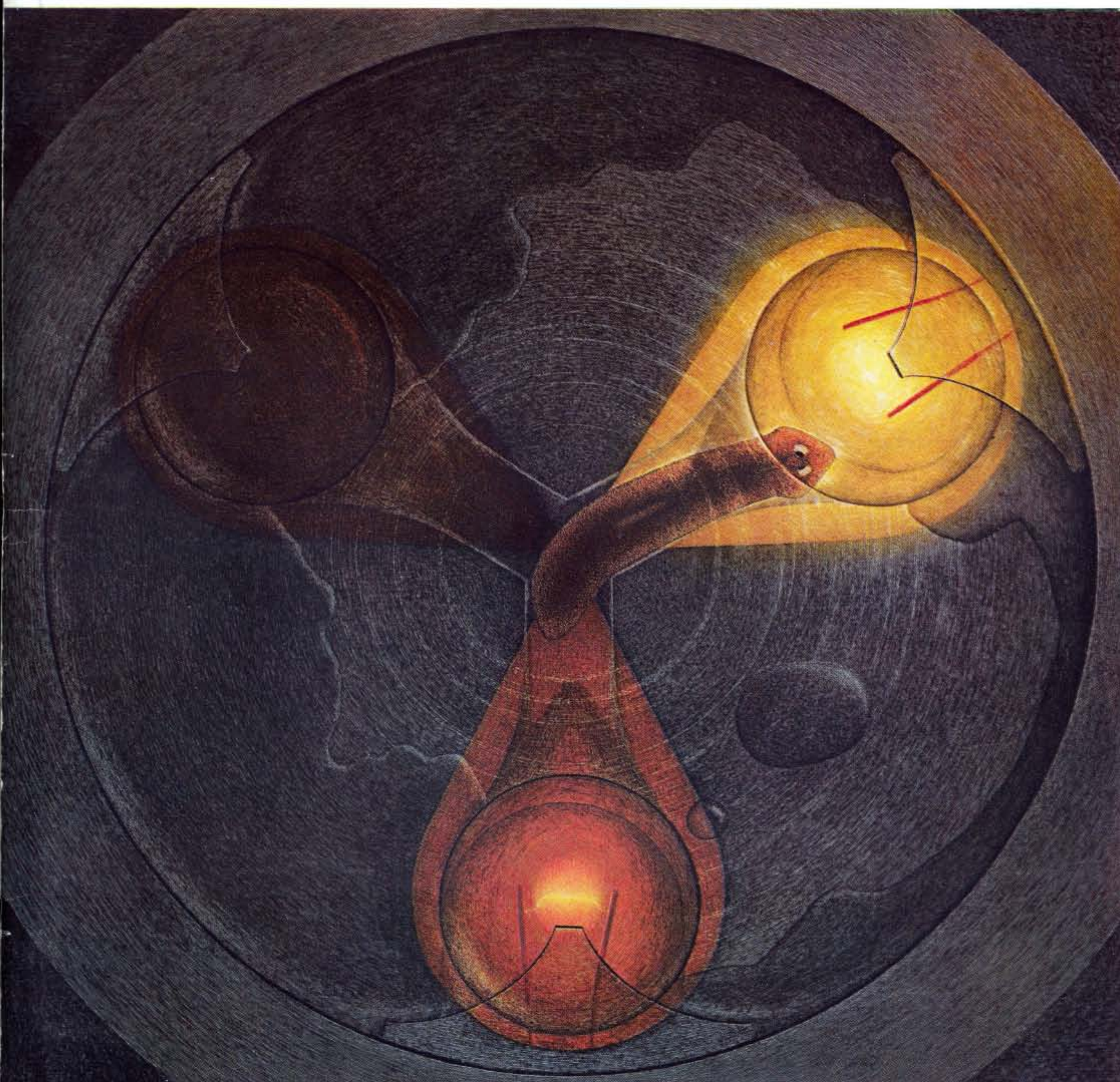
SCIENTIFIC AMERICAN

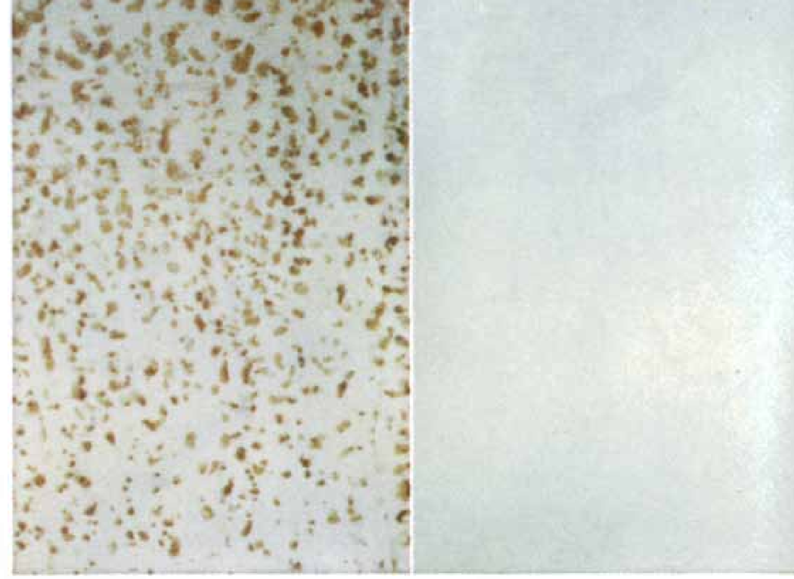


PLANARIAN WORM IN MAZE

FIFTY CENTS

February 1963

Foamed plastisol protects highly finished parts: Our new flame-resistant foamed plastisol is an ideal "wrapper" for plated and machined parts—partly because it is so easy to peel off, mostly because it costs less and protects better than a paper wrap. This vinyl material doesn't develop its economical, cellular structure until heated. It is easily applied by spraying, which means less waste, with more accurate control of its thickness.



How microscopic cracks retard corrosion of plated metal: Plate more than 20 millionths of an inch of ordinary chromium on auto brightwork and it soon develops relatively gross cracks, some extending right to base metal, inviting corrosive action *(left)*.

A new M&T plating process can plate 50 millionths or more, controlling fissures to micro-cracks that reduce galvanic action, retard corrosion of the nickel undercoat and basis metal *(right)*.

Fast cure for bubbles in fine glass: Molten glass that includes M&T Sodium Antimonate is free from objectionable bubbles or "seeds." Sodium antimonate contributes an oxygen pressure, forming large scavenging bubbles that sweep small bubbles from the glass. This "fining" cuts rejects—in T.V. tubes, for example.

An added advantage is that M&T Sodium Antimonate prevents glass from darkening due to ultra-violet light. The same M&T chemical works particularly well with photosensitive glasses.

Uniting imagination in chemicals with know-how in metals... M&T research and technical service engineers can help with problems in chemistry, ceramics, plating, organic coatings, minerals and welding. Write M&T Chemicals Inc., General Offices, Rahway, N.J.

M&T Chemicals Inc.

FORMERLY METAL & THERMIT CORPORATION

FALL IN!

New-type recorder assembles slow or random data, spaces it uniformly on tape for computers

If your digital computer is as finicky as most, it won't listen to a magnetic tape that

t al k s li k e t h is

It will insist on characters uniformly spaced on the tape

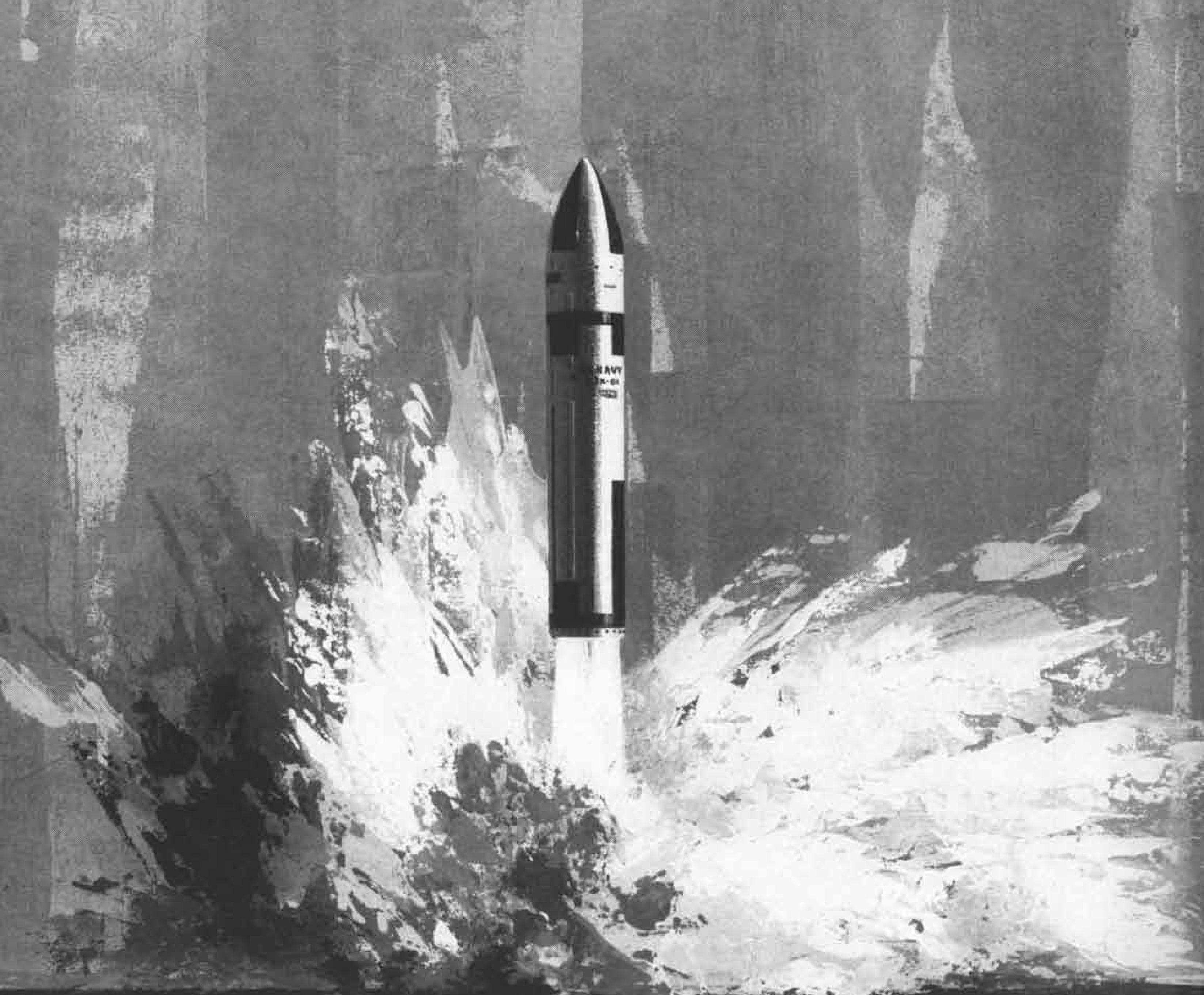
like this

Which means that life can be difficult for people who have data that is otherwise perfectly reputable, but just doesn't happen to occur at the right time intervals to suit the computer.

Now comes a wonderful device that will gladly accept irregular data — such as the output of a teletypewriter or an analog-to-digital converter — and put it on magnetic tape just the way the computer wants it. The secret is incremental tape motion. Our new recorder stands still awaiting each character, records it, then moves the tape a uniform distance to await the next. As a result, whether characters arrive 100 per second or 1 per month, they are recorded in a proper, uniform packing density.

The PI incremental recorder shown here records 200 bits per inch (556 BPI optional), a recording fully compatible with the input requirements of IBM computers. To tell you more, we've put together a brochure fully compatible with the input requirements of discriminating users. Send for bulletin #73; address us at Stanford Industrial Park, Palo Alto 12, California.

PRECISION INSTRUMENT



Established 1845 **SCIENTIFIC AMERICAN** February 1963 Volume 208 Number 2

ARTICLES

DEPARTMENTS

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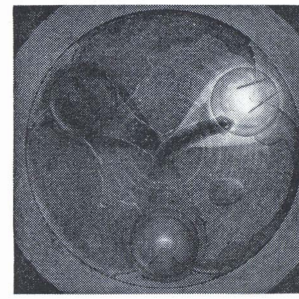

THE COVER

The painting on the cover shows a planarian worm in a laboratory maze (see “Protopsychology,” The maze consists of three wells connected by a Y-shaped tunnel. When the worm has entered the tunnel from any one of the wells, it must make a choice when it reaches the fork. One branch of the fork leads to a dark well, the other to a brightly lighted well. The worm has made the right choice and is about to be rewarded with a supply of water. After a little practice it makes a correct choice most of the time.

THE ILLUSTRATIONS

Cover painting by
John Langley Howard

Page	Source
42	Joan Starwood
43–44	James Egleson
45	Joan Starwood
46–48	Helmut A. Abt
49–52	Dan Todd
53	Mount Wilson and Palomar Observatories (*top*), Yerkes Observatory
54	William Vandivert
56–60	John Langley Howard
62	Teiichi Betchaku
66	Alexander Rich
76	Norman D. Newell
78–79	Thomas Prentiss
80–82	Hatti Sauer
83	National Parks Association (*top*), Hatti Sauer
84–90	Hatti Sauer
96	Tahsin Özgüç
98–99	Thomas Prentiss
100	Tahsin Özgüç
101–102	Thomas Prentiss
104–106	Tahsin Özgüç
109	Walker Bleakney
110	George Rodger
111–118	James Egleson
122	Vernon Ahmadjian
124–125	Bunji Tagawa
126	Vernon Ahmadjian
127	Bunji Tagawa
128–132	Vernon Ahmadjian
135	Lotte Jacobi
136–142	Irving Geis
148–156	Allen Beechel


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When one wheel starts to lose its grip on the road, this remarkable device automatically transfers the lost driving force to the other wheel. This added bite greatly reduces the chance of a dangerous swerve—when passing a truck, for example. And it means you'll *go* in drifting snow, sand or mud that would stop cars with conventional differentials.

A spin-resistant differential engineered by Borg-Warner helps make big luxury automobiles handle like the nimblest sports cars. Surprisingly, it also gives a secure "big car" feel to the lightest compacts.

This new dimension of driving ease and highway safety is just one example of Borg-Warner's contribution to the safety, reliability and pleasure in today's automobiles. Borg-Warner Corporation, 200 S. Michigan Avenue, Chicago 4.

B-W

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where research and engineering work wonders for you

Creative Engineering At Sun Oil Company

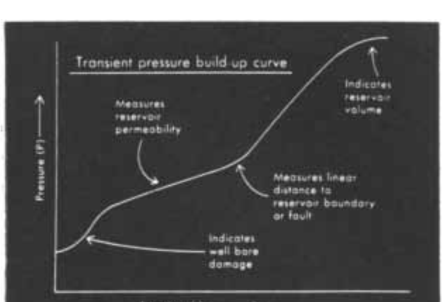
Engineering is a creative activity at Sun Oil Company. Two typical examples of Sun's creative engineering at work are presented here. One involves the development of a sophisticated engineering technique utilizing the laws of mathematics and physics. The other tells how a creative idea led to an unusual new way to store petroleum products.

Using Pressure Transients To Determine Reservoir Parameters

There are many ways to recover oil from a reservoir. Among the more common techniques are solution gas drive, external gas drive, water flooding, miscible displacement and thermal recovery.

In order to decide which of these methods should be used in a particular reservoir, it is necessary to have a detailed description of the reservoir including many physical properties which are not easily determined. Cores obtained at the time of drilling a well represent only a very small sample of the reservoir and can give misleading results if the core properties at the well are not representative of the entire reservoir. Fortunately, many of the unknown reservoir parameters can be determined indirectly by measuring the transient pressure response of the reservoir.

Each production rate sets up a corresponding pressure distribution pattern throughout the reservoir. Any change in production rate results in a new pressure pattern. The transient pressure behavior in the producing formation is measured by lowering a sensitive instrument into the well. This instrument was designed and built in Sun's production research laboratories near Dallas, Texas. In practice, the well is produced at a constant rate until a steady pressure distribution is obtained. Then the rate is suddenly changed to zero and the resulting transient pressure buildup is measured and plotted (see curve).



The curve graphically illustrates a pressure distribution that satisfies both the following differential equation and the boundary conditions imposed by the geometry of the reservoir.

$$\frac{d^2P}{dx^2} + \frac{d^2P}{dy^2} = A\frac{dP}{dt}$$

This equation is basic in heat flow and electrical theory as well as in fluid flow. The idea of superposition and the method of images are used in the solution of fluid flow problems, just as in the familiar heat flow problems. Solution of this equation shows that pressure increases linearly with the logarithm of time during a substantial part of the test. The shape of the curve before the linear portion is controlled by the physical properties of the formation in the immediate vicinity of the well.

The slope of the linear segment is directly related to the reservoir permeability, an important parameter for any reservoir engineering calculation. If a reservoir boundary is near, its effect causes the curve to rise more rapidly. A linear boundary, such as a fault, causes the slope to increase to twice that of the earlier part of the curve. The final part of the curve indicates the volume of the reservoir.

The transient pressure performance thus provides many details of the reservoir which are vital to the proper engineering design of an operating plan for the reservoir.

Storing Products In Underground Caverns

Sun Oil Company has found that underground storage of petroleum products at the refinery offers many advantages. At the Marcus Hook refinery, these caverns are mined from solid granite.

Sun stores petrochemicals and light hydrocarbon petroleum products in four such caverns at its Marcus Hook, Pa. refinery.

