the spectrum:




*Effect of adding a solution of minerals*

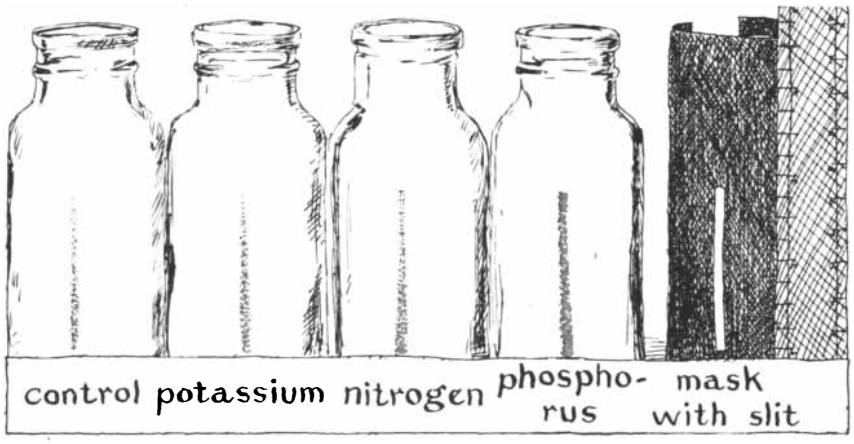
the light meter indicated that the red portion was almost 20 times more intense than the blue. The difference in energy was therefore masking the effects of the difference in wavelength."

(If the amateur does not own a prism, an alternate source of intense spectral light can be improvised by equipping an ordinary 35-millimeter projector with a vertical slit in the position normally occupied by the slide and placing a replica diffraction grating in front of the projection lens. This scheme is suggested by Roger Hayward, who illustrates this department. Transmission gratings of adequate quality for this application can be obtained for $1.50, in a sheet that measures eight by 11 inches, from the Edmund Scientific Co. in Barrington, N.J. Details of the arrangement are depicted in the top illustration on the opposite page.)

"On one occasion, when a very dense, older culture of *Euglena* was exposed to light overnight, I was surprised to find no phototactic response. Although apparently all experimental conditions were in order, the organisms failed to aggregate and to adhere to the side of the vessel. This and related evidence suggested that not all cultures are phototactically equivalent. Therefore care should be taken in the design of experiments to equate only the results of cultures that are comparable in terms of age, nutrition and similar factors.

"Since there is some indication that the inorganic environment may influence phototaxis (and other processes as well) I decided to investigate whether or not this might be a factor in the lack of response of the inactive cultures. The inactive organisms were older, denser cultures in which the pea extract I used as a nutrient in the medium had not been replenished for several weeks. In lieu of waiting for a culture to become nutritionally depleted one could separate the organisms from the culture solution by aggregating active *Euglena* on the sides of a vessel and either pouring off the balance of the culture, centrifuging or filtering. The aggregated organisms could then be resuspended in tap water or distilled water.

"To investigate the effect of mineral nutrition I dissolved a commercial N-P-K (nitrogen-phosphorus-potassium) plant-fertilizer tablet in water and added the equivalent of half a tablet to a 400-milliliter suspension of phototactically inactive *Euglena*. I kept another suspension without fertilizer as a control. Essentially no phototaxis and aggregation were observed in the control, but the experimental culture to




*Results of adding minerals individually*

which the plant tablet had been added displayed marked activity [*see bottom illustration on page 130*]. This suggests that mineral nutrients may be a decided factor in phototaxis.

"In another experiment made to disclose the effect of mineral salts on inactive organisms, nitrogen, phosphorus and potassium were added to separate phototactically inactive cultures in amounts equivalent to their concentration in the plant-fertilizer tablet. To each 100 milliliters of cultures of inactive *Euglena* I added 15 milligrams of phosphoric acid, 16 milligrams of potassium chloride and 190 milligrams of ammonium sulfate. Light intensity was maintained at 400 footcandles. The light source was placed 20 centimeters from the cultures. The light exposure was five hours. The salts most effective in promoting phototaxis and aggregation were, in descending order, phosphorus, nitrogen and potassium. All produced more aggregation and phototaxis than appeared in the control. These results indicate not only the general effect of mineral nutrients on phototactic response but also the differential effects of the several ions, particularly the pronounced influence of phosphorus and nitrogen.

"Sets of inorganic 'sufficient-and-deficient' plant-growth salts are available from biological supply houses. The results of experiments made with them not only are readily apparent to the eye but also are automatically plotted by the differential adhesion of the organisms to the glass. Permanent records of the responses can be made by simply photographing the aggregated organisms. The same general procedure can be used for investigating the effect on phototaxis of light intensity, *p*H, drugs, vitamins, hormones and age of cultures.

"Active *Euglena* organisms as well as many other cultures are stocked by the larger biological supply houses. Pure cultures of both green and colorless species of *Euglena* for research uses are available from the Culture Collection of Algae at Indiana University. Algae and other organisms can also be collected in the field. The specimens are placed in an aquarium, concentrated phototactically by a light source placed at one end of the aquarium in an otherwise darkened room and pipetted into a simple culture medium. Alternatively, the organisms can be placed in a volumetric flask that is darkened except at the neck; after they have aggregated they can be pipetted out of the neck.

"Two nutrient media are widely used for culturing *Euglena*. The split-pea medium is made up of the fluid obtained by boiling 40 split-pea halves in one liter of tap or pond water for a few minutes and then discarding the solid residue. The second medium, known as the soil-water type, is also highly recommended for *Euglena* as well as for a wide variety of other algae. It is prepared by adding successively to a test tube a pinch of calcium sulfate, a half-inch of good garden soil and a quarter of a dried split pea. About 75 milliliters of water (tap, pond or distilled) is then added along the side wall of the test tube. After the test tube has been loosely plugged with cotton it is steamed (do *not* autoclave) for one hour on each of two successive days. After the resulting fluid has cooled and cleared by settling it can be inoculated with the desired organisms.

"I have used split-pea medium with consistently satisfactory results. One may observe a temporary rapid increase in bacteria after adding split-pea medium to a culture. The bacteria will diminish over a period of several days as the concentration of the *Euglena* increases until they are no longer apparent.

"The experiments need not be confined to *Euglena*. Although most species of *Paramecium* will be found to be indifferent to moderate light intensities, *P. bursaria*, which plays host to enough green algae to give it a green and plant-cell-like appearance, is positively phototactic. In these organisms phototaxis has been found to be a response related to the oxygen produced by the symbiotic algae in photosynthesis. It is sometimes referred to as secondary phototaxis arising from chemotaxis or aerotaxis. I once observed the response by placing a culture of *P. bursaria* in a miniature beaker that was completely darkened except for a single 1/4-inch hole punched in the black paper on the bottom. The culture was placed on the stage of a stereoscopic binocular microscope equipped with a transilluminating substage. The hole was illuminated overnight from below, the spot of light being centered in the field of view. By morning the spot was covered with *P. bursaria*.

"In a similar experiment made with five green *Hydra* only three organisms were found in the light spot after an overnight exposure. Incidentally, the prior condition of organisms tends to influence their response to a given set of conditions. In my experience more uniform patterns are observed when the organisms are kept in darkness for a 24-hour period before their use in an experiment.

"Many refinements of the above techniques can be developed for investigating the phototactic responses of an entire range of smaller organisms. Given a choice of various wavelengths, where would *P. bursaria* and *Hydra viridissima* preferentially aggregate? Flatworms are considered negatively phototactic. If given no opportunity to remain in the dark, in what wavelength, if any, would they preferentially remain? Many smaller crustaceans exhibit phototaxis; brine shrimp, for example, are readily cultured in the laboratory. What effect, if any, would a competing population of other organisms have on their phototactic responses?

"The fundamental question of just why and how the energy of light triggers and then guides the swimming motion of these organisms still awaits explanation. Doubtless the full answer will come when data from experiments such as these are correlated with comparable information derived from the disciplines of cellular physiology, biochemistry, biophysics and electron microscopy."

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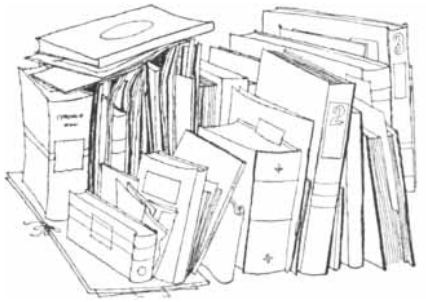

# BOOKS

## *Genetics and human affairs*

by A. E. Mirsky

ESSAYS OF A HUMANIST, by Sir Julian Huxley. Harper & Row, Publishers ($4.95).

Geneticists, more than other biologists, are inclined to air their views about the nature of man and the proper ordering of society. Over a period of 100 years it has become evident that these views are due to the social background of the individual geneticist as well as to what is known of genetics. In his recent book Sir Julian Huxley gives us his views concerning the implications of genetics, and he is careful to explain that he does so as an "evolutionary humanist."

The reader soon becomes aware of Huxley's wide interests. Charles Darwin is one of his heroes, but he also refers to the arguments about angels in Thomas Aquinas' *Summa Theologica*. He is sensitive to Beethoven's last quartets, but he is also aware of Marilyn Monroe and Sophia Loren. For him not only Giotto and Michelangelo but also Paul Klee and Henry Moore are creative artists.

"The central belief of Evolutionary Humanism," Huxley tells us, "is that existence can be improved, that vast untapped possibilities can be increasingly realized, that greater fulfillment can replace frustration. This belief is now firmly grounded in knowledge: it could become in turn the firm ground for action." In *Essays of a Humanist*, as in his other books, Huxley indicates what kind of knowledge is most significant for policy and action in practical affairs.

Although Huxley is anything but a narrow specialist, he is primarily a biologist. He feels strongly that "biology is the necessary basis for understanding ourselves and nature and our place in nature," and that Darwinism is the necessary background for understanding biology. Evolutionary biology is basic for evolutionary humanism.

An understanding of "the genetic basis of our life" is of the first importance for Huxley. We find, indeed, that much of evolutionary humanism boils down to eugenics. The following passage will give the tone of Huxley's eugenics:

"In the case of the so-called social problem group, somewhat different methods will be needed. By social problem group I mean the people, all too familiar to social workers in large cities, who seem to have ceased to care, and just carry on the business of bare existence in the midst of extreme poverty and squalor. All too frequently they have to be supported out of public funds, and become a burden on the community. Unfortunately they are not deterred by the conditions of existence from carrying on with the business of reproduction: and their mean family size is very high, much higher than the average for the whole country.

"Intelligence and other tests have revealed that they have a very low average I.Q.; and the indications are that they are genetically subnormal in many other qualities, such as initiative, pertinacity, general exploratory urge and interest, energy, emotional intensity, and willpower. In the main, their misery and improvidence is not their fault but their misfortune: our social system provides the soil on which they can grow and multiply, but with no prospects save poverty and squalor.