One cavern, having a 75,000 bbl capacity (3,150,000 gallons), is used to store high purity propylene. While this is the smallest of the caverns, it is a relatively large storage facility for propylene or lighter hydrocarbons. By storing liquefied propylene in this cavern, the company is able to operate its propylene distillation units at the optimum rate for

best economy on an intermittent basis without diminishing its ability to meet customer demands.

Two other caverns, each with a capacity of 250,000 bbl (10,500,000 gal), are used to store butane products. One stores a mixture of isobutane and butylene, the charge stock to the alkylation unit, and permits this plant to be shut down annually for maintenance without losing production. This also saves over 125,000 lb of steam per hour during the period.

The other is used to store butane, which must be reduced to a minimum in motor fuels during the summer to prevent vapor lock and added in the winter to insure rapid engine starting. Without this storage facility, the company would be forced to sell butane at low prices in the summer and buy it at higher prices in the winter.

The largest cavern (shown above) is a mammoth one of 450,000 bbl (18,900,000 gal) capacity located 420 ft below ground that is used to store liquefied petroleum gas. This cavern permits the storage of all excess LPG production during the summer, when prices are depressed, so that it can be sold and shipped at higher prices during the winter.

SUN OIL COMPANY

1608 Walnut St. Philadelphia 3, Pa.

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To begin with it's fast . . .
(effective memory access time: 3 microseconds)
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within the Philco 4000 Series you can choose
some of the fastest
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There's been a lot of debate
about fixed and variable word length computers.
With the Philco 4000 Series there's no need to debate.
It works fixed or variable word length . . .
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We wish it were.
If you need a small special purpose computer,
a Philco 4000 probably has too much stuff.
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we recommend a Philco 2000 Series computer.

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(and most of us are these days) we think
a Philco 4000 will measure up to your unique needs
for scientific or business applications, or both.
Because the 4000

**is today's most sensible computer—
with today's most sensible pricing.**

To prove our point we would appreciate an opportunity
to measure Philco 4000 cost and performance
in terms of your specific needs.

LETTERS

Sirs:

The recent discovery of stimulated emission of light from p-n junctions of gallium arsenide has created great interest in the scientific world ["Science and the Citizen"; SCIENTIFIC AMERICAN, December, 1962]. Although long recognized as a theoretical possibility, the practical realization came much sooner than expected by many. It is of interest that the late John von Neumann anticipated this discovery as early as 1953. At that time he held discussions with Edward Teller about the possibility of using stimulated emission from recombination of electrons and holes in semiconductors to make a light amplifier. Among the unpublished papers found in his files there was a working paper entitled "Notes on the Photon-Disequilibrium-Amplification Scheme." These notes were reviewed by one of us (J. B.), who wrote a summary of them that will appear in Volume V of the collected works of John von Neumann, published by the Pergamon Press. The following is an excerpt from this summary:

"The possibility of making a light amplifier by use of a stimulated emission in a semiconductor is considered. By various methods, for example by injection of minority carriers from a p-n junction, it is possible to upset the equilibrium concentrations of electrons in the conduction band and holes in the valence band. Recombination of excess carriers may occur primarily by radiation, with an electron dropping from the conduction to the valence band and the energy emitted as a photon with an energy slightly greater than the energy gap. The rate of radiation may be enhanced by incident radiation of the same frequency in such a way as to make an amplifier. The basic principle was used later by Townes and by Bloembergen in the MASER (Microwave Amplification by Stimulated Emission of Radiation), although not with recombination radiation in a semiconductor."

JOHN BARDEEN

University of Illinois
Urbana, Ill.

A. H. TAUB

Institute for Advanced Study
Princeton, N.J.

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Sirs:

Bruce I. H. Scott's description of current research on electricity in plants ["Electricity in Plants"; SCIENTIFIC AMERICAN, October, 1962] is reminiscent of an account of plant magnetism that appeared in your pages more than 80 years ago. *Scientific American* for February 26, 1881, calls attention to the so-called compass plant (*Silphium laciniatum*):

"The first announcement of the tendency of the leaves of the compass plant to direct their edges to the north and south was made by General (then Lieutenant) Alvord of the U.S. Army in the year 1842, and again in 1844, in communications to the American Association for the Advancement of Science. . . . The lines in 'Evangeline' (familiar to many readers), and beginning

Look at this delicate plant that lifts
its head from the meadow,
See how its leaves are turned north
as true as the magnet;
It is the compass plant that the finger
of God has suspended,
Here on its fragile stalk, to direct
the traveler's journey,
Over the sealike, pathless, limitless waste
of the desert . . .

were inspired by a personal communication made by General Alvord to the poet Longfellow."

Laboratory investigations of the relation between electricity or magnetism and plant life are quite old. As early as 1777 Tiberius Cavallo noted in his *A Complete Treatise on Electricity:* "Mr. Koestlin... has found that both animal and vegetable life are retarded by negative electrification." Plant electricity seems to have quickly become a field of some interest, because the 1795 edition of Cavallo's book observes:

"That electricity promotes vegetation is a proposition which was admitted many years ago, and has at various times received apparent confirmation from the publication of experiments and observations made either accidentally, or expressly for the purpose... but Dr. Ingen-Housz's attentive examinations of the subject, and the result of his numerous experiments, have shown the fallacy of the proposition, by having exposed the insufficiency of the experiments upon which it was established."

Jan Ingen-Housz (1730–1799) was an eminent Dutch physician and natural philosopher. His experimental conclusions were based on a large number of carefully controlled tests with different plants, polarities and electrode dispositions. The mistakes of earlier workers were attributed by him principally to the effects of unequal lighting.

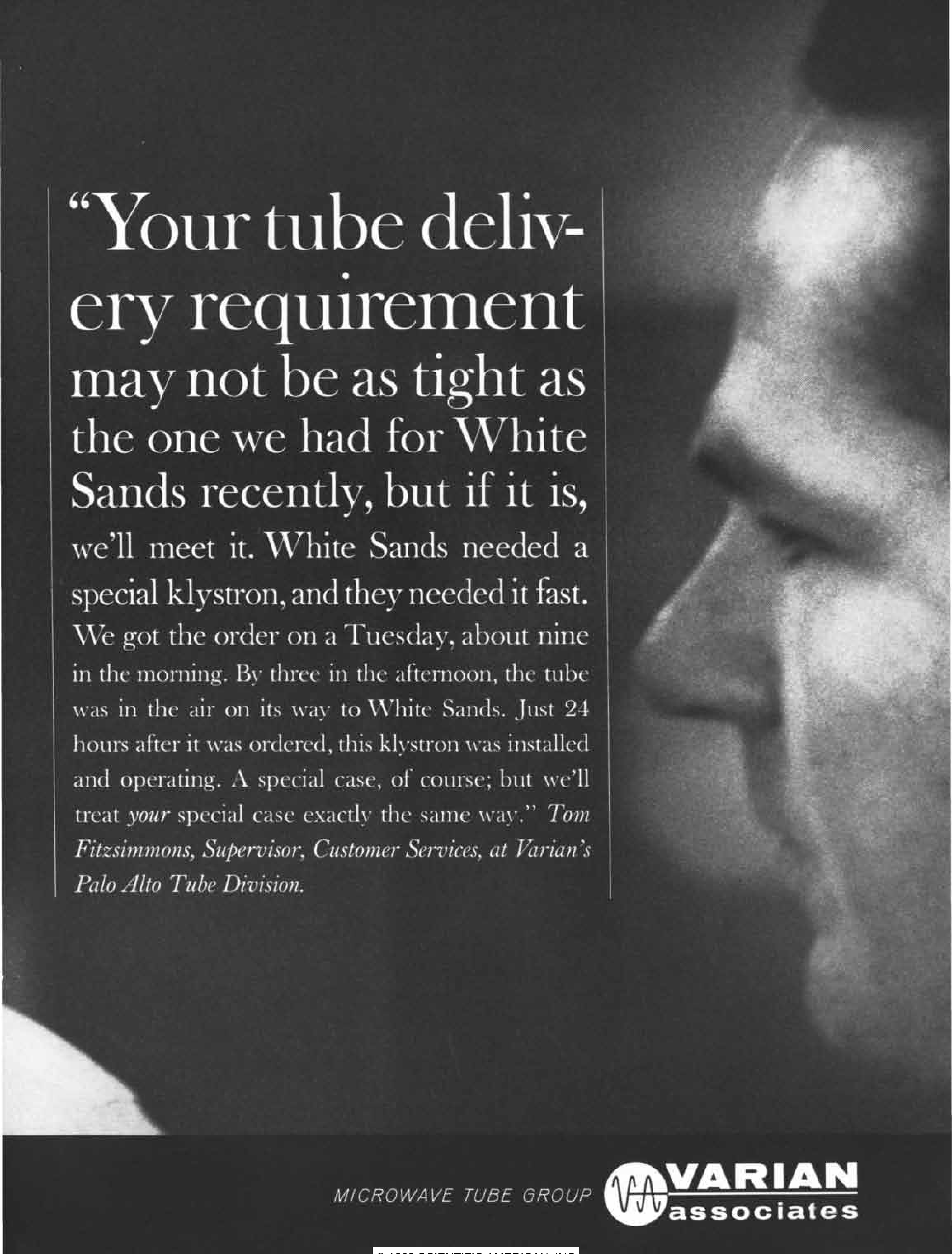
Ingen-Housz's results, however, hardly settled the matter. Mottelay's *Bibliographical History of Electricity and Magnetism* (1922) gives dozens of conflicting references to the literature, from the time of Ingen-Housz to 1879, dealing with the influence of electric and magnetic fields on vegetation.

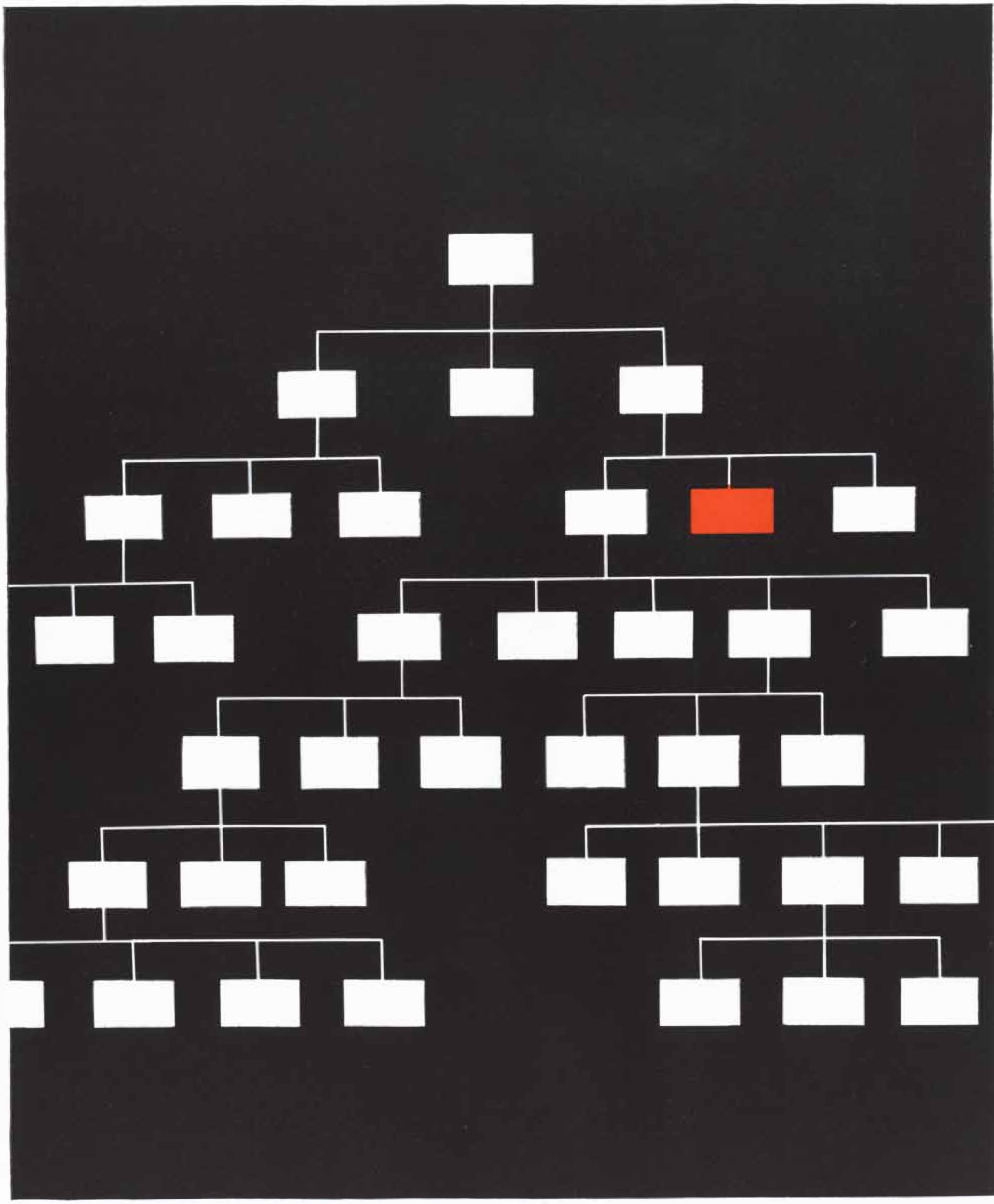
MYRON ROBINSON

Research-Cottrell, Inc.
Bound Brook, N.J.

ERRATUM

In "Authors" for December, 1962, it is stated that John A. Clements, the author of the article "Surface Tension in the Lungs," is assistant chief of the Directorate of Medical Research, a division of the Army Chemical Center in Maryland. In actuality he was formerly assistant chief of the Clinical Investigation Branch at the Army Chemical Center and is now research physiologist at the Cardiovascular Research Institute of the University of California Medical Center in San Francisco.


"Your tube delivery requirement may not be as tight as the one we had for White Sands recently, but if it is, we'll meet it. White Sands needed a special klystron, and they needed it fast. We got the order on a Tuesday, about nine in the morning. By three in the afternoon, the tube was in the air on its way to White Sands. Just 24 hours after it was ordered, this klystron was installed and operating. A special case, of course; but we'll treat *your* special case exactly the same way." *Tom Fitzsimmons, Supervisor, Customer Services, at Varian's Palo Alto Tube Division.*
MICROWAVE TUBE GROUP
VARIAN associates



RIGHT AT THIS MOMENT SOMEONE at Allis-Chalmers is working on a product idea or application that can dramatically influence your business and personal future because today, more than ever before, ***ALLIS-CHALMERS*** is doing its share to help you share in a better future.

Northrop had many problems building its latest communications system.

Hit and run. This is how Viet Cong guerrillas operate. And these tactics were frequently successful because of South Vietnam's lack of adequate communications.

To overcome the problem, Northrop was asked to build a complete military communications network across this troubled land.

Normally, survey work on such a project would take a full year. Northrop had less than a year to complete the *entire system.*

But Northrop had tackled tough assignments before. Its Page Communications subsidiary had built communications systems in Turkey, Greenland, Europe, and for the Atlantic Missile Range.

This experience enabled Northrop to complete survey work in just six weeks. Then the real work began. Northrop engineers slogged through dense jungles and over rugged mountain ranges. Where roads were non-existent or impassable, they built new

"Why we chose the NCR 390 Computer." SOULÉ STEEL COMPANY

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"In our opinion 'experience is a good teacher.' This may be an old cliché but we feel it is a good one. We have used NCR Accounting Machines for years. We have always found the equipment to equal or better the standards specified by NCR representatives. Our experience with the NCR 390 is no exception.

"Two major factors dominated our thinking and planning for the 390: ONE: We were able to modify existing equipment and utilize it to provide input for the computer. We are able to continue processing daily transactions and as a by-product provide punched paper tape for high-speed processing of volume distribution data into summary form. This enables us to speed closing of cost records and provide management with faster reports.

"TWO: The NCR 390 utilizes a record that can be processed electronically and at the same time furnishes a historical record for reference. We like records that can be readily referred to for cost information and other data necessary in estimating and bidding on contracts.

"We now consolidate accounting work that was previously done in the field and other branch locations. We feel the NCR 390 is a practical, low-cost answer to our data processing needs."