"Here again, voluntary sterilization could be useful. But our best hope, I think, must lie in the perfection of new, simple and acceptable methods of birth control, whether by an oral contraceptive or perhaps preferably by immunological methods involving injections. Compulsory or semicompulsory vaccination, inoculation and isolation are used in respect of many public health risks: I see no reason why similar measures should not be used in respect of this grave problem, grave both for society and for the unfortunate people whose increase has been actually encouraged by our social system."

It is startling to find all this in a book by a "humanist." The very least that can be said about Huxley's statement is that almost nothing is known about the genetics of "initiative, pertinacity, general exploratory urge and interest, energy, emotional intensity, and willpower" and about the relative importance of heredity and of environmental conditions in the origin of these human qualities. This problem was rationally and humanely considered in "The Geneticists' Manifesto" put forward at the Seventh International Congress of Genetics, held in Edinburgh in 1939. The manifesto, concerned with the question of "how could the world's population be improved most effectively genetically," began by saying: "In the first place there can be no valid basis for estimating and comparing the intrinsic worth of different individuals without economic and social conditions which provide approximately equal opportunities for all members of society instead of stratifying them from birth into classes with widely different privileges." This statement is as sound in 1964 as it was in 1939. Ironically one of the signers of the manifesto was Huxley.

In the past eugenics has been so closely associated with class and race prejudice that for many biologists and social scientists it has been a subject of ill repute. Today its main proponents include Huxley and some other evolutionary humanists. The eugenics they promote differs in some ways from the eugenics of the period before World War II. Francis Galton, who coined the term "eugenics," was the most significant figure in the older eugenics and is much admired by Huxley. What is the difference between what Galton preached at the end of the 19th century and what Huxley preaches today? ("Preach," it should be noted, is the right word; Huxley, H. J. Muller and other evolutionary humanists feel, as Galton felt, that they have an urgent message that is essential for the preservation and future well-being of mankind.)

Galton invoked genetic constitution to explain a wide variety of social phe-

nomena. "I began," he said in the preface to his *Hereditary Genius,* "by thinking over the dispositions and achievements of my contemporaries at school, at college, and in after life, and was surprised to find how frequently ability seemed to go by descent." One should note that Galton was the son of a wealthy banker and had many relatives in the upper middle class at a time when this class was quite self-assured in its success. Galton's inquiry into the origins of judges in Britain has this conclusion: "Out of the 286 Judges, more than *one in every nine* of them have been either father, son, or brother to another judge, and the other high legal relationships have been even more numerous. There cannot, then, remain a doubt but that the peculiar type of ability that is necessary to a judge is often transmitted by descent."

Galton's opinion of the genetic characteristics of the judges and Huxley's opinion of the genetic qualities of "the so-called social problem group" have much in common: critical genetic data are lacking, and it is difficult to avoid the conclusion that class bias is involved.

In comparing different races Galton believed he could assess the genetic virtue of each race. He rated the Negro race, for example, much below the Anglo-Saxon. The basis for Galton's ratings is not very different from that of racists today, in spite of his pseudo-scientific terminology. Beyond this he presented a genetic interpretation of historical events; he simply equated the historical achievement of a people with its genetic quality. It followed, therefore, "that the average ability of the Athenian race is, on the lowest possible estimate, very nearly two grades higher than our own—that is, about as much as our race is above that of the African Negro." Even so, those British judges had an average natural ability three and a half degrees above that of the average Athenian. Coming closer to his own times, Galton believed the aboriginal inhabitants of North America and other lands were swept away "less by the pressure of a stronger race than through the influence of a civilization they were incapable of supporting."

Galton believed that in Britain itself the development of civilization called "for more brains and mental stamina than the average of our race possess." There was, he felt, a desperate need for genetic improvement. Racial quality, the level of civilization and the need for eugenic measures are all closely integrated in Galton's discussion of social problems.

Huxley has tried to dissect racism from Galton's philosophy. Otherwise his viewpoint follows closely along the lines laid down by Galton. The following passage of Huxley's could almost have been taken from *Hereditary Genius:*

"Reflect further on the fact, originally pointed out by Galton, that there is already a shortage of brains capable of dealing with the complexities of modern administration, technology and planning, and that with the inevitable increase of our social and technical complexity, the greater will that shortage become. It is thus clear that for any major advance in national and international efficiency we cannot depend on haphazard tinkering with social or political symptoms or *ad hoc* patching up of the world's political machinery, or even on improving general education, but must rely increasingly on raising the genetic level of man's intellectual and practical abilities. As I shall later point out, artificial insemination by selected donors could bring about such a result in practice."

The sentence beginning "It is thus clear" is an extreme expression of the eugenic outlook. All that *is* clear, however, is that the evidence to justify such a sweeping statement does not exist. This statement and the passage previously quoted about "the so-called social problem group" enable us to evaluate to what extent "the central belief of Evolutionary Humanism . . . is now firmly grounded in knowledge" and how "it would become in turn the firm ground for action." Yes, for action by the radical right. Even Huxley's attempt to eliminate racism from his eugenics is ineffective, because in this country "the so-called social problem group" of our cities is now largely colored.