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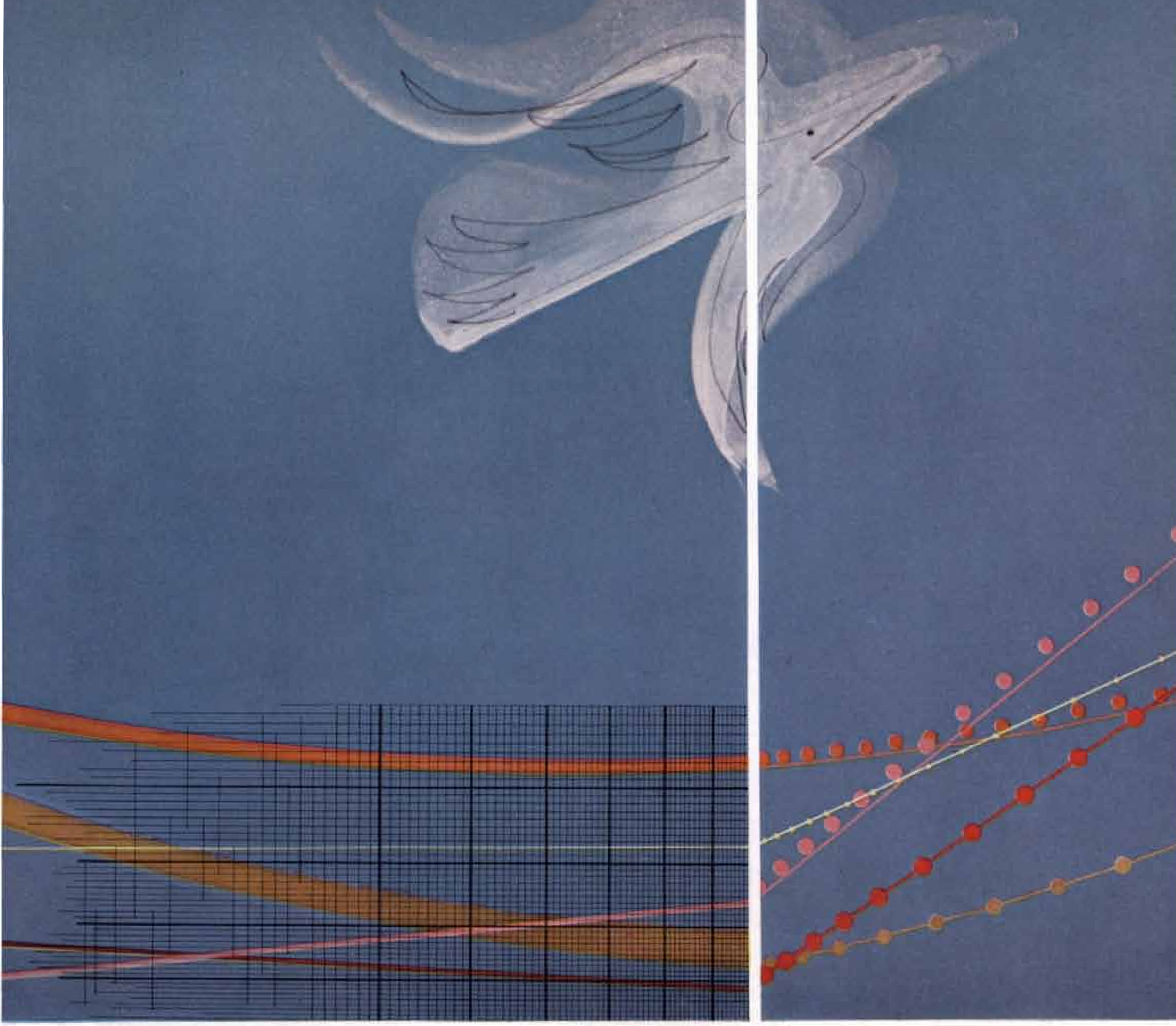

Projection or Plan?

The solid lines on all the charts stop at "today." To be ready for tomorrow's opportunity requires more than a projection. It requires a plan.

In our view a projection is an educated guess at what may happen. A plan is a specific program of action to make as sure as possible that the right thing *does* happen.

Celanese takes planning seriously. It is a separate, specially staffed and high ranking function at the corporate level. It is a continuing and detailed function in each operating company. Formal plans are on a one-and-five year basis and are continuously reviewed and brought up to date.

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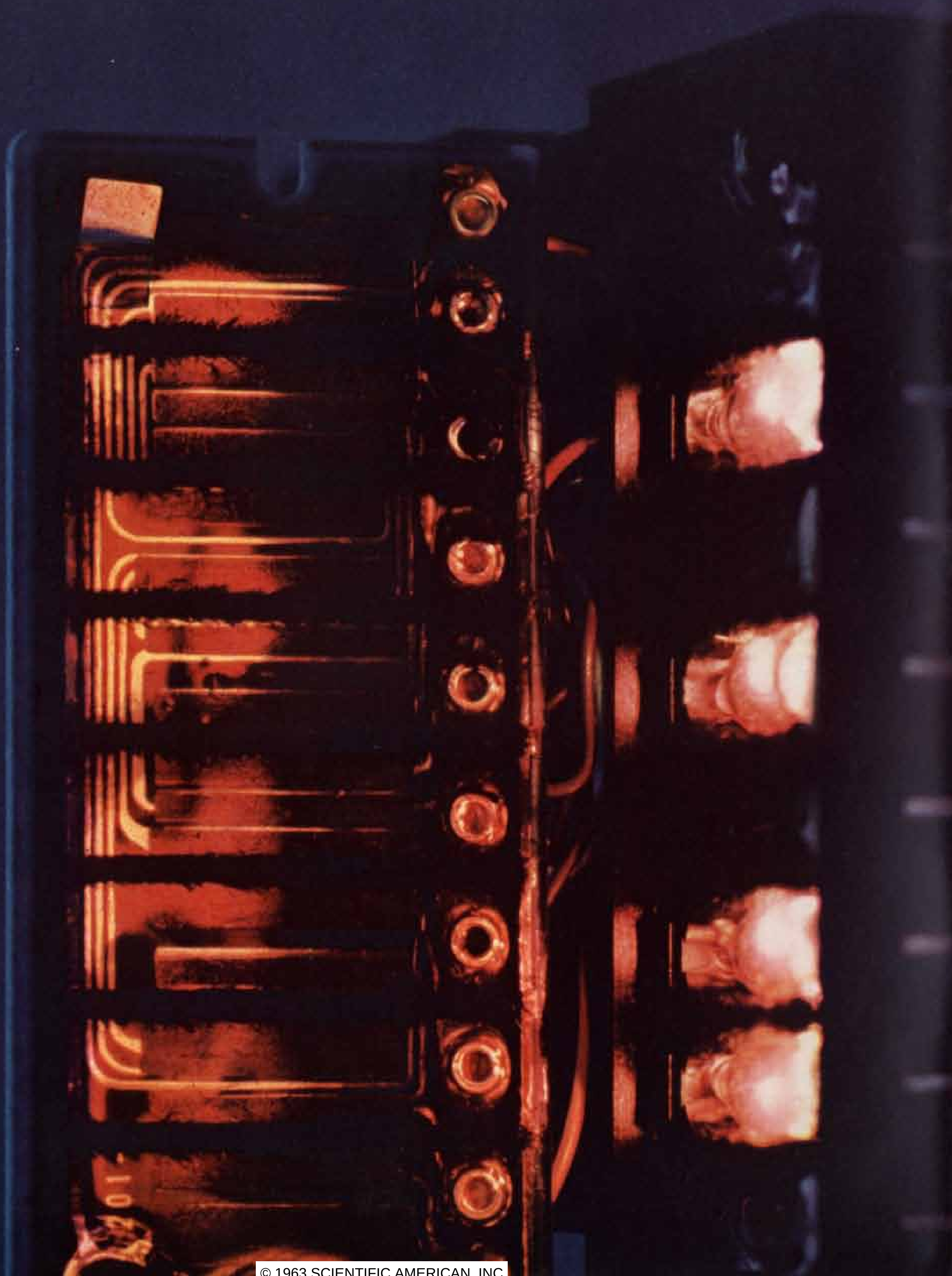

PROGRESS

Frequency and time measurement demand continuing improvement in the operation, readability and reliability of electronic counters. These instruments are used in all scientific disciplines for making measurements involving time and frequency. The electronic counter is capable of measuring frequencies with extreme accuracy, measuring the period of unknown frequencies directly, making time interval measurements, counting random events, and determining the ratio of one frequency to another. This is accomplished by the use of a precision time base and high speed binary electronic circuits that perform mathematical functions. The measurement is displayed directly and accurately in an in-line display of numerals.

Solid state electronic counters usually require complex circuitry to drive these numerals. This circuitry must take binary information and convert it to decimal data before it can be displayed and read. Many counters employ networks of 10 high voltage transistors, 10 diodes and many resistors for each numeral. Some use space consuming relay networks. Hewlett-Packard has pioneered a totally new technique which simplifies circuitry and provides the needed amplification for readout signals while still retaining the rapid speed of operation. This technique incorporates a photoconductor—a device that changes its electrical conductivity by a factor of several thousand under varying degrees of illumination.

The high speed photoconductor developed by Hewlett-Packard and manufactured by its affiliate, HP Associates, translates the binary information to decimal data. Eight neon bulbs that are part of the binary counting circuits are lighted according to the count. These illuminate the photoconductor matrix, cause it to conduct, and light the correct readout numeral on the instrument's front panel. No other switching or amplification is required.

In addition to translation and switching, the photoconductor matrix allows the last reading of the counter to remain while the next count is being made. Because the display does not continually change, it is easier to read and faster measurements may be made.

Photoconductor research is but one way that Hewlett-Packard seeks constantly to produce definable advances in the state of the art of measurement. Electronic counters are but one example of progress from the world's largest manufacturer of precision electronic test equipment.

...own three times actual size, ...s Hewlett-Packard developed ...otoconductor matrix (a network ...light operated switches). ...minates many components formerly ...wded into a bulky assembly. ...es cost and increases reliability ... Hewlett-Packard solid state ...ctronic counters.

hp 5245L 50 MC Solid State Counter This counter employs the hp photoconductor matrix for driving its 8-digit in-line display. The instrument measures directly to 50 mc and also measures period, period average of up to 10^5 periods, ratio between two frequencies, and, with the addition of plug-ins, will count frequencies, up to 512 mc and will measure time interval of 1 μsec to 10^9 sec. $3,250. Frequency-extending and time interval plug-ins optional at extra cost.

HEWLETT-PACKARD COMPANY

1501 Page Mill Road, Palo Alto, California

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1913: "In the desolate, icy waste of an unexplored Antarctic country Capt. Robert Falcon Scott gave up his life after having reached the South Pole. Capt. Scott and the four men with him reached the pole on January 18, 1912, but on the return journey all perished. Their bodies were not found until a search party, sent out on October 30, discovered them on November 12, nearly eight months after the disaster. Evans died from concussion of the brain on February 17, 1912; Oates from exposure on March 17, 1912. The remaining three men made their way back to within 155 miles of Cape Evans, when they were caught in a blizzard that must have lasted nine days, and were overcome about March 29, within 11 miles of the shelter and supplies at One Ton Camp. In the last tent pitched by the party a final message, from Scott himself, was found. Written with the shadow of death upon him, its pathetic appeal has deeply moved the civilized world. In it he wrote: 'I do not think human beings ever came through such a month as we have come through, and we should have got through in spite of the weather, but for the sickening of a second companion, Capt. Oates, and a shortage of fuel in our depots, for which I cannot account, and, finally, but for the storm that has fallen on us within 11 miles of the depot at which we hoped to secure the final supplies. Surely misfortune could scarcely have exceeded this last blow! We are weak. Writing is difficult, but for my own sake I do not regret this journey. We took risks. We knew we took them. Things have come out against us and therefore we have no cause for complaint but bow to the will of Providence, determined still to do our best to the last. But if we have been willing to give our lives to this enterprise, which is for the honor of our country, I appeal to our countrymen to see that those who depend on us are properly cared for.' "

"In patent No. 1,050,601 Dr. Alexander Graham Bell, instead of making the supporting surfaces of a flying machine flexible at their lateral marginal portions and flexing or warping those portions to preserve or restore the balance of the machine, makes such supporting surfaces rigid and nonflexible and employs a vertical balancing rudder that, when the machine is in the normal horizontal position, lies approximately in the medial vertical fore and aft plane of the machine. This rudder is mounted on an upright axis, and when the balance of the machine is disturbed, the rudder is by suitable means turned about its axis to incline it to that side of the axis toward the lower side of the machine, the resistance offered by the air as the machine moves rapidly forward operating to again restore the balance of the machine when the rudder is returned to its normal position."

"With the practical necessity for eliminating the smoke nuisance and the efforts of very nearly every engine manufacturer turned in that direction, some tests recently conducted by the Royal Experiment Station for Testing Materials at Berlin are interesting. A sample of commercial motor lubricating oil was separated into two portions, one portion being treated with acetone, and the other was tested in its normal condition. The results demonstrated that the 'treated' oil was an efficacious lubricant and that it burned without producing either smoke or irritating odors. The normal oil, on the other hand, burned, emitted considerable volumes of smoke and an odor described as 'highly irritating to the nose and eyes.' The tests suggest that methods in vogue to abate the smoke nuisance are perhaps directed wrongly, and that chemical rather than mechanical means might better be employed."

Scientific American.

FEBRUARY, 1863: "The Committee on Agriculture in the House of Representatives has prepared a bill defining the duties and providing for the officers in the new Agricultural Bureau. It authorizes the employment of a chief clerk, a botanist, chemist and entomologist at a salary of $2,000 each per annum; also a disbursing clerk and a chief of statistics at $1,800 each; a translator and draughtsman at $1,400 each and six clerks at $1,200 each."

"A new survey of the sea bottom between Ireland and Newfoundland has

NEWS FROM

BELL TELEPHONE LABORATORIES

New high-purity alloys make better electron tubes

Ingot of high-purity nickel alloy is removed from controlled atmosphere melting furnace. Alloy is virtually free of impurities which inhibit electron emission. The new alloying technique and the methods for making cathodes and evaluating their electron-emitting properties were developed by K. M. Olsen and H. E. Kern.

Scientists at Bell Telephone Laboratories have developed new high-purity nickel alloys which are proving highly effective in lengthening the life of advanced-design electron tubes used in the Bell System. This development meets the demand of new electronic technology for long life and high reliability in electron tubes.

One of the new alloys is now providing the outstanding performance required in the electron-emitting cathode of the traveling wave tube in the Telstar satellite.

The first step was to devise new means for the fabrication of ultra-pure nickel to eliminate those impurities harmful to cathode performance. It was then possible to add to the ultra-pure nickel the alloy constituents and activating agents desired for optimum cathode performance, and at the same time to hold the undesirable impurities at levels below 50 parts per million. These techniques involved purifying the nickel raw materials and melting, alloying and casting in controlled atmospheres of hydrogen and helium.

This development is an example of how metallurgical scientists work to improve communications. The new nickel alloys are now being produced by the Western Electric Company, manufacturing unit of the Bell System.

Bell Telephone Laboratories

World center of communications research and development been made by the British ship *Porcupine.* The primary object of the survey was to ascertain the most gradual slope of the bed of the ocean and the route most suitable for a line of telegraph cable. Two routes have been selected for examination. For a distance of 160 miles due west from Cashla Bay there was found to be a gently undulating terrace, having a decline from 100 to 185 fathoms. At the western extremity rises a bank that is but little more than 80 feet below the surface. Beyond this is a descent of 700 fathoms in 10 miles, when the telegraphic plateau is gained—a vast submarine plain, stretching thence to the banks of Newfoundland with a tolerably even depth of two miles of water. The second route starts from Valentia. A valley 525 fathoms deep is first met with. A ridge 25 miles in width rises from the opposite edge, which ridge is between 195 and 230 fathoms below the surface. At the western extremity of this the bed again declines till the bottom of a much deeper valley is found. In this sea valley the waters are three miles in depth. Beyond this a gradual rise takes place till the telegraphic plateau is reached."

"From January 1st up to the 30th ult. no less than 1,556,117 gallons of petroleum have been shipped from New York, and in addition to this there were exported from Boston 217,298 gallons; from Philadelphia, 129,513 gallons; from Baltimore, 55,369 gallons; and from Portland, Maine, 47,466 gallons—total 449,646 gallons—making a total export from the United States since the 1st of January of 2,005,763 gallons. The petroleum trade, in its sudden rise and rapid progress, is the most extraordinary on record. The importation into London last year was 28,335 barrels; Liverpool, 39,309 barrels; Glasgow, 650 barrels. Exports to Europe from America totaled 257,914 barrels, or 10,318,658 American gallons."

"On the new metal thallium the Paris Academy of Sciences has received a second communication from M. Lamy, from which it appears that if the discoverer, Mr. Crookes, at first discovered it to be a nonmetallic substance, he was not far wrong. At least M. Lamy finds it wanting in one of the chief properties of metals—viz., the power of conducting electricity and heat, since the power of induction developed in the metal is of but slight intensity when the circuit of the pole is successively closed and broken."

WHAT'S IN THE AIR FOR ASTRONAUTS

Hundreds of contaminants, many toxic, can be present in a capsule's atmosphere. Even ordinary materials like plastics can produce dangerous out-gassing under extreme heat or shifts in barometric pressure. The vital job of continuous atmosphere monitoring on extended space flights is an application for gas chromatography, a versatile technique that can measure multi-components in the parts per million level quickly. Perkin-Elmer has pioneered the development and made important advances in chromatography for industrial and research use. It now is applying this capability, plus its understanding of space system packaging, to capsule atmosphere monitoring, planetary surface and atmosphere analysis and other sophisticated space science efforts. Gas chromatography is another example of Perkin-Elmer's dedication to the development of instrumentation for precise measurement in the interest of industry, science and defense. Perkin-Elmer Corporation, Norwalk, Connecticut.