When Huxley speaks of "ground for action," he reminds us of the political role played by eugenics in the past. Galton was the doctrinal father of the eugenics movement in the U.S., and this movement was influential in restrictive immigration legislation. The center for eugenic influence was the House Committee on Immigration and Naturalization, under its chairman Albert Johnson, a Republican congressman from Washington and originally a small-town newspaper editor. In 1923 this congressman was elected president of the Eugenics Research Association. The immigration law of 1924, which unquestionably discriminates in favor of certain peoples and against others, is still in force.

In a recent lecture on the world population problem (published in *The Human Crisis,* 1963) Huxley refers to immigration into the U.S. He has this to say concerning the migration of Puerto Ricans to New York: "They are causing considerable social difficulties in their new homes—not primarily because of race prejudice, but because groups of people with different habits and different standards are invading already overcrowded parts of the world."

Those familiar with the history of immigration into U.S. cities know that at least as far back as the arrival of the Irish after the potato famine of 1847 "social difficulties" have been encountered by Italians, Jews, Greeks, Armenians, Poles and many other peoples, of whom the Puerto Ricans are only the most recent arrivals. Slums have always been overcrowded. Race prejudice was certainly an important factor in the "social difficulties." A eugenicist should know this, because American eugenicists played a leading role in drafting the immigration law of 1924, which favors the people of northwestern Europe and discriminates against those of southeastern Europe and those with colored skins.

Huxley considers the outlook of evolutionary humanism to be "firmly grounded in knowledge" and that "science can become the ally of religion instead of its rival or its enemy, for it can provide a 'scientific' theology, a scientifically ordered framework of belief, to whatever new religion emerges from the present ideological disorder." And yet he is aware that "various critics insist on the need for far more detailed knowledge of genetics and selection before we can frame a satisfactory eugenic policy or even reach an understanding of evolution. I can only say how grateful I am that neither Galton nor Darwin shared these views, and state my own firm belief that they are not valid."

The critics to whom Huxley refers are among the leading geneticists. Reference to recent books on human genetics would quickly show that outstanding investigators think much more knowledge (and not simply "detailed knowledge") would be required before policies far more modest than those Huxley advocates could be implemented.

The reason that Huxley is unimpressed by his critics is simply that he himself is so uncritical. His book is studded with examples of his uncritical attitude, some of which have already been mentioned. Let us return to Huxley's discussion of intelligence:

"It is to man's higher level of intelligence that he owes his evolutionary

dominance; and yet how low that level still remains! It is now well established that the human I.Q., when properly assayed, is largely a measure of genetic endowment. Consider the difference in brainpower between the hordes of average men and women with I.Q.'s around 100 and the meagre company of Terman's so-called geniuses with I.Q.'s of 160 or over, and the much rarer true geniuses like Newton and Darwin, Tolstoy and Shakespeare, Goya and Michelangelo, Hammurabi and Confucius. . . ."

There is, in fact, no reason to assume that Tolstoy, Goya or Hammurabi had high I.Q.'s. The notion that the I.Q. is a *general* measure of a person's "intrinsic" intellectual powers is naïve. The I.Q., it has been supposed, gives a fairly reliable prediction of the probable success in school of the person tested. Even this value of the I.Q. has recently been rendered suspect. Liam Hudson of the Psychological Laboratory at the University of Cambridge has found that there is scarcely any relation between scores on the intelligence test taken in the last years at secondary school and the attainment of academic distinction (as shown by winning an open scholarship or exhibition) on reaching Oxford or Cambridge. Whatever the significance of the I.Q. may be, it is now well known that not only "genetic endowment" but also environment affects a person's I.Q. and that it is exceedingly difficult to evaluate the relative importance of these two variables.

As investigation of man's intellectual faculties continues we can anticipate that both genetic and environmental variables will affect every facet of intelligence. Even when the genetic factor has clearly been demonstrated to be a weighty one, it would be ill-considered to say, as Huxley does, that we cannot depend on "tinkering" with environmental conditions but must rely on "raising the genetic level." A suggestive example is provided in the field of infectious disease. There must surely be human genes that affect resistance to the poliomyelitis and yellow fever viruses; in experiments with animals, susceptibility to infection has frequently been demonstrated to have a genetic basis. And yet nobody would propose that, instead of using vaccines for poliomyelitis and yellow fever, we use artificial insemination by selected donors.

We have found the discussion of human genetics by an evolutionary humanist to be impassioned and messianic as well as uncritical and lacking in humane feeling. These have been the characteristics of most eugenicists from

Galton to the present. With respect both to critical insight and to generous social feeling, far superior discussions of eugenics are found in books by geneticists who have a special interest in human genetics. Among such books are those by J. V. Neel and W. J. Schull, Curt Stern, Theodosius Dobzhansky and Charlotte Auerbach.

In these books, recent though most of them are, there is only slight mention of a development that has been taking place in biology for nearly a decade—the bringing about of a fusion of cell biology, biochemistry and genetics—that has given us new insight into interactions of genes and the environment. This influences our conceptions of human nature and has a bearing on the fundamental problems raised by eugenics.

Treatises on genetics, of course, customarily discuss questions of heredity v. environment. Such discussions take two forms: (1) a genetic character such as an eye pigment is considered with reference to its adaptive value in a clearly defined environmental niche; (2) substances formed as the result of gene activity subsequently take part in chemical reactions, and these "peripheral" processes are influenced by environmental factors such as temperature. It has been supposed that each gene, sheltered in the cell nucleus, was ticking away autonomously.

There is now direct evidence that in the cells of higher organisms as much as 80 percent of the genetic material is inactive and that the level of activity of a gene depends on environmental factors. Some environmental effects are peripheral; others penetrate to the genes themselves. It has recently been discovered, for example, that some hormones that produce well-defined changes in organs do so by activating certain genes. Other genes are activated by a change in diet. Since hormonal secretion and dietary regimen are influenced by such conditions as the season and climate and the emotional state of the organism, it can be seen that environmental factors affecting the organism as a whole ultimately reach into the nuclei of particular cells and there activate certain genes.

In the course of development of an organism the differential activation and inactivation of particular genes can now be recognized as the events underlying the appearance of the different cell types that form a higher organism. One of the main lines of investigation in biology today is the identification of the environmental factors that activate genes in the developing organism as well as in the adult.

The work of the past eight years on how the genetic material directs the synthesis of proteins has shown that genic control of the cell is far more complete than even geneticists had supposed. The search now is for the factors that control the controller. These factors are in the broadest sense environmental. The gene-environment problem now confronting investigators is entirely different from the problem mentioned in the textbooks of genetics. As we learn how gene activity is controlled we shall be in a position to guide it deliberately under optimal conditions. It would be absurd to suppose that the conditions for activity of the enormous multitude of different genes in human beings are now the most favorable that can be achieved. We can be confident that the existing gene complements of our fellow men have desirable potentialities that have not yet been recognized.

Understanding of the importance of genetic constitution goes back to the Neolithic period, when man began breeding animals and plants. Ever since, the implications of selective breeding for man himself have been apparent, particularly for groups that considered their own "seed" to be superior. A far deeper understanding of breeding came with Gregor Mendel and the discipline of genetics. Even with the development of genetics, selective breeding (supplemented by the production of random mutations by radiation and other agents) remained the only way to deal with the genetic material. Now that variable gene activity has been recognized and is being studied, procedures for changing the operations of genetic material are becoming available—procedures that do not change the intrinsic constitution of the genes. The way is now being opened for environmentally affecting gene activity and so not incurring the awful risks of a eugenic program, the risk of irreversibly changing the biological character of our species on the basis of inevitably subjective attitudes and insufficient scientific information.

## Short Reviews

CHARLES DARWIN, by Sir Gavin de Beer. Doubleday & Company, Inc. ($4.95). Probably no other voyage in the history of the world has yielded such a rich intellectual harvest as Darwin's five-year expedition on H.M.S. *Beagle*. The things he saw, the journals he kept, the ideas planted in his mind were for the next 45 years to result in magnificent contributions to both biology and geology. A less happy consequence was the ill health that dogged him for the rest of his life. (It is said that he never spent a day of his last 40 years feeling really well.) On the night of March 26, 1835, in the Andes town of Luxan, he was bitten by a *benchuca*, "the great black bug of the Pampas." This bug, now known as *Triatoma infestans*, is the principal carrier of a trypanosome that causes Chagas' disease. In recent years a number of students of tropical medicine have pointed out that Darwin's wretched, debilitating symptoms add up to a classical description of this disease. De Beer's biography is not primarily concerned with Darwin's personal life—there are other biographies that consider the man much more fully—but it presents a succinct, masterly account of his scientific achievements and of the modern status of evolutionary theory. Highly recommended.

FROM DREAM TO DISCOVERY, by Hans Selye. McGraw-Hill Book Company ($6.95). Considering Selye's experience and capabilities as an investigator and the clear way in which he has presented his theory of stress, this is a disappointing book. What is it like to be a scientist? What are the reasons for doing research? What qualifications must a scientist have? What is the researcher's day-to-day routine? How can he "learn to think"? What kind of reading should he do? How should he write about his work? These are the questions the book considers, based on Selye's own personal experience. The end product is tedious, pompous and sententious. It is excessively self-absorbed and self-adulating, filled with painfully amateurish confessions and sentimentalities, preachy and elder-statesmanly. One of the most extraordinary passages favors us with an hour-by-hour description of how Selye spends "a typical day," which sounds like a cross between a bus schedule and an activities program for a summer camp. Selye has succeeded in telling us something of his emotions and motivations, but in holding up this mirror he seems to have forgotten that others are not like him and that copybook maxims are as much help in teaching others how to become a scientist as how to become a saint.

THE HISTORY OF THE BAROMETER, by W. E. Knowles Middleton. The Johns Hopkins Press ($10.95). A comprehensive, scholarly history of the barometer as a scientific instrument from

the time of Evangelista Torricelli onward. It is surprising how many different kinds of barometer were designed in the past 300 years, considering the fact that measurement of the pressure of the atmosphere can be effected only by a limited number of techniques. For all the advances that have been made, the original idea of using a column of mercury is still the most reliable, and barometers other than mercury barometers, however useful and interesting for special purposes, do not measure up to the highest levels of accuracy. Middleton's book is based on an extensive survey of original documents and instruments to be found in collections in western Europe and North America. Well illustrated.

AMERICANS ON EVEREST, by James Ramsey Ullman. J. B. Lippincott Company ($8.95). A full account of the large-scale, carefully organized and richly endowed U.S. expedition to Mount Everest that, under the leadership of Norman G. Dyhrenfurth, succeeded in getting no fewer than three teams of two men each to the top of the mountain. Ullman, who was the official historian, tells the main story, and other members contribute interesting monographs on special aspects of the ascents. The chronicle is gripping in spite of the author's heavy-breathing prose, carried away as he is by everything from patriotic fervor to the complexities of the logistics. One point stands out: that no matter how well-financed an expedition of this kind may be, how elaborate the equipment, the precautions and the planning, it is still a formidable and hair-raisingly dangerous undertaking to clamber up one of the Himalayan peaks, and success depends on the almost superhuman determination of the strange people who enjoy this sort of thing.