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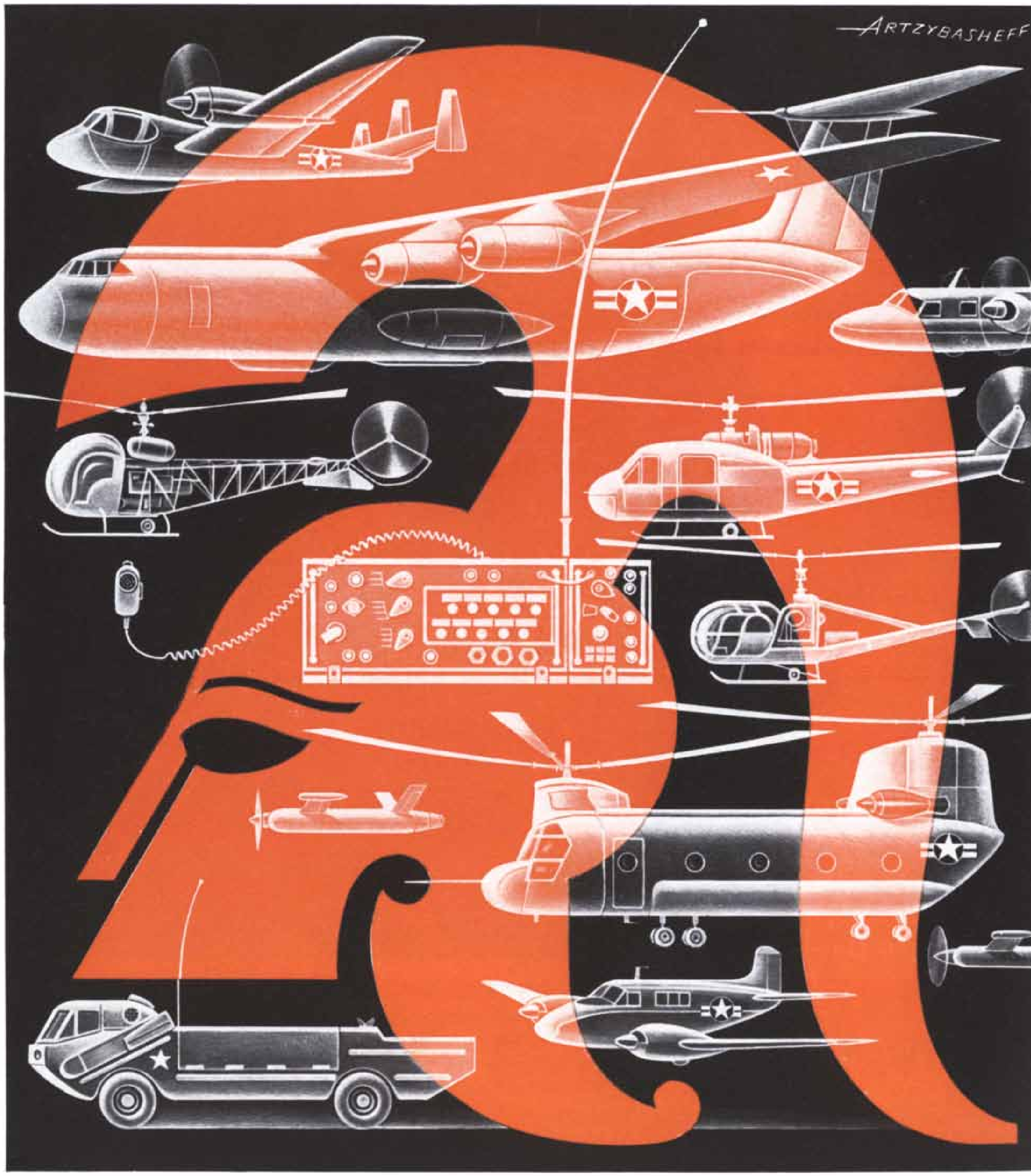

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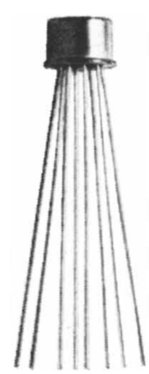

Why this Fairchild device...

is wearing a new hat.

At Northwestern University, researchers are finding out how to make football helmets safer. To aid them, Northwestern players wore a special helmet in eight games last year. Within its lining are six Fairchild Micrologic units—complex electronic circuits in a package the size of a pencil eraser—part of a system to measure the direction and intensity of impact.

The equipment frequently registered impacts as high as 300 G's—300 times the force of gravity. To a football player, that's a lot of impact—but it's nothing new to a Fairchild device. Built to withstand factory tests as high as 200,000 G's, they're used to rough games.

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THE AUTHORS

HADLEY CANTRIL ("A Study of Aspirations") is chairman of the board of the Institute for International Social Research in Princeton, N.J. Cantril also holds the position of research associate in the department of psychology at Princeton University, where until 1955 he was Stuart Professor of Psychology and chairman of the department. Following his graduation from Dartmouth College in 1928, Cantril studied at the universities of Munich and Berlin and at Harvard University, acquiring a Ph.D. from the last in 1931. In 1940, four years after he joined the faculty of Princeton, Cantril became director of the university's Office of Public Opinion Research, and from 1942 to 1945 he served as a special consultant to the U.S. Secretary of War and the Office of War Information. Other extracurricular work has included the editorship of *Public Opinion* from 1935 to 1946, the directorship of the UNESCO Tensions Project in 1948 and the authorship of some dozen books.

HELMUT A. ABT ("The Rotation of Stars") is associate astronomer at the Kitt Peak National Observatory, near Tucson, Ariz. Born in Germany and educated in the U.S., Abt obtained a B.S. in mathematics and an M.S. in physics at Northwestern University. In 1952 he was the first to receive a Ph.D. in astronomy from the newly formed department of astrophysics at the California Institute of Technology. After a year at the Lick Observatory, Abt went to the University of Chicago's Yerkes Observatory in Williams Bay, Wis. During the latter part of his six-year residency there he did field work in the selection of a suitable site for a national observatory. When Kitt Peak was chosen, Abt joined the staff and supervised the design and employment of the observatory's stellar spectrographic equipment.

JAY BOYD BEST ("Protopsychology") is associate professor of physiology at the University of Illinois College of Medicine. Best, who was a combat intelligence officer with a heavy-bomber squadron in the Pacific and Far Eastern theaters during World War II, received an A.B. in physics from the University of Texas in 1947. He went to the University of Chicago to study physiology, worked in the department of mathematical biophysics from 1948 to 1950, received a two-year U.S. Public Health Service fellowship in 1951 and was awarded a Ph.D. in physiology in 1953. After serving as research associate in psychology at Chicago and then as consulting theoretical biophysicist in the biological and medical research division of the Argonne National Laboratory, Best joined the neuropsychiatric division of the Walter Reed Army Institute of Research in 1955. It was there, as a theoretical biophysicist in the Institute's department of neurophysiology, that Best did research on the behavior of planarian worms, which he discusses in his article. This coming May he will join Colorado State University as Distinguished Professor of Biophysics.

NORMAN D. NEWELL ("Crises in the History of Life") has since 1945 been curator of the Department of Fossil Invertebrates at the American Museum of Natural History in New York and professor of invertebrate paleontology at Columbia University. Newell acquired his B.S. and M.A. from the University of Kansas and in 1933 received a Ph.D. in geology from Yale University. After a year as a Sterling Fellow at Yale, Newell taught at the University of Kansas until 1937, when he left to serve as a U.S. delegate to the 17th International Geological Congress held in Moscow. He returned to the U.S. and became associate professor of geology at the University of Wisconsin, remaining there until he joined the museum and Columbia. Since 1950 Newell has been involved in extensive research on the paleontology and ecology of the coral reefs of the Bahama Islands in the West Indies. This work has included expeditions to Andros Island and to Raroia (the Pacific atoll reached by the *Kon-Tiki*). He made a fossil-collecting tour of Mexico and Guatemala in 1956 and did field work in Greece and Turkey in 1960. The present article was originally given as the Ermine Cowles Case Memorial Lecture at the University of Michigan in 1962.

TAHSIN ÖZGÜÇ ("An Assyrian Trading Outpost") is chairman of the department of Near Eastern archaeology at the University of Ankara in Turkey. At present he is in the U.S. as a member of the Institute for Advanced Study in Princeton, N.J. Özgüç received a Ph.D. from Ankara in 1942, conducted excavations in the vicinity of the city from 1945 to 1947 and the following year began the dig described in his article.

MALCOLM McCHESNEY ("Shock Waves and High Temperatures") is lec-

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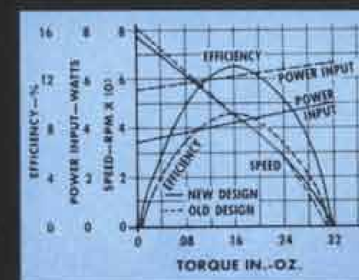

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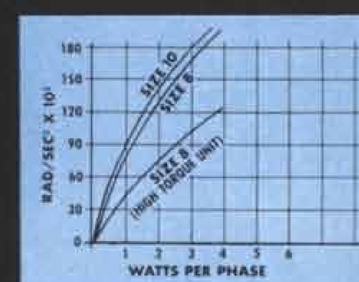

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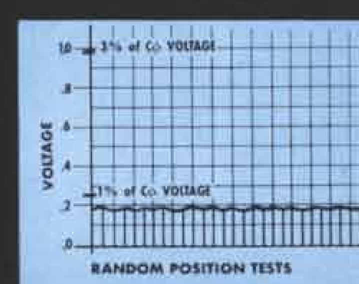

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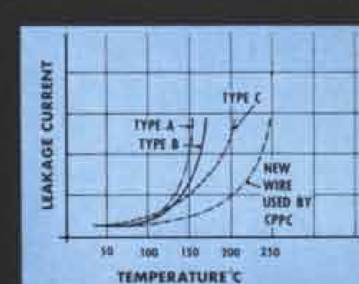

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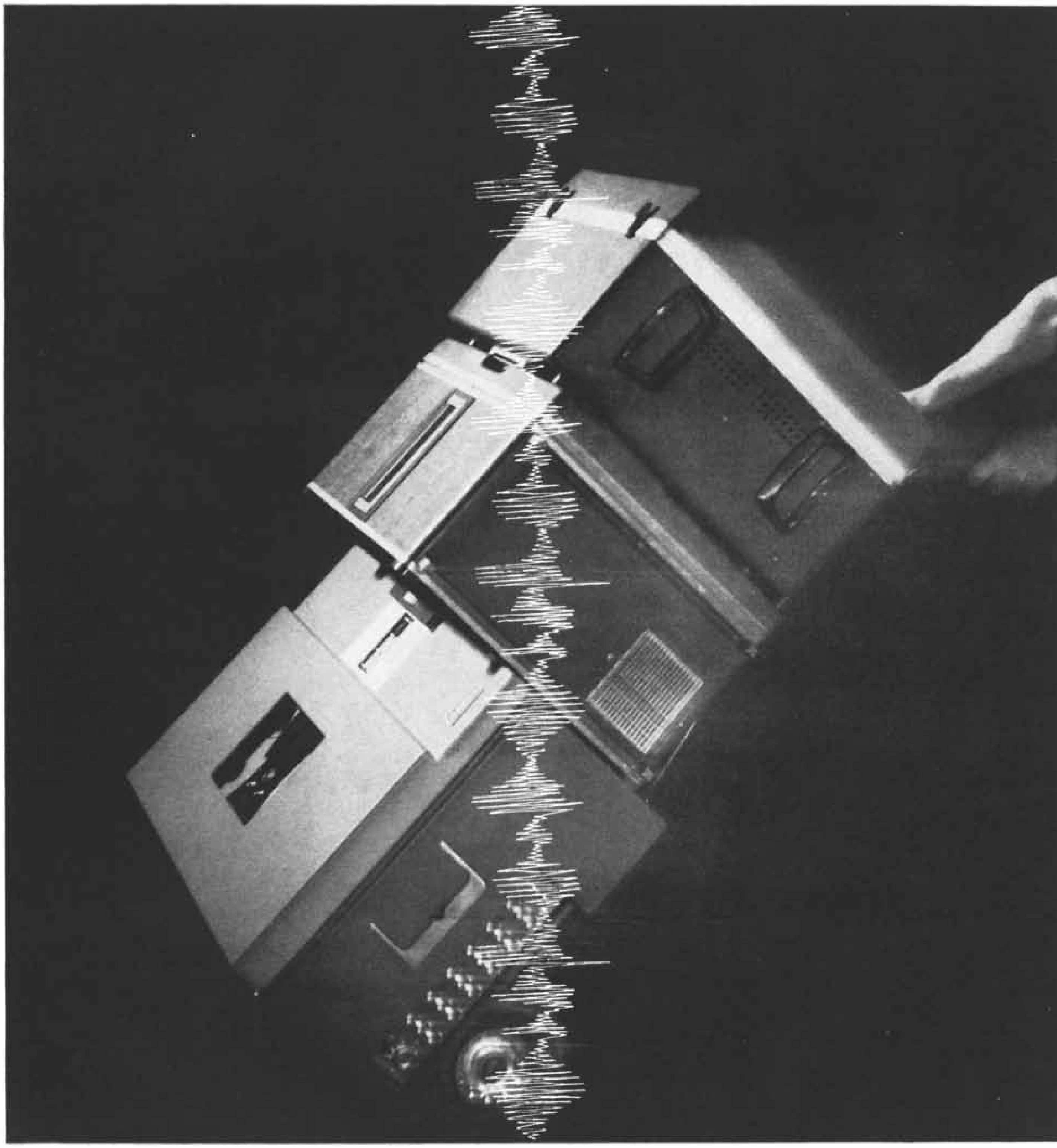
turer in charge of the Shock Wave Group in the Department of Mechanical Engineering at the University of Liverpool. Born in England, McChesney studied physics at the University of Glasgow and received a First Class Honors degree in 1952. He was awarded his Ph.D. at Liverpool in 1955. Until 1960, when he took his present job, McChesney worked for two private companies, first doing shock tube research and, later, research on controlled thermonuclear reactions.

VERNON AHMADJIAN ("The Fungi of Lichens") is assistant professor of biology at Clark University in Worcester, Mass. Ahmadjian obtained his A.B. at Clark in 1952, served two years in the U.S. Army Medical Corps and returned to take an M.A. at Clark in 1956. In 1958 he was an American-Scandinavian Foundation Fellow at the University of Uppsala in Sweden. Ahmadjian joined the faculty of Clark in 1959 and was awarded a Ph.D. by Harvard University in 1960. He would like to acknowledge here the contribution, to portions of the work discussed in his article, of his research assistant, Joyce P. Roche, and Karen A. Anderson and Edmund A. Schofield, Jr.

J. BRONOWSKI ("The Clock Paradox") is a mathematician and author who directs the development of new processes for Britain's National Coal Board. Born in Poland and raised in Germany, Bronowski studied mathematics at the University of Cambridge, receiving his Ph.D. in 1933. From then until 1942, when he entered the service of the British Government, Bronowski taught mathematics at University College, Hull. The Government assigned him to the assessment of bomb damage and later to work in the field of operations research. Bronowski joined the Chiefs of Staff mission to Japan in 1945, served as Head of Projects with UNESCO in 1948 and came to the U.S. in 1953 as Carnegie Visiting Professor at the Massachusetts Institute of Technology. He joined the National Coal Board in 1950 as Director of the Coal Research Establishment. His books include *The Poet's Defence*, *William Blake: A Man without a Mask* and, most recently, *The Western Intellectual Tradition* (with Bruce Mazlish). Bronowski is also a nonresident fellow of the Salk Institute for Biological Studies.

THEODOSIUS DOBZHANSKY, who in this issue reviews Carleton S. Coon's *The Origin of Races*, is professor at the Rockefeller Institute.



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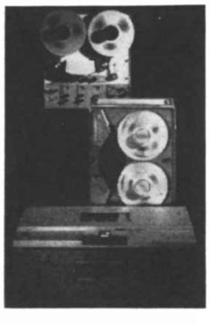

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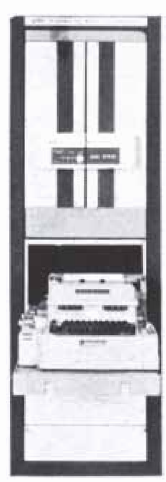

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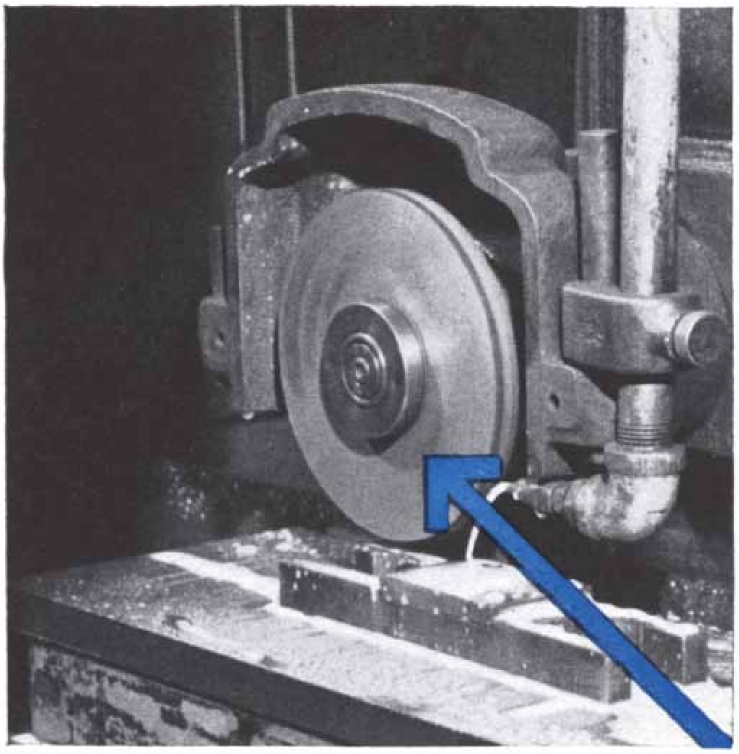
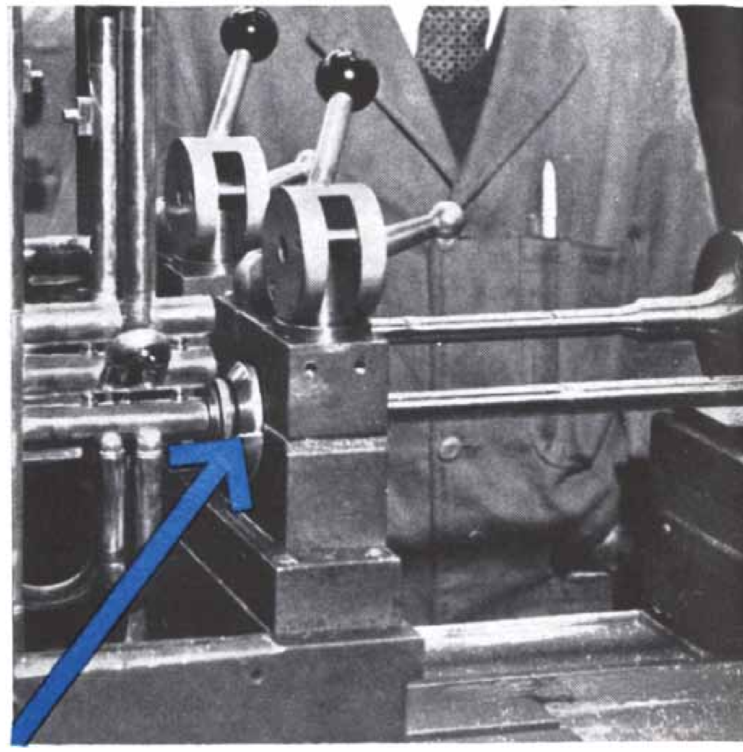


Natural diamond wheel is used to surface-finish carbide blank at Textile Machine Works, Reading, Pa. For roughing of carbide, 100-mesh diamond grit is employed; for finishing, 220-mesh.