THIS VIEW OF LIFE: THE WORLD OF AN EVOLUTIONIST, by George Gaylord Simpson. Harcourt, Brace & World ($5.95). A collection of essays on fundamental problems of science and philosophy by one of the world's foremost biologists. The separate pieces, all of which have, in one form or another, appeared previously, have been revised or modified (some quite drastically) to give unity and coherence to the book as a whole. Where Simpson discusses the origins, growth and meaning of evolution, the state of contemporary knowledge of the subject and its importance not only in biology but also in other spheres of thought, he is brilliant; no

one has equaled him in telling this story. He is less successful, although always very much his own man, in examining questions of philosophy such as determinism, causality, the theory of knowledge and the like. One of Simpson's merits is that he is not overawed by the opinions of the great, and that with formidable intellectual vigor and an unwavering sense of moral commitment he slashes through to his own conclusions. At times, however, these are surprisingly naïve and insensitive for a man who thinks as clearly and feels as deeply as he does. Nevertheless, these qualifications should not deter anyone from reading this first-class book.

SCIENCE: THE GLORIOUS ENTERTAINMENT, by Jacques Barzun. Harper & Row, Publishers ($6). The point of this book—if a reviewer may be permitted a capsule summary—is that science is a fine enough thing in its place but its place is not everywhere. In other words, if we are to get the best out of science, yet not allow it to dominate us or to elbow out other forms of human invention, expression and understanding, we have to make sure that the boundaries of the scientific domain are well defined and its jurisdiction sharply restricted. This is not a strikingly original idea, nor is it helpful in dealing with the questions the prodigious growth of science has flung before us. Barzun is a clever, literate and somewhat overfluent writer who is better at weaving a pleasant spell than at unraveling knots in the complex fabric of our intellectual life.

THIS HIGH MAN: THE LIFE OF ROBERT H. GODDARD, by Milton Lehman. Farrar, Straus & Company ($6.50). A biography of the noted American rocket designer, most of whose fame came to him after he died in 1945. Some of the work Goddard did was quite interesting and, it is said, of major importance in the development of rocketry, but mainly his story is one of heartbreaking disappointments and failures and of an almost unbelievable single-mindedness. This does not make for absorbing reading, particularly when coupled with the fact that Goddard was personally an unexciting man and normally as communicative as an oyster.

NOBEL LECTURES: PHYSICS, 1942–1962. American Elsevier Publishing Company, Inc. ($85). This is the first volume to appear of a three-volume set that will reprint the Nobel Lectures in physics from 1901 to 1962. The volumes will not be sold separately; $85 is the price of all three. Each lecture is preceded by a brief biographical note and is published in the English language; that is, translations have been made where necessary. The names and the topics treated are, it is almost unnecessary to say, something to conjure with, and the format of the volume itself—illustrations, typography and so on—measures up to the quality of the themes. Still, considering the fact that the books are prepared by the Nobel Foundation and that the purpose of the enterprise is to make the lectures available to students, scientists and scholars, not all of whom own oil wells, the price is bizarre.

MATHEMATICS AND SCIENCE: LAST ESSAYS, by Henri Poincaré. Dover Publications, Inc. ($1.25). A new English translation of Poincaré's *Dernières Pensées* that includes such topics as space and time, why space has three dimensions, mathematics and logic, the quantum theory; these articles and lectures were intended to form the fourth volume of Poincaré's writings on the philosophy of science, and although some of the material is dated, all of it is both incisive and delightful. As a writer Poincaré simply never missed. Paperback.

THE KINEMATICS OF MACHINERY: OUTLINE OF A THEORY OF MACHINES, by Franz Reuleaux. Dover Publications, Inc. ($3). This book, first published in German in 1875 and translated into English the following year, is of both historical and expository interest. Reuleaux, for many years professor of kinematics and director of the Royal Industrial Academy in Berlin, had a keen understanding of the motions occurring in mechanisms, of the functions of the fixed and moving links, and of the other mechanical components. He had a feeling for the go of a machine, an understanding sympathy for the cooperation of gears, levers and rods comparable to that of a gifted physician for the working of the human body, and he could impart what he felt to the reader. Despite its Germanic long-windedness, this book is a tour de force, and the sections that discuss the process of innovation—how machines grow and become more and more complex and versatile—have never been surpassed.

DISORDERS OF LANGUAGE, edited by A. V. S. de Reuck and Maeve O'Connor. Little, Brown and Company ($11). In May, 1963, the Ciba Foundation brought together for a three-day symposium on aphasiology, or the disorders of language, 22 specialists: aphasiologists, neurophysiologists, psychologists, linguists, phoneticians, information theorists, communication theorists and a philosopher. They read 14 papers to one another and engaged in much lively discussion, while a faithful tape recorder caught every vocalized flash of insight, wise or injudicious. One concludes that aphasiology is a lively field that does not know its boundaries and is not yet able to agree on a proper classification of the many aphasic phenomena. A recurrent thought in the discussion—that language is used more as a means of self-expression than for effective communication—is well illustrated by the inconsequential character of much of the printed discussion itself.

## Notes

HOW THEY LIVED: 55 B.C.–1485, compiled by W. O. Hassall. Barnes & Noble, Inc. ($6). A collection of passages from contemporary writings about everyday life in England and Wales during the first 15 centuries of our era, touching on such subjects as ships, roads, tools, crops, usury, bathing, gardening, public affairs, schools, sports, pastimes and so on.