Boring machine with two boring bars in tandem finishes internal bore of valve boxes on trumpets at Boosey & Hawkes, Ltd., Edgware, England. Each bar carries a carbide tip for rough boring and a natural diamond tip for finish boring. Tolerance on finished bore is held within .0003 inch of diameter and taper.

EACH OF THESE JOBS IS DONE BETTER WITH NATURAL DIAMONDS

The grinding and finishing jobs shown on these pages are being performed on alumina ceramic, brass, tungsten carbide and abrasive wheels. Yet they share one important detail: in every instance, natural diamonds are doing the job quickly—and economically.

When you use diamonds, you get the unique combination of excellent cutting ability linked with fantastic endurance. Result: your diamond tools last longer than any other tools you can use. Your people spend more time producing, less time changing tools.

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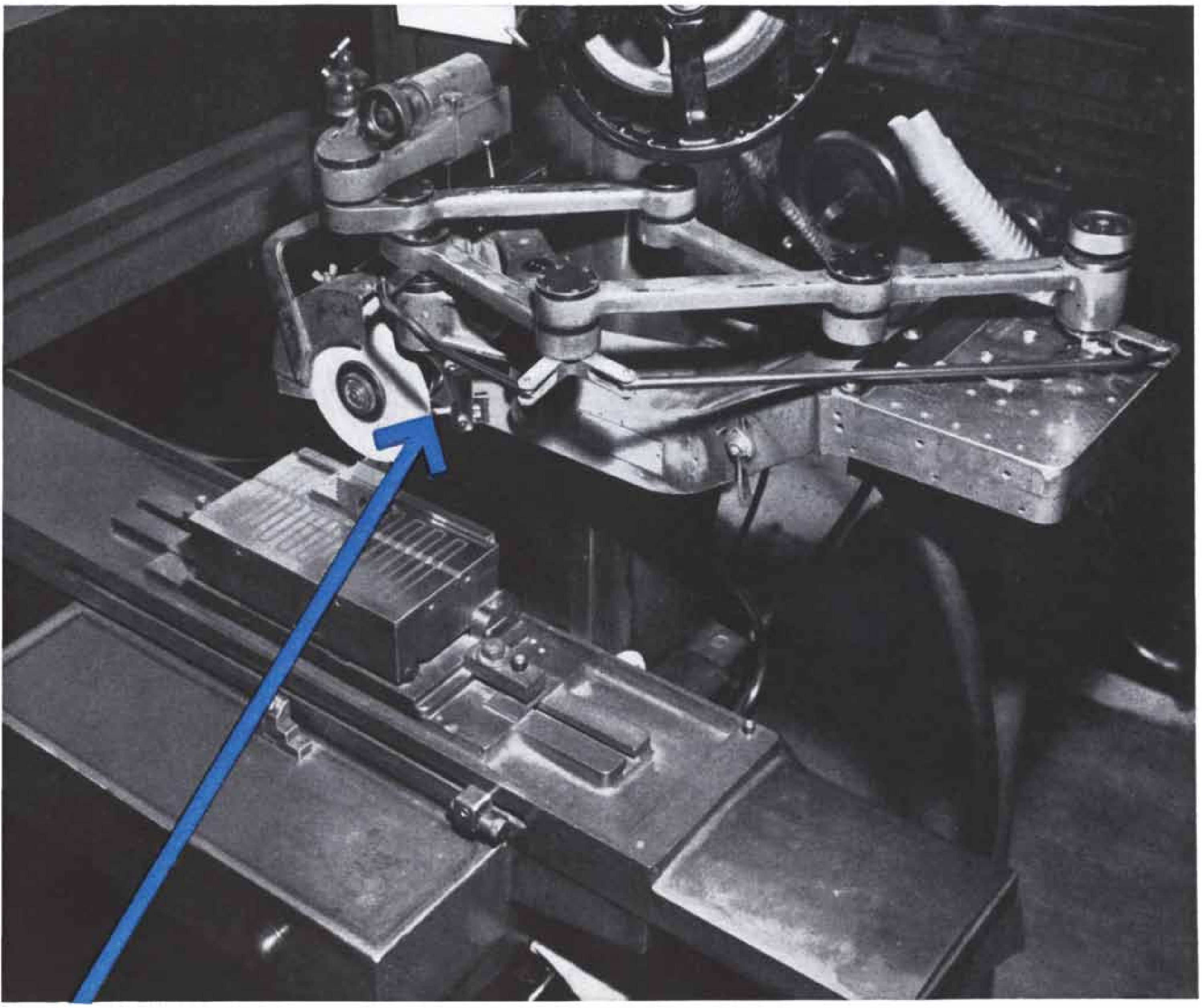
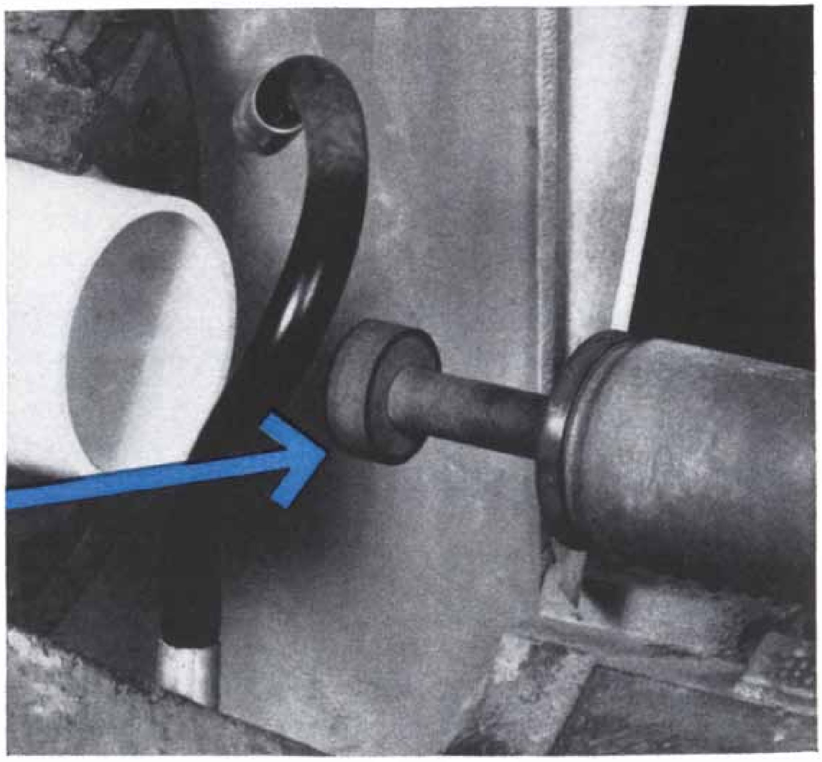
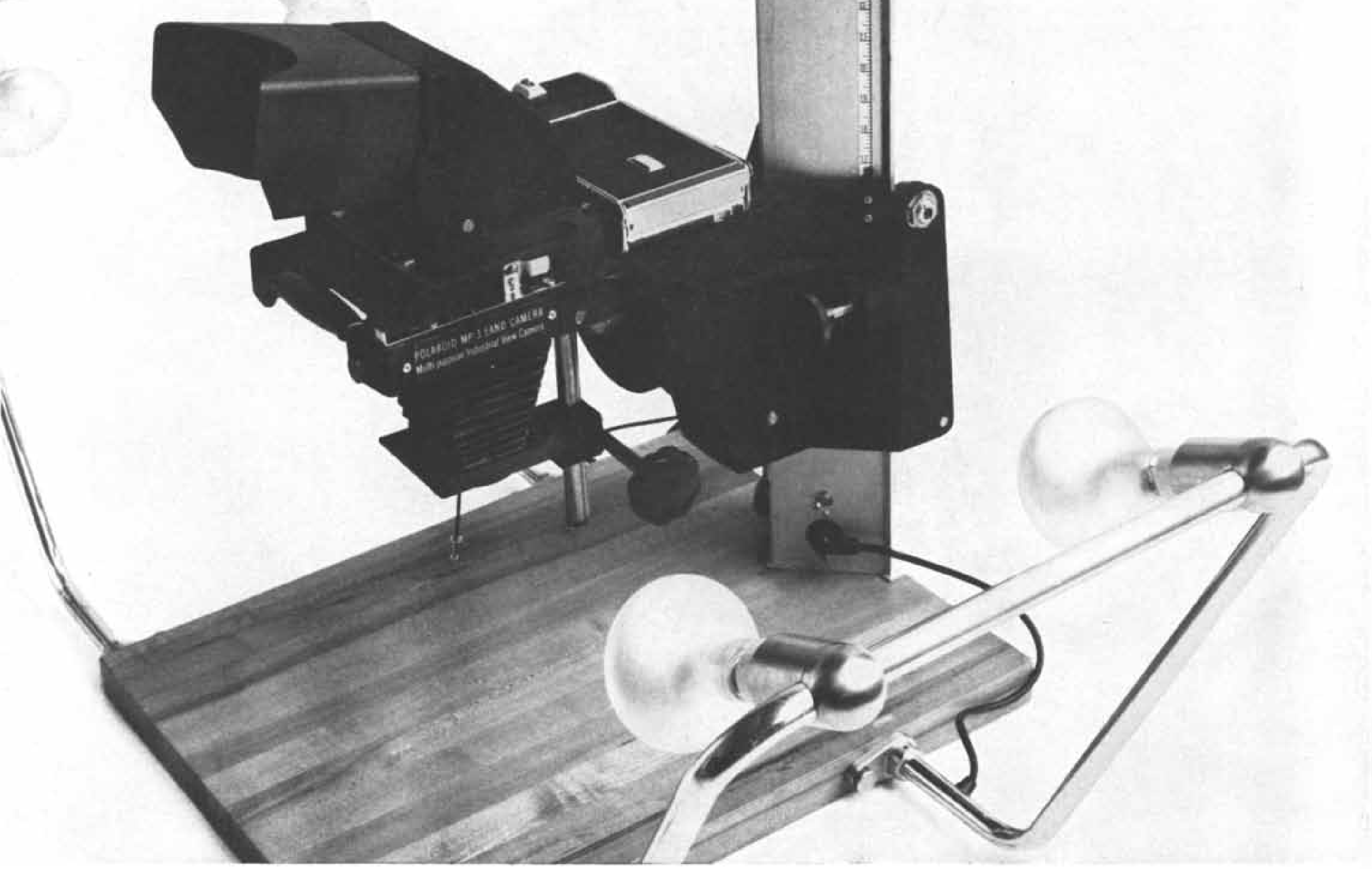


Pantograph attachment for grinder permits rapid forming of contoured abrasive wheels for Moore Special Tool Company, Inc., Bridgeport, Conn. Template is mounted on grinder's pantograph; a stylus is guided along the outline of a template, while diamond roughing tool cuts form into wheel. Final forming is done with fine-shaped diamond tool. After forming wheel, same setup can be used for wheel-dressing.



Inside diameter of alumina ceramic component (hardness 9-plus on Mohs scale) for electronic device is ground with natural-diamond wheel at Diamonite Products Mfg. Co., Shreve, Ohio. Wheel has speed of approximately 5000 sfm. These parts are machined to tolerances within .001 inch.



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Physically, the MP-3 is a rigid stand on a laminated wood base. A counterbalanced camera body rides easily up and down the stand and swings to a horizontal position for bigger work mounted on a wall. Prepositioned floodlights illuminate regular size work on the base.

Optically, the MP-3 is even more sophisticated. You can work with four interchangeable lens and shutter combinations plus a lensless shutter for photomicrography. In all cases you work with an eye-level, ground-glass reflex viewer for fast, easy, hairline focusing.

But it's the film systems that give the MP-3 such speed and versatility. It uses five different kinds of Polaroid Land Film (some not widely known among amateurs) plus conventional 4x5 b&w and color films.

Many jobs call for just a black and white print. You can get it in 10 seconds with 3¼ x 4¼ roll film or two speeds of 4 x 5 film (one is A.S.A. 3,000!). If you need a negative to work with, another 4 x 5 Polaroid Land Film will supply a fully developed fine-grain negative and a matching positive print, in just 20 seconds.

Then there are two kinds of transparency film (one for line work, one for continuous tone) which can be mounted and ready for projection in seconds. And, of course, if you aren't in a hurry you can use any conventional 4 x 5 black & white or color film.

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Established 1845 **SCIENTIFIC AMERICAN** February 1963 Volume 208 Number 2

A Study of Aspirations

The development of a "self-anchoring" scale makes it possible to study the hopes and fears of people in different countries and to find where each man thinks he stands in his own world

by Hadley Cantril

U.S. citizens—known for their material prosperity and a certain smug contentment in it—may be surprised to learn that samplings of public opinion in West Germany, Brazil and Cuba have shown that the peoples of these countries are even more buoyant about their recent progress and more hopeful of the future. Americans may be chastened as well to learn that these peoples also identify their personal well-being more closely with the fortunes of their countries. These very general statements represent the first findings of an experimental effort to develop a technique for making comparative studies, across national boundaries, of the concerns and aspirations of people around the world. Such studies may offer a systematic approach to many fundamental questions about people and their societies in the present period of rapid social change and political evolution: What sort of order and stability do people require of viable social and political systems? What sort of demands do existing systems impose in turn on the individual? What are the characteristic concerns of people in societies that are breaking away from tradition or from a colonial past? Under what circumstances does the preoccupation of people with elemental material needs give way to the flowering of more subtle and complex interests? Can one discern any sequential phases in political development?

The difficulty here is twofold. On the one hand, it is necessary to get people to voice their concerns and aspirations in their own terms; on the other, this information must be secured in such a form that the responses of different individuals and groups of individuals either within the same society or in different societies can be compared to one another in some meaningful way. As soon as the investigator sets up categories of information to be secured, with the aim of obtaining comparable and quantitative data, he runs the risk of imposing arbitrary boundaries and thereby blurring the richness, uniqueness and variety of the individual response. And yet people's reports of their concerns must be fitted into some categories if comparisons are to be made.

My colleagues and I at the Institute for International Social Research in Princeton, N.J., have undertaken to meet this difficulty by designing a "self-anchoring" scale for the comparison and measurement of human concerns. Starting with the premise that each individual creates for himself his own world of reality, in which he assigns significance to what he perceives in terms of his life's purpose, we set out to elicit his own view of his world. The self-anchoring scale allows an individual's expression of his concerns, values and perceptions to establish the top and bottom points of a self-defined measurement continuum. On this "first person" scale he is able to estimate his present estate on the basis of his recollection of the past and his hopes and expectations for the future. When many such scales are laid down side by side, they reveal significant similarities and contrasts in people's estimates of where they stand in their respective worlds.

Since we began our field work in 1957 we have surveyed representative samples of the adult populations, usually 2,000 individuals, in the U.S., West Germany, Brazil, Cuba, the Philippines, Israel, Panama and the Dominican Republic. Surveys are now under way in Poland, Yugoslavia, Nigeria and India. In addition, in nine countries we have surveyed approximately 100 members of the national legislative bodies of each. Wherever possible we have enlisted social scientists or survey experts who are citizens of the country being studied to serve as our interviewers. Where no such individuals were available we have arranged for the training of competent local people. In order to ensure uniformity of procedure, either Lloyd A. Free, my principal associate in this work, or I have visited each country for prolonged periods to assist in organizing the research. On occasion we have had to spend considerable time teaching local personnel the principles of making a social survey, from the drawing of a probability sample from census data to the conducting of an interview.

In Brazil, for example, where our survey was done by an extremely able Brazilian research group, Free had to work out with them a probability sample for the whole rural area of the country, because that area had never before been covered in a social survey. Many of our Brazilian interviewers had to ride horseback in order to get to their respondents. In the rural areas of the Dominican Republic our interviewers were at times threatened by machete-wielding natives, who suspected that the interviewers' activity was a subterfuge for locating conscripts for the armed forces, after the precedent set by census takers under the dictatorship of Rafael Leonidas Trujillo.

A special problem, in view of the nature of our research, was to secure faithful translation of our questions into the native language. This was not easy even in the case of other European languages. In the Philippines interviews had to be conducted in seven different languages, and in India we had to translate questions into 13 languages to obtain an adequate population sample.

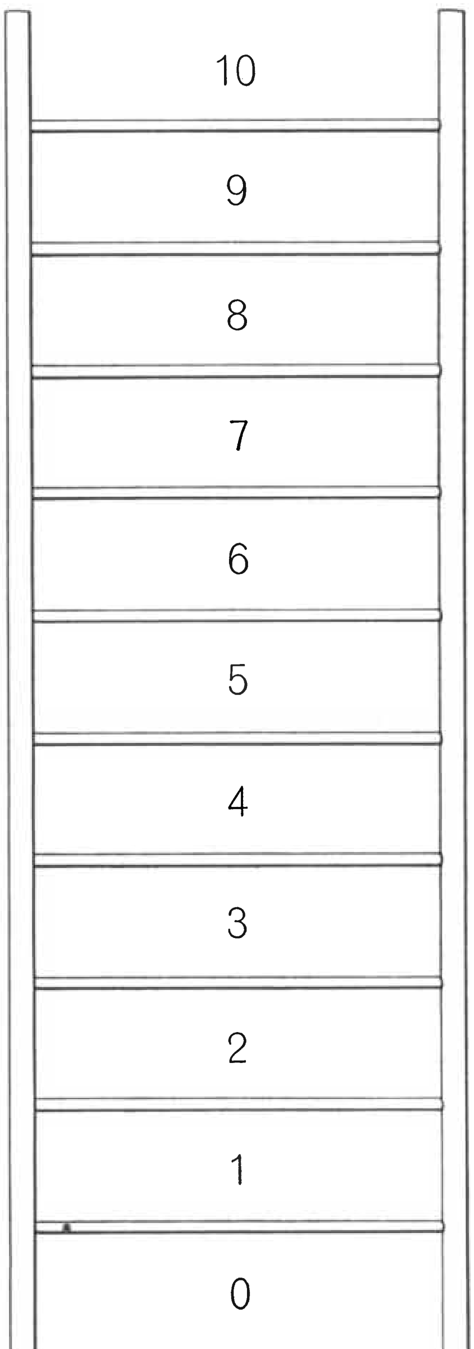
In an interview the respondent is first of all asked the following question: "All of us want certain things out of life. When you think about what really matters in your own life, what are your wishes and hopes for the future? In other words, if you imagine your future in the best possible light, what would your life look like then, if you are to be happy? Take your time in answering; such things aren't easy to put into words."

The interviewer records the reply in as verbatim a fashion as possible. When the respondent falters, the interviewer may prompt him with questions, being careful not to ask leading questions, until there is nothing further to report. The interviewer then continues with this question: "Now, taking the other side of the picture, what are your fears and worries about the future? In other words, if you imagine your future in the worst possible light, what would your life look like then? Again, take your time in answering."

Again the responses are recorded verbatim with whatever prompting is necessary. The interviewer then shows the respondent a drawing of a ladder with 10 rungs [*see illustration at left*] and says: "Here is a picture of a ladder. Suppose we say that the top of the ladder represents the best possible life for you. Where on the ladder do you feel you personally stand at the present time?"

As he speaks the interviewer points to the top of the ladder and then to the bottom, and when he comes to the question of where the respondent now stands on the ladder, he moves his finger rapidly up and down it. When the respondent has indicated the appropriate rung, he is asked: "Where on the ladder would you say you stood five years ago?" Then he is asked: "Where do you think you will stand on the ladder five years from now?"

Although there is nothing sacred about the number of rungs the ladder might contain, experience has shown that the zero-to-10 interval is easily understood. There is nothing crucial about the interval of five years either, but we find that many people have difficulty recalling where they were more than five years ago and equal difficulty foreseeing the future more than five years hence. The device of the ladder has proved meaningful and workable in all groups except among certain primitive peoples, where it was tested in the preliminary phases of the study. Some untutored Bantu in South Africa found a crude sketch showing climbers on a hill more intelligible.



DRAWING OF LADDER is presented to a subject after he has established his own "self-anchoring" scale by defining his personal aspirations and fears. The subject is asked to assume that the top of the ladder is the best possible life for him and the bottom the worst possible, and to judge where he stands now and where he was five years ago and will be five years from now.

The underlying self-anchoring principle embodied in this procedure can, of course, be used to elicit information on a wide variety of subjects. For the purpose of our studies, in addition to asking people to tell us what they regard as the best and worst possible life for themselves and where they stand on the ladder, we ask them a complementary pair of questions about their hopes and fears for their country. With the top and bottom of the scale thus again defined, we once more present them with the picture of the ladder and ask them to indicate the present, past and future positions of their country as they see them on this scale.

Perhaps the most crucial step in this research is the coding of the topics mentioned by the respondents into meaningful categories that will make it possible to compare different social and national groups. We had to devise a code at the outset that would handle any type of response given by any person anywhere, without having to force a response into some category not entirely appropriate. From pilot tests of the technique we constructed a code that after several revisions now contains approximately 145 items.

When a small group of people who are going to do the coding on a given run of responses has worked with us for a few days, we find well over 90 per cent agreement on the categories to which all of us assign the responses. To keep in mind what the categories refer to we select from the interviews a number of illustrative quotations. When a response is put into the category of "Improvement of present standard of living for self or family," we are able to see at a glance the wide variation in the content of this aspiration for people in different groups and in different countries and thereby to study the extent to which it is functionally or psychologically equivalent.

In certain countries we have found it necessary to add a few new items to accommodate indigenous preoccupations. In West Germany, for example, the question of German reunification came up often enough to require a new item; in Israel enough people were concerned with the preservation of the integrity of Jewish culture to call for a special category. After any such categories have been added, we generally find that not more than 5 per cent of all topics mentioned have to be lumped under the heading of "Miscellaneous." We keep as categories in our code any topic that turns up in 5 per cent or more of the responses in any country. The coded results, together with the coded ladder ratings, are then transferred to punched cards for subsequent tabulation and statistical treatment.

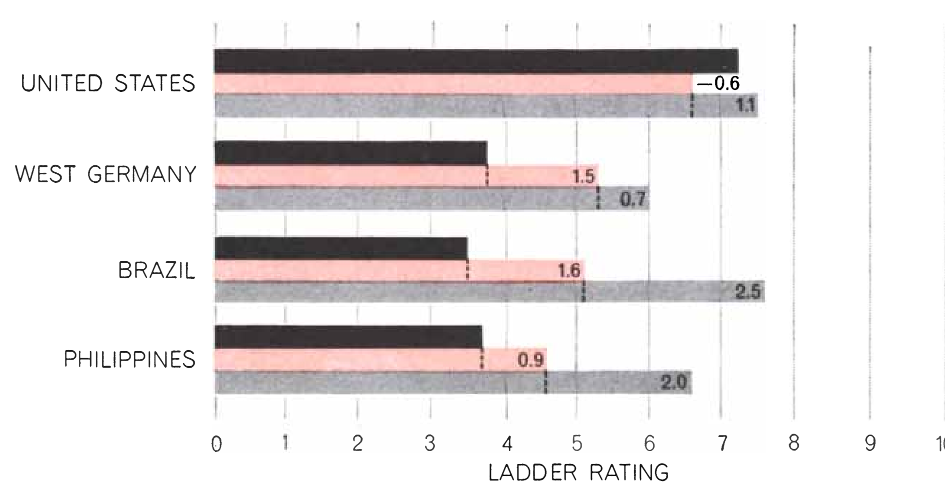
So far we have completed our tabulations for only the five countries represented in the charts that illustrate this article: the U.S., West Germany, Brazil, Cuba and the Philippines. The field work should be completed in another six months, and we will then need time for systematic analysis and interpretation of the rather large mass of data. The results presented here are for purposes of illustration of the work that is in progress.

From tabulation of some of the general categories into which we sort all the items in our code, certain interesting uniformities and differences among national groups emerge. A few common denominators characterize the concerns of people in all five countries: concern with their economic situation and standard of living; with their own health and that of the members of their families; the desire to provide adequate opportunities for their children. These interests cut across class boundaries within each country as well. Concern for an improved standard of living was mentioned as often in the U.S. as it was in poorer countries, such as Cuba and Brazil; in the U.S. persons in the upper- and middle-income groups were just as concerned with the question as those in the lower-income group. For one upper-income American it took the form of "I want enough money to own a boat and send my four children to private preparatory schools"; for the wife of a worker in Havana the wish was "to have enough food and clothes so we won't have to beg for these things."

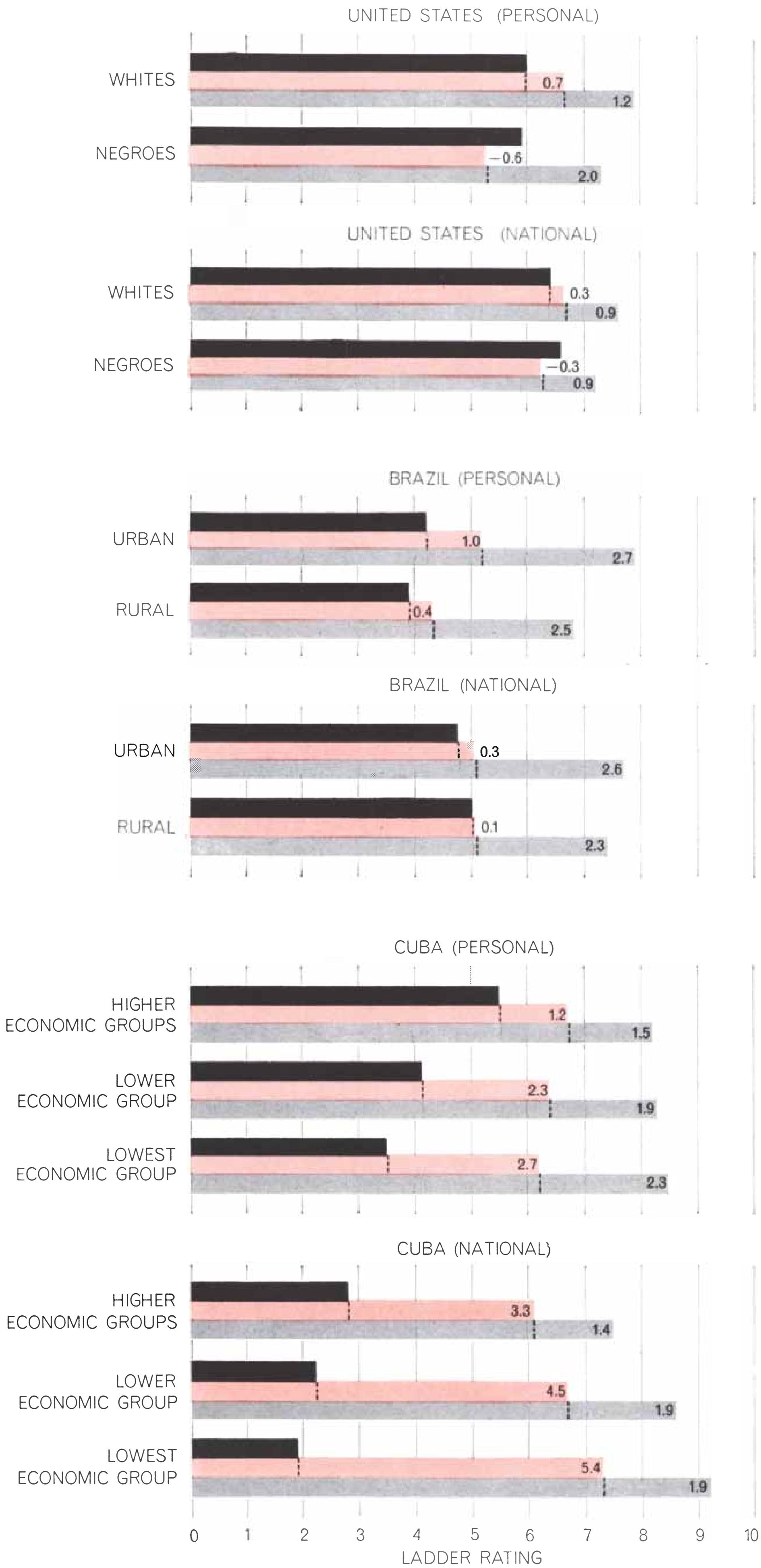
Such nonmaterial values as emotional maturity, independence of thought and action, recognition by others, feeling of accomplishment and so on [*see illustration on page 45*] were mentioned as personal aspirations by about a third of the people of Cuba. About a fourth of the Cuban respondents mentioned these values in association with fears that they

PERSONAL LADDER RATINGS are charted for five countries. The bars indicate the average responses to questions on where "you personally stand at the present time" (*color*), where "you stood five years ago" (*black*) and "will stand five years from now" (*gray*). Numbers at ends of bars show increments from past to present and present to future.

NATIONAL LADDER RATINGS were obtained in the same way. As in the preceding chart, the three bars represent (*from top to bottom*) the past, present and future ratings. The ends of the ladder were assumed to be "your greatest hopes" and "worst fears" for the nation.



LEGISLATORS' NATIONAL RATINGS are presented for four countries. Parliamentarians in Brazil and the Philippines were more satisfied than the public with their national progress.



DIFFERENT OUTLOOKS of various social and economic subpopulations in each country are reflected in their differing personal and national ratings, such as those shown here. Again the bars represent average ratings for past (*black*), present (*color*) and future (*gray*).

might not attain their life goals. In the U.S., on the other hand, only a fifth of the respondents expressed concern with these values and only 3 per cent mentioned them in answering the second question in the interview with regard to the "worst" outlook for their lives.

In response to questioning about concern for nation, the citizens of different countries again showed differences in attitude. Among Americans, for example, hope for peace and fear of war were mentioned by nearly 60 per cent; among West Germans this percentage was 70 and among Cubans it was only 10. Concern for the independence of their countries was expressed by about 10 per cent of the Cubans, West Germans and Filipinos interviewed but by less than 5 per cent of the Brazilian and U.S. citizens. Whereas respondents of all nationalities voiced a uniformly high concern about their personal economic well-being, only 6 per cent of the citizens of the industrial countries mentioned such concern in speaking of the future of their countries. In the underdeveloped countries of Cuba and the Philippines, on the other hand, at least a fourth expressed hopes that were classified under the code item "An improved standard of living or greater national prosperity through technological advances—increase in the rate of mechanization, use of modern scientific advances, nuclear energy; greater productivity in industry or agriculture; development of natural resources."

Within each national population group our interviewers found significant divergence of outlook among the rich and the poor, the city dweller and the farmer, the skilled worker and the businessman, the young and the old. Some 45 per cent of U.S. Negroes, for instance, expressed the wish to have their own house or apartment, something mentioned by only 21 per cent of U.S. whites. In Brazil more than half of those in the low-income groups in urban communities craved a decent or better standard of living, something that concerned less than a fourth of middle-class Brazilians in the cities. Whereas half the West Germans over 60 years old indicated their concern for good health, only about 10 per cent of those under 30 are as yet worrying about health. For the small Moslem population in the Philippines the most widespread desire was to have great wealth, mentioned by a third of them; less than 1 per cent of the small Protestant population there expressed any such concern. In Cuba the fear of Communism was expressed by 15 per cent of those with a university education but by only 3 per cent of those who had only an elementary school education.

It is the wealth of material of this kind volunteered by the respondents that, in each case, establishes the top and bottom of the self-anchoring scale and so lends meaning to the more summary ladder ratings of the respondents. In considering the ladder ratings it is well to bear in mind when the data were gathered in each country. In the Philippines the study was made in the spring of 1959, while Carlos P. Garcia was still president and before the victory of the reformist candidate Diosdado Macapagal; in Cuba the study was made in the spring of 1960, a little more than a year after the revolutionary government headed by Fidel Castro had seized power; in Brazil, in the spring of 1961 not long after the election of the progressive candidate Jânio Quadros, whose presidency was soon afterward terminated by his resignation. All three of these countries were deliberately selected for study at these times because they were in a state of ferment. The study was conducted in the U.S. in August, 1959, and in West Germany in September, 1957.

The "personal" ladder ratings for the citizens of all five countries show a prevalence of hope for the future and, with the exception of the Philippines, a sense of progress from the past to the present. Over the 10-year period embraced in the interview the Cubans and the Brazilians expressed an experience and an expectation of greatest total progress: 4.3 steps on the ladder from the past into the future in the case of the Cubans and 3.2 steps in the case of the Brazilians. At the time we made our survey the people of Cuba thought they would have climbed on the ladder in the next five years to a higher step (8.4) than that to which the Americans aspired (7.8). The contrast between the sentiments expressed by the Cubans and the Brazilians and the relatively low standard of living prevailing in their countries provides a measure of the discrepancy between the subjective self-anchored ratings and the objective situations that actually obtained in those countries. Obviously the anchor points in the minds of the respondents in these countries are very different from those in the minds of the respondents in the U.S. and West Germany. There is ample testimony to this effect in the record of the interviews that preceded the ladder ratings in each case. The self-anchoring scale makes it possible to secure insight into the diverse worlds in which people of different nationalities live and to compare their outlooks on those worlds.

The "national" ladder ratings show much the same contrast among the outlooks of the people of the three developing countries and the two industrially advanced countries. Again the Cubans and the Brazilians showed the warmer optimism. In the total 6.6 climb from the past to the future projected by the Cubans for their country, it is interesting to observe that they thought they had already achieved a 4.8-step advance by the spring of 1960. The Filipinos show the only negative rating, a one-step decline in their country's present situation compared with the past; this decline was barely offset in their expectations for the future.