THE UNIVERSAL ENCYCLOPEDIA OF MATHEMATICS. Simon and Schuster ($8.95). An English translation of a popular German reference book of mathematics based on the *Rechen Duden* of the Bibliographisches Institut in Mannheim. Adapted to Anglo-American needs, the book provides information, alphabetically arranged, on topics through the college level, and a large collection of formulas and tables.

PHILOSOPHY OF MATHEMATICS: SELECTED READINGS, edited by Paul Benacerraf and Hilary Putnam. Prentice-Hall, Inc. ($8.95). A collection of essays by philosophers and mathematicians on the nature of mathematics, this volume includes reprints of a number of excellent pieces not easily come by.

SUICIDE, by Louis I. Dublin. The Ronald Press Company ($8). A sociological and statistical study of suicide, based on the extensive literature on the subject and Dublin's own professional preoccupation with it over a period of many years.

THE EARTH SCIENCES, edited by Thomas W. Donnelly. The University of Chicago Press ($6). A collection of

papers on problems and progress in current research in geology, geophysics and paleontology.

THE THEORY OF SPACE, TIME AND GRAVITATION, by V. Fock. The Macmillan Company ($15). The second edition of this admirable text, translated into English from the Russian by N. Kemmer, differs from the first by some additions and reformulations.

MANUAL OF CONTRACEPTIVE PRACTICE, by Mary S. Calderone. The Williams & Wilkins Company ($9.95). A clearly written, comprehensive survey dealing with every aspect of contraception, suited to the needs of physicians and public health workers and of the ordinary educated reader.

WHO'S WHO IN INDIAN SCIENCE, edited by H. Kothari. Kothari Publications ($3). This small volume, the first publication of its kind for Indian science, gives biographical sketches of leading scientists, physicians, engineers and other technical men and women.

PHOTOPHYSIOLOGY, edited by Arthur C. Giese. Academic Press ($29). The articles in this two-volume cooperative work deal with the action of nonionizing radiation (ultraviolet, visible and infrared) on living things. Volume I is primarily concerned with the action of light on plants; Volume II, with the effects of light on animals and microorganisms and the mechanisms underlying these effects.

THEORY OF THE MOTION OF THE HEAVENLY BODIES MOVING ABOUT THE SUN IN CONIC SECTIONS, by Karl Friedrich Gauss; translated and with an appendix by Charles Henry Davis. Dover Publications, Inc. ($2.95). A republication of the original 1857 English translation of Gauss's famous *Theoria Motus*. Paperback.

VIRUSES, NUCLEIC ACIDS, AND CANCER. The Williams & Wilkins Company ($16). Concepts, theories and experimental results concerning the function of viruses and nucleic acids in cancer, presented in a collection of papers at a symposium held at the University of Texas in 1963.

THE LAST REDWOODS, by Philip Hyde and François Leydet. Sierra Club ($17.50). A handsomely illustrated book that pleads for the preservation of these magnificent trees and the unique forests in which they grow.

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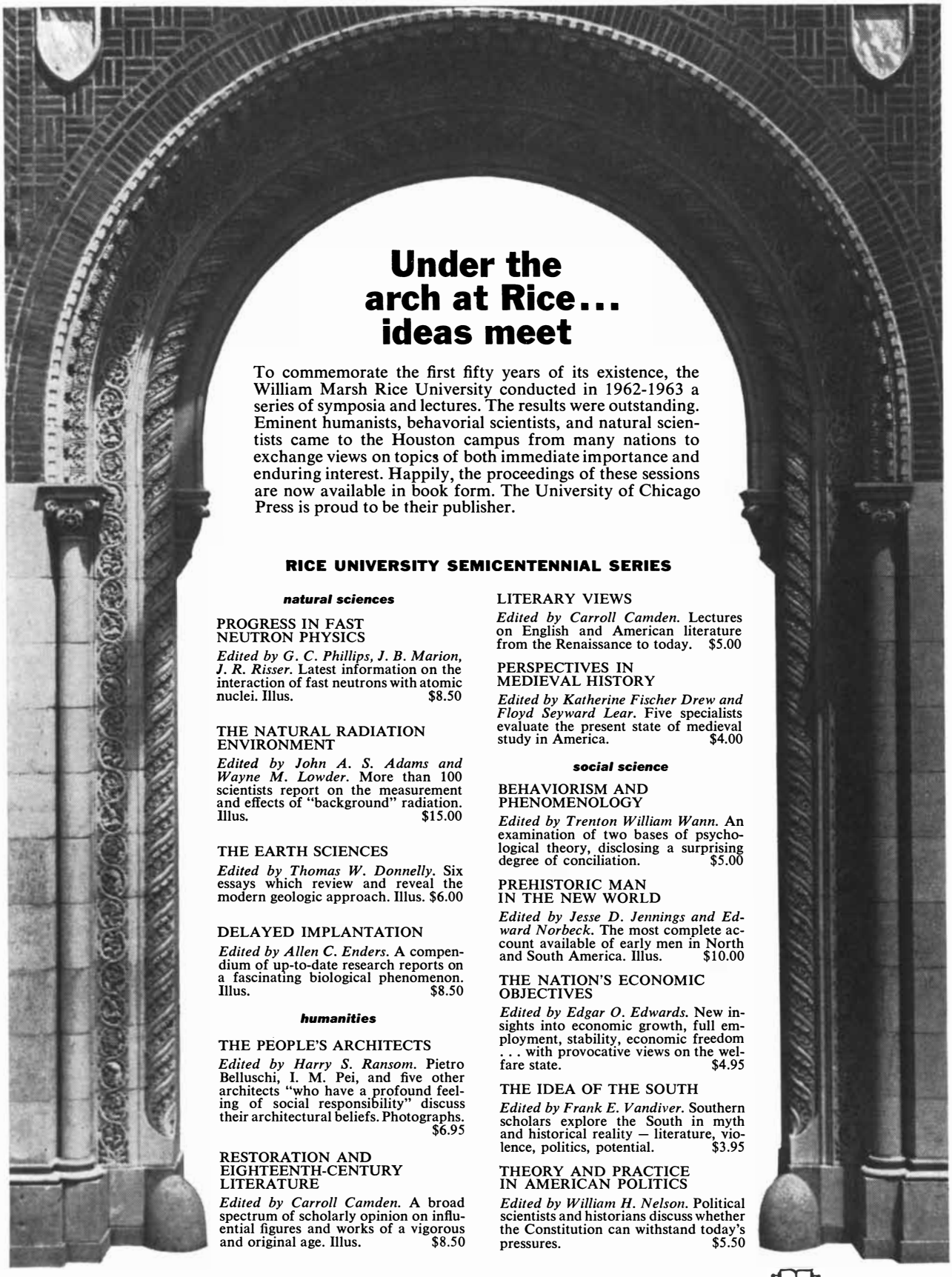