Of interest is the degree of correlation between the personal and the national ladder ratings. In general it appears that when people have a sense that they are successful participants in a national political movement, there is an appreciable relation between the ratings they assign to their personal situation and to that of their country. For the Cubans in the spring of 1960 this correlation was a high .43, in contrast to the low .08 correlation between the personal and the national ladder ratings of Americans.

The studies of the attitudes of parliamentarians in four of the countries show some interesting divergences from the public attitudes in these countries. In the two developing countries, Brazil and the Philippines, the legislators evinced considerably more satisfaction and hope than their electorates. In the U.S., on the other hand, members of Congress thought that the country had gone backward during the preceding five years, which was in disagreement with public opinion in the country at large—perhaps in part because 1958 had been a recession year and because this was a Democratic Congress during a Republican administration.

Analysis and comparison of the ladder ratings obtained from various groups in the several countries yield additional significant insights. The U.S. Negro, for example, thought he was worse off personally at the time of the survey than he had been five years earlier, but he also thought the gap between his rating of himself and of the country five years thereafter would have closed. Compared with U.S. white citizens, he rated both his personal estate and the condition of the country lower. In Brazil the rural population correctly estimated its situation as being less favorable than that of the urban population of the country; this is apparent not only in the difference between the personal and the national ladder ratings given by the rural population but also in the difference between the personal ladder ratings of the rural and the urban populations. In the contrasting ladder ratings of the three Cuban income groups one can see plainly the psychological hold and sweep of the Castro revolution among the country's poor; it was the poorest who had the brightest vision of the future for themselves and their country.

The sampling of our results presented here illustrates the kind of information that becomes accessible through application of the self-anchoring scale. Above all, the technique makes it possible to see and compare the wide variety of ways in which different people look at the world, or, more properly, the wide variety of worlds in which people live their lives.

1. EMOTIONAL STABILITY AND MATURITY—peace of mind, mental health and well-being; sense of humor, understanding of others, etc.; harmonious life.
2. BE A NORMAL, DECENT PERSON, leading a quiet life, harming no one.
3. SELF-DEVELOPMENT OR IMPROVEMENT—opportunity for independence of thought and action, for following through with own interests; further study; reading for nonleisure purposes; no "rut."
4. ACCEPTANCE BY OTHERS—recognition of my status by others; to be liked, respected or loved. (Exception: Where reference is restricted to family or marriage, code under Col. 4-1.)
5. ACHIEVE SENSE OF MY OWN PERSONAL WORTH—self-satisfaction; feeling of accomplishment; life of content. (Note: Recognition by SELF as contrasted to recognition by others.)
6. RESOLUTION OF ONE'S OWN RELIGIOUS, SPIRITUAL OR ETHICAL PROBLEMS.
7. TO LEAD A DISCIPLINED LIFE.
8. MISCELLANEOUS aspirations regarding one's own personal character.

Y. Nothing to code in this column.

CODING of widely different answers as to aspirations and fears for self and nation is a critical phase of the investigation. Each answer is fitted into one of 145 categories. This small sample of categories deals with personal characteristics, one of the subtopics in the personal-aspirations section.

THE ROTATION OF STARS

As the sun turns, its equator moves at two kilometers per second. Some stars turn at 550 kilometers per second, fast enough to spin off matter. Such measurements are clues to the history of a star

by Helmut A. Abt

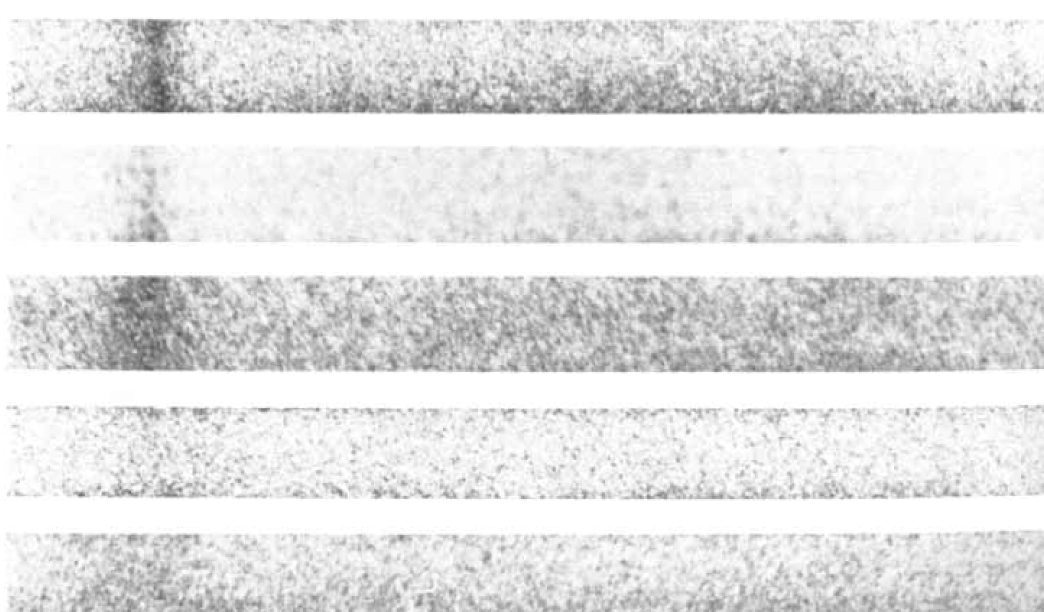
All stars except the sun appear as pinpoints of light even in the largest telescopes. The nearest stars are so distant that their diameters are imperceptibly small. Yet from the pinpoint of light that reaches the earth the astronomer can often measure the diameter of the star, determine its mass, detect the presence of a close companion that does not show up separately in the telescope and even tell something about the features of its unseen surface. This article is concerned with a related feat of modern astronomy: the determination of the speed of rotation of stars. In completing the portrait of a star, this determination helps to establish its relative age in the evolutionary cycle and allows significant deductions about its interior structure.

Like most other information about a star, the measurement of its rotation is derived from its spectrum. One can spread out the pinpoint of light into a streak on the photographic plate by interposing a prism or a diffraction grating in the path of the beam and dispersing the light into its component rainbow colors. With red (the longest waves) at one end, followed in order by orange, yellow, green, blue and violet (the shortest waves), each color changing imperceptibly into the next, the wavelengths register in order on the emulsion. Beyond the red and violet ends of the spectrum, the invisible infrared and ultraviolet wavelengths can also be photographed on emulsions of appropriate sensitivity. A prism or defraction grating to spread out the light, plus lenses, slits and other optical parts, make up the spectrograph, which has been called the queen of scientific instruments.

Any object that is hot enough to give off light has its own characteristic spectrum. The spectrum of a tungsten filament is a continuous streak of uninterruptedly changing color. Narrow black lines appear in such a spectrum, however, when a glass tube containing hydrogen gas is interposed between the glowing filament and the spectrograph. The hydrogen absorbs light of certain colors: a deep red with a wavelength of 6,562 angstrom units, a shade of blue-green at 4,861 angstroms, blue-violet at 4,340 angstroms, violet at 4,101 angstroms and some wavelengths in the ultraviolet. Hydrogen gas always absorbs these same wavelengths. When it is heated to a high temperature, it emits light at these and no other wavelengths in the visible region of the spectrum.

The vapor of every element or compound has a characteristic set of wavelengths that it absorbs when cool and emits when hot. The dark lines of absorbed light or the bright lines of emitted light that show up on the spectrogram reveal not only the presence of the element or compound but also the quantity, which directly determines how much light is absorbed or given off at the characteristic wavelengths.

A star, consisting of a large, extremely hot mass of gas surrounded by an "atmosphere" of cooler gas, produces a spectrum crossed by many dark lines. In a typical stellar spectrum, absorption lines appear at the wavelengths of hydrogen, helium, oxygen, nitrogen, titanium vapor, iron vapor and many other elements. Iron vapor absorbs at several thousand different wavelengths and marks the spectrum of the sun with as many dark absorption lines. The spectra



SPECTRA OF FIVE DWARF STARS reveal different apparent speeds of rotation. The absorption (dark) lines are broader for stars that spin faster if all five have their axes of rotation nearly at a right angle to line of sight. Broadening occurs because dark lines from spectrum of edge of stellar disk approaching the earth are shifted toward the violet and of stars hotter than 8,000 degrees Kelvin (degrees centigrade above absolute zero) do not show these absorptions because each iron atom has lost two of its 26 electrons and accordingly produces absorption lines outside the visible part of the spectrum. The large differences in stellar spectra arise mostly from differences in the temperatures of the stellar atmospheres.

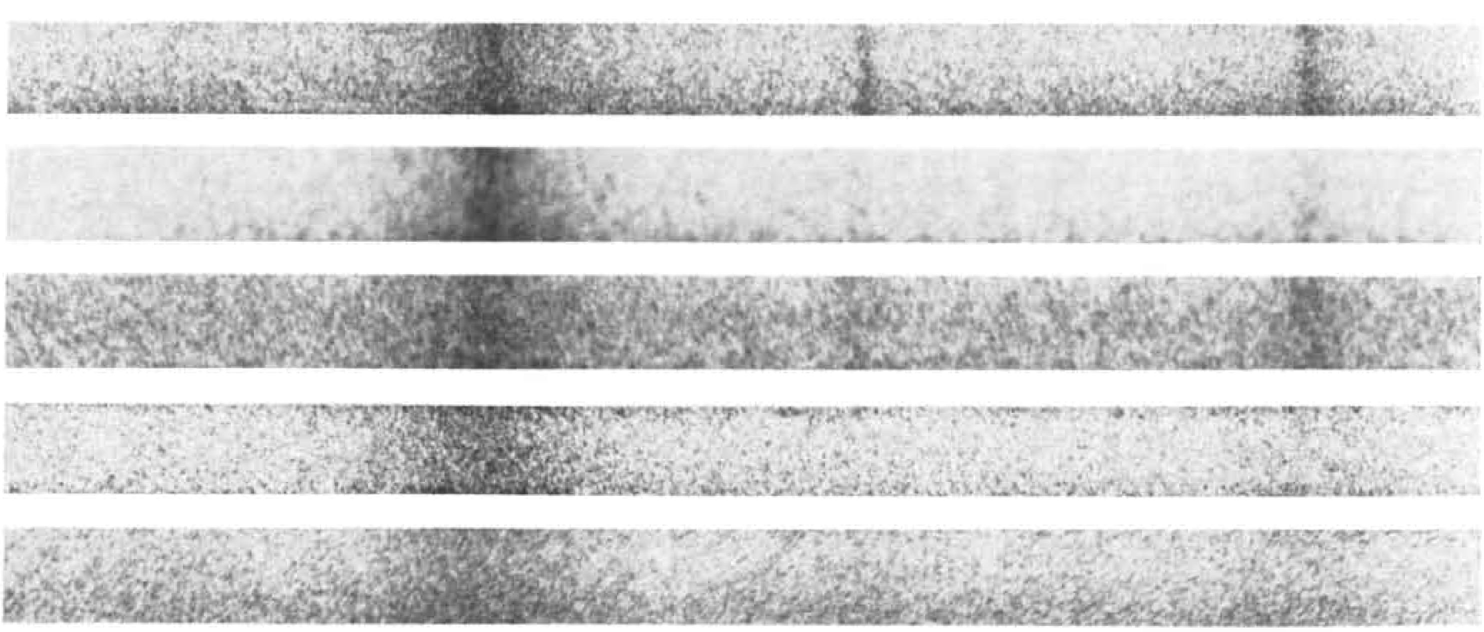
To detect and measure the rotation of a star the astronomer makes use of shifts in the characteristic position of the absorption lines that arise from the well-known Doppler effect. These shifts, including the famous "red shift," provide much information of other kinds about the stars and the galaxies. They show up most strongly when a star or a galaxy is in rapid motion toward or away from the observer on earth. If the object is approaching, the lines are shifted toward the violet (short wave) end of the spectrum; if it is receding, the lines are shifted toward the red. As in the more familiar experience with sound, the crests of the waves arrive with higher frequency from a source that is approaching and with lower frequency from a source that is receding.

The Doppler effect in a stellar spectrum caused by the linear motion of the star is usually so small that only the most accurate measurement can detect it. A typical star, moving at 35 kilometers per second toward or away from the earth, will have a Doppler shift of only half an angstrom. The most distant galaxies, on the other hand, have shifts toward the red of as much as 1,600 angstroms; this extreme red shift indicates motion away from the earth at speeds of up to 120,000 kilometers a second, or 40 per cent of the speed of light. In the spectra of these galaxies a correction must be made for a further shift toward the red caused by the slower passage of time associated with their accelerating speed of recession, an effect that is explained by Albert Einstein's special theory of relativity [see "The Clock Paradox," by J. Bronowski, page 134].

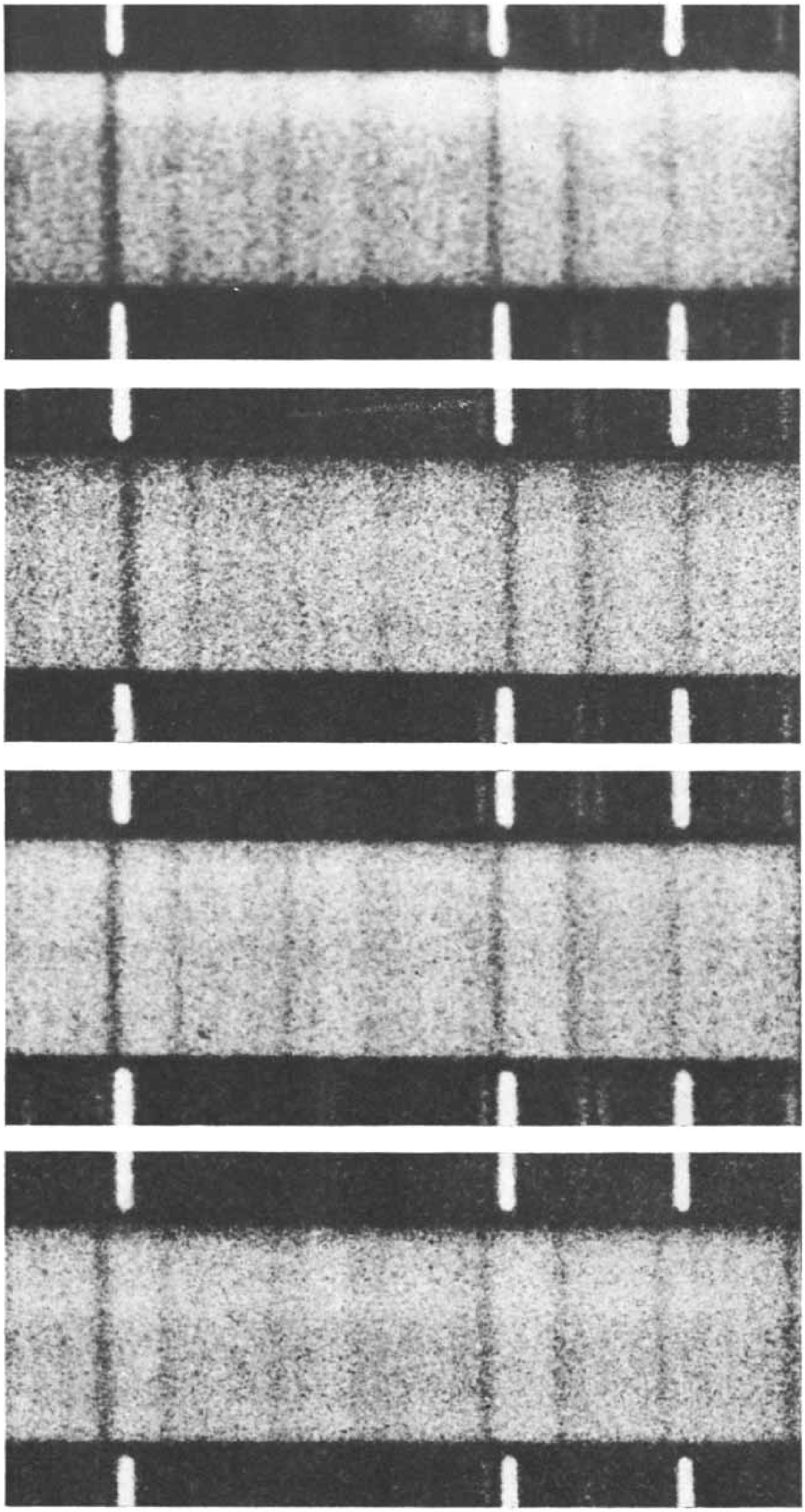
It now begins to be clear how the Doppler shift might be employed to measure the rotation of a star. If the star could be resolved into a disk and if its axis of rotation also happened to be at a right angle to the line of sight, one edge of the disk would be moving toward the observer and the other edge would be moving away. Correspondingly the lines in the spectrum from the approaching edge would be shifted toward the violet and those from the receding edge toward the red, whereas the spectrum from the center of the disk would show no Doppler shift because there the rotational motion would be at a right angle to the line of sight. In the case of the single star that can be resolved as a disk—that is, the sun—such measurements show the rotation at the equator to be at the rate of two kilometers per second.

In the case of all stars other than the sun the pinpoint of light that reaches the earth comes from all parts of their surfaces at once. Yet the Doppler effect still makes it possible to detect rotating stars and to measure the speed of their rotation. It is true that the spectral lines from one edge, shifted toward the violet, and the lines from the other edge, shifted toward the red, as well as the lines from intermediate points, are all superimposed. If the star is rotating with sufficient speed, however, the shift in both directions will widen the absorption lines [*see upper illustration on pages 50 and 51*]. Moreover, the breadth of the lines furnishes an accurate measure of how fast the star is turning. The most rapidly rotating stars, for example, are turning at an equatorial rate of 550 kilometers per second and the lines are about 15 angstroms wide.