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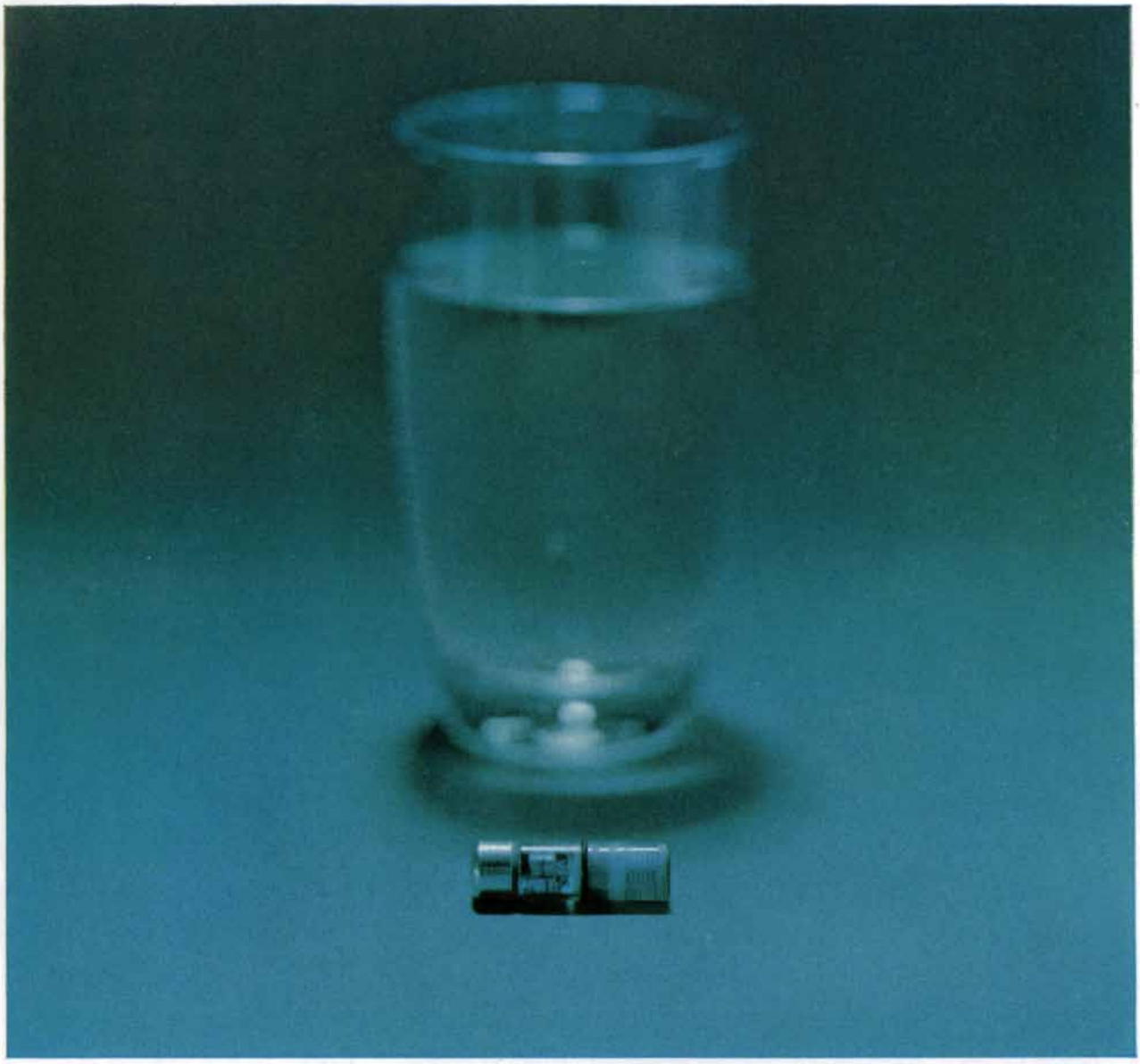

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