There remains one ambiguity in this method: the orientation of the axis of rotation of the star. When the line of sight is not at a right angle to the axis of rotation, no part of the star is approaching or receding at full equatorial rotational speed and the absorption lines are correspondingly narrower. In the extreme case the line of sight is directly along the axis of rotation: one of the stellar poles points right at the observer. Then all the rotation is at a right angle to the line of sight and the absorption lines are as narrow as though the star were not turning, regardless of how fast it may really be doing so. Of course, if a star has very broad absorption lines, it is obviously rotating rapidly and its axis of rotation may be taken to lie roughly at a right angle to the line of sight.



those from edge that is receding are shifted toward the red. Lines from all parts of stellar disk are superimposed in actual spectrum, resulting in broad absorption lines when star is spinning rapidly. Top spectrum indicates star is rotating at 20 kilometers per second. Lines in spectrum of second star indicate apparent speed of 75 kilometers per second; of third star, 165 kilometers per second; of fourth, 300; and of fifth, 365. The spectra were made with 82-inch reflector at McDonald Observatory of the University of Texas.



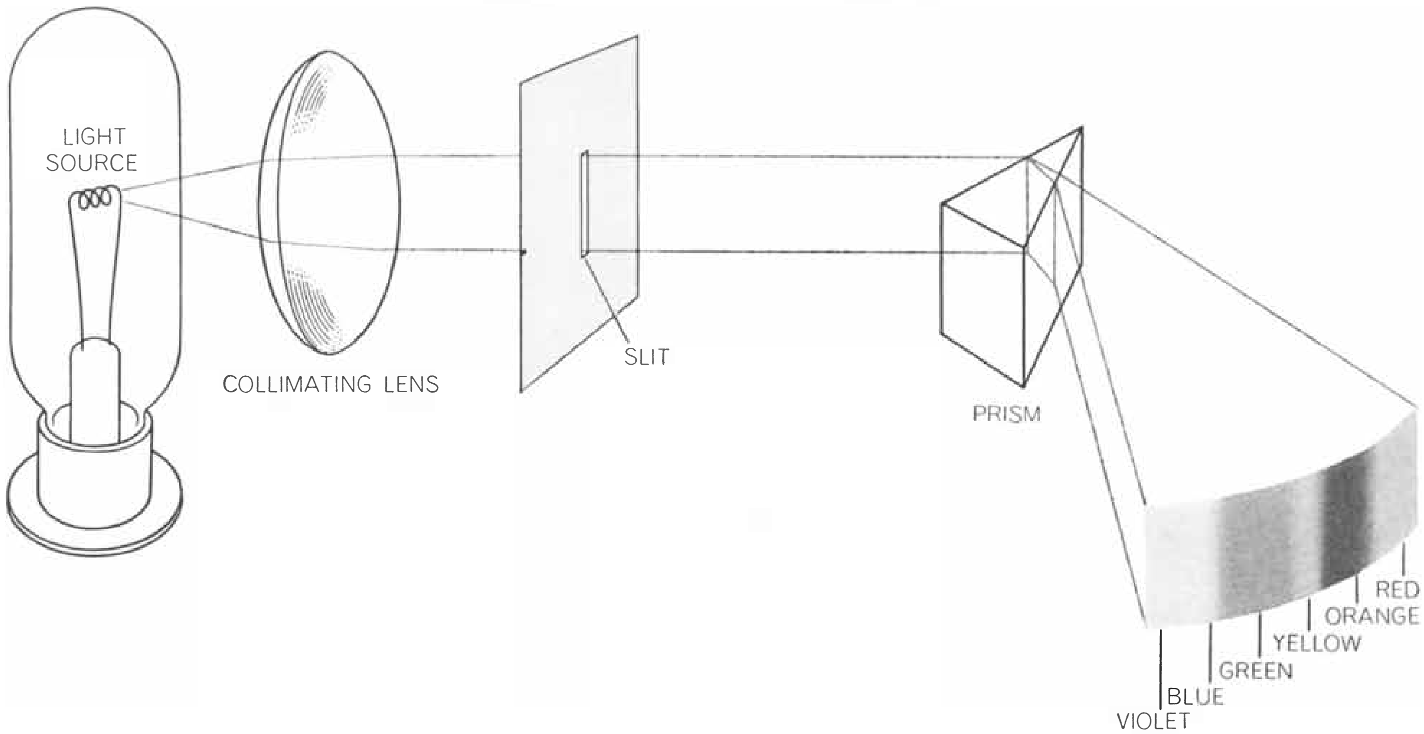
SPECTRUM REVEALS DOUBLE STAR, although faint member of pair contributes no light. The four spectra were made at the McDonald Observatory by the author on four successive nights in June, 1959. The bright vertical lines above and below each spectrum are emission lines from an iron arc light projected into the spectrograph in order to calibrate the wavelengths in the stellar spectra. Shift in dark lines of the star's spectra indicate motion toward or away from the earth, which shows that the star, Zeta Lyrae A, is revolving around common center of gravity shared by the invisible star. Complete cycle takes about 4.3 days.

Statistics provides a way out of this ambiguity. It seems reasonable to suppose that the axes of rotation of stars scattered over the sky are oriented in random directions, so that there should be as many stars with their poles pointing toward the earth as there are stars with axes pointing in any other given direction. For any large sample of stars, calculations can predict what fraction will be canted at any particular angle as seen from the earth. The astronomer can then adjust the apparent rotational velocities to allow for this effect. Therefore, although there is residual doubt whether any particular star with narrow lines is rotating slowly or rapidly, it can be assumed that for a large number of roughly similar stars (same size, temperature and evolutionary stage) a known fraction of those with narrow lines are rotating rapidly but are seen nearly pole on.

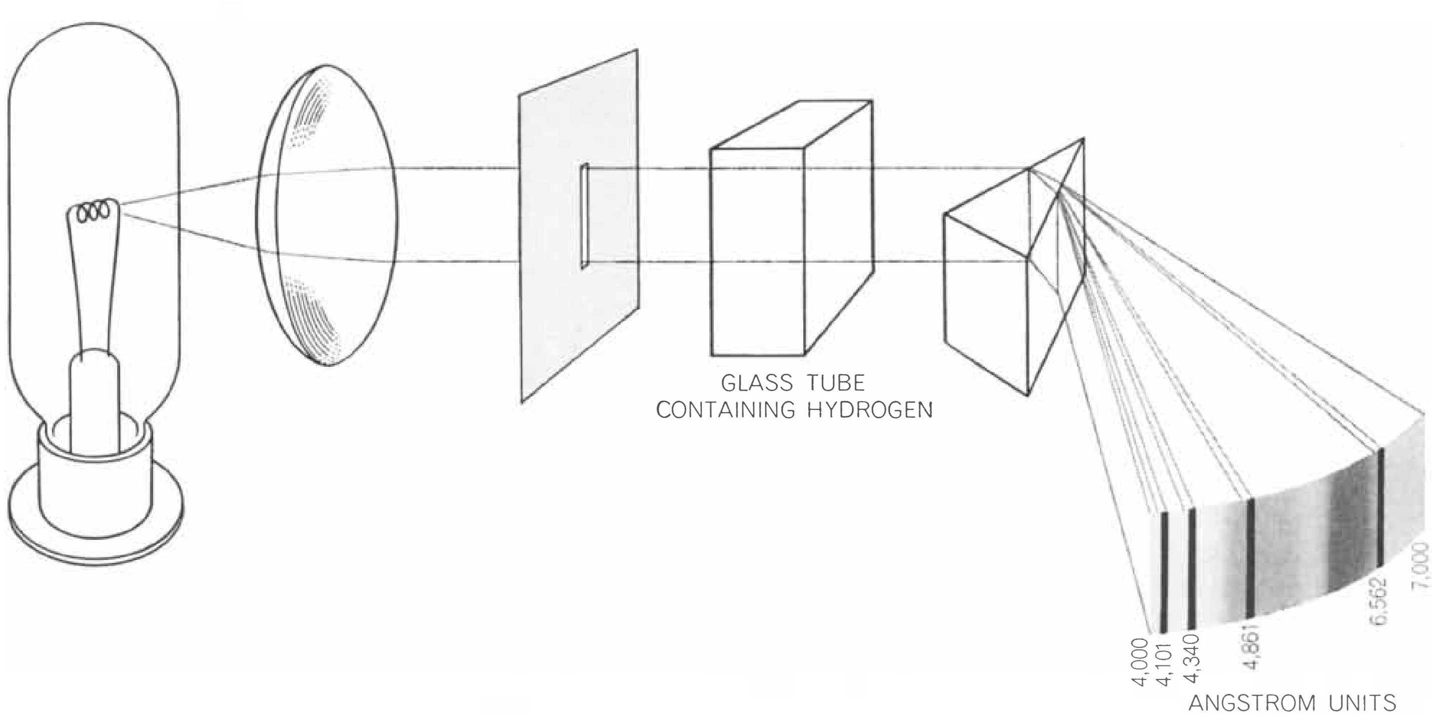
Rotational velocities have been determined for several thousand stars, notably by Arne Slettebak of Ohio State University. A summary of his results for approximately 300 unevolved, or main-sequence, stars, of which the sun is one, shows that in general the more massive the star is, the faster it rotates. (The data have been corrected for the effects of different angles of axis.) The more massive stars on the average rotate at roughly 200 kilometers per second [*see illustration on page 52*].

Certain surface features can be detected on stars rotating at almost the maximum speed, even though they are pinpoints in the telescope. Some of these stars are rotating at velocities of 550 kilometers per second, which is the maximum possible. In such stars the centrifugal force of rotation at their equators is greater than the centripetal force of gravity, with the result that they are actually losing material. Their spectra show bright emission lines that evidently represent spirals of extremely hot gas spinning off from their equatorial regions. These stars must also be appreciably flattened at their poles as a result of the rapid rotation, more so than the planet Jupiter. Such rapid rotation can also be detected even from the pole-on view, in which the absorption lines are narrow. A massive star turning at 500 kilometers per second seen pole on exhibits an unusual spectrum, indicating that the temperature at the equator is about 8,000 degrees Kelvin, whereas that at the pole is 24,000 degrees. The composite spectrum of the two regions thus reveals rapid rotation and an otherwise invisible surface feature: a polar "hot spot."

Slettebak's diagram also shows that no star less massive than the sun rotates faster than 25 kilometers per second; every one of these smaller stars has very narrow absorption lines. This leads to an interesting speculation. Although the sun turns at two kilometers per second, which means that it has little spin or angular momentum (the product of mass, radius and rotational velocity), it is accompanied by a set of planets that have little mass but a great deal of angular momentum by virtue of their large distances from the sun. It turns out that if the planets should fall into the sun, the sun would gain only .1 per cent more mass but would rotate 100 times faster! A rotational velocity of 200 kilometers per second is typical of the more



CONTINUOUS SPECTRUM is produced by light from tungsten filament. A collimator lens to make the light rays parallel, a slit to give a fine beam and a prism to break white light up into its component colors (wavelengths) are essential parts of the spectrograph.



ABSORPTION LINES appear in spectrum when light passes through a glass tube of hydrogen gas. The gas always absorbs at the wavelengths shown, or, when heated to incandescence, emits visible light only at these wavelengths. In same way, atmosphere of a star absorbs light at the wavelengths characteristic of atoms and molecules in the atmosphere, making dark lines in stellar spectrum.

massive stars. Does this mean that stars of low mass all have planets? Not necessarily; other conditions can cause low rotational velocities.

This has been demonstrated by studies of star clusters. Slettebak obtained his data largely from field stars, which are distributed over the sky and do not, for the most part, belong to recognized clusters. One of the earliest investigations of rotation in stars that belong to clusters was made of the Pleiades during the 1930's by Otto Struve, who was then director of the Yerkes Observatory of the University of Chicago. He found that the 15 brightest and most massive stars in the Pleiades rotate significantly faster than field stars. Since then measurements of the speed of rotation of more than 100 stars in four clusters have been made from spectrograms obtained with the 82-inch reflecting telescope at the McDonald Observatory of the University of Texas. The clusters and associations, which are larger groupings sometimes containing several clusters, were the Pleiades, the group of stars around Alpha Persei, the I Lacerta association and the I Orion association, which includes most of the stars of the constellation Orion. In addition, Father Patrick J. Treanor of the Vatican Observatory has measured the rotational speed of stars in the Hyades and Praesepe clusters; Arthur J. Meadows of the University of Illinois, in the Messier 39 cluster and the Ursa Major (Big Dipper) cluster; and D. H. McNamara of North American Aviation, Inc., in the I Orion association [*see illustration on page 52*].

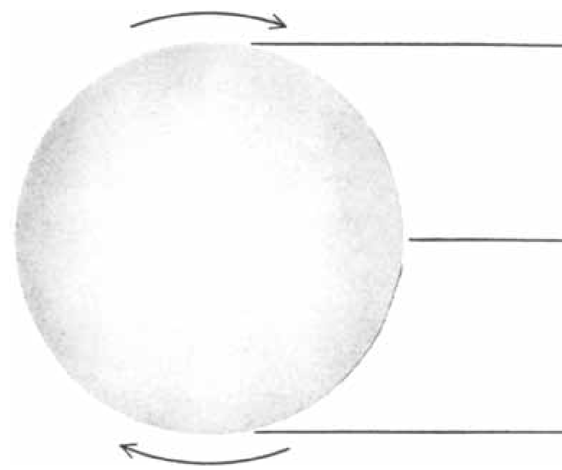
Nearly every cluster has its own characteristic association of rotational velocity with mass. For example, on the average the heaviest stars of the Pleiades rotate faster than field stars of the same mass, but the stars in the Pleiades of less than four times the mass of the sun rotate unusually slowly. On the other hand, the most massive stars in the Hyades and Praesepe clusters rotate rather slowly, and the lighter ones rotate more rapidly than similar field stars.

These differences can be partly explained by the relative frequency of double, or binary, stars. Large telescopes reveal that quite a few nearby stars are actually two stars close together. An even greater number are "spectroscopic" binaries, in which only one point of light appears in the telescope but the spectra show Doppler shifts that vary with time [*see illustration on page 48*]. Such a shift indicates that the star is moving in an orbit, and an object in orbit moves around a center of gravity shared with some other object. Thus the spectrogram can detect a binary even when it is too far away to show up as two stars in the telescope. Roughly half the stars in the sky are either spectroscopic or visual binaries.

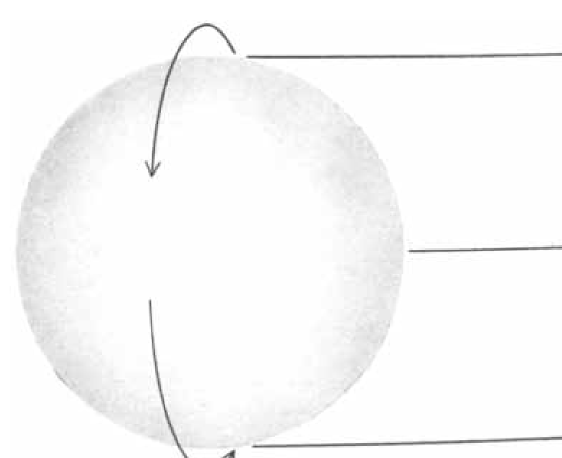
Among the 15 brightest and most massive stars of the Pleiades, none is known to be double and all rotate with unusually high velocity. In contrast, half and probably more of the brightest and most massive stars in the I Orion and I Lacerta associations are definitely spectroscopic binaries, and all of them rotate with unusually low velocity. In general, it is evident that members of binaries rotate slowly and that single stars rotate rapidly.

The explanation for this lies in the process in which stars originate. Stars form out of gaseous nebulae such as the Great Nebula in Orion, which is visible as the fuzzy central area in the "dagger" of the hunter Orion. At present the gas is turbulent, but gradually it will contract into stars, as the gas has in many other nebulae. The angular momentum of the turbulent gas cloud may be conserved in the resulting stellar cluster and show up in two principal forms: in the orbital motion in binary systems and in the rotational spin of the stars. Where single stars form, all the angular momentum goes into rotation and the stars rotate rapidly. If a binary forms, most of the angular momentum generally goes into the orbital motion of the two stars about their common center of gravity, with the residual momentum showing up in the low-speed rotation of the member stars. The over-all differences in the speed of rotation that distinguish the members of clusters reflect the differences in the frequency with which binaries have formed in that cluster.

The two dips in Slettebak's diagram at 2.5 and 10 solar masses have given rise to some discussion. In view of the differences in the speed of rotation that characterizes the members of clusters, however, these dips in the curve are not hard to explain. The curve is based on the 300 stars that are easily visible from the Northern Hemisphere without a telescope (brighter than fifth magnitude). Some belong to clusters or have drifted away from clusters. For instance, a quarter of the stars having a mass between 2 and 2.5 times greater than that of the sun are members of the Ursa Major stream: a collection of more than 100 stars distributed over a large portion of the sky, the motions of which indicate that they are traveling together in space. The Ursa Major cluster is the nucleus of this stream and the association between rotational velocity and mass seems to be the same for the stream members and the cluster members. For these stars the speed of rotation decreases with increasing mass rather than the reverse. Hence the admixture of an appreciable number of Ursa Major stars in the sample of field stars has distorted the field-star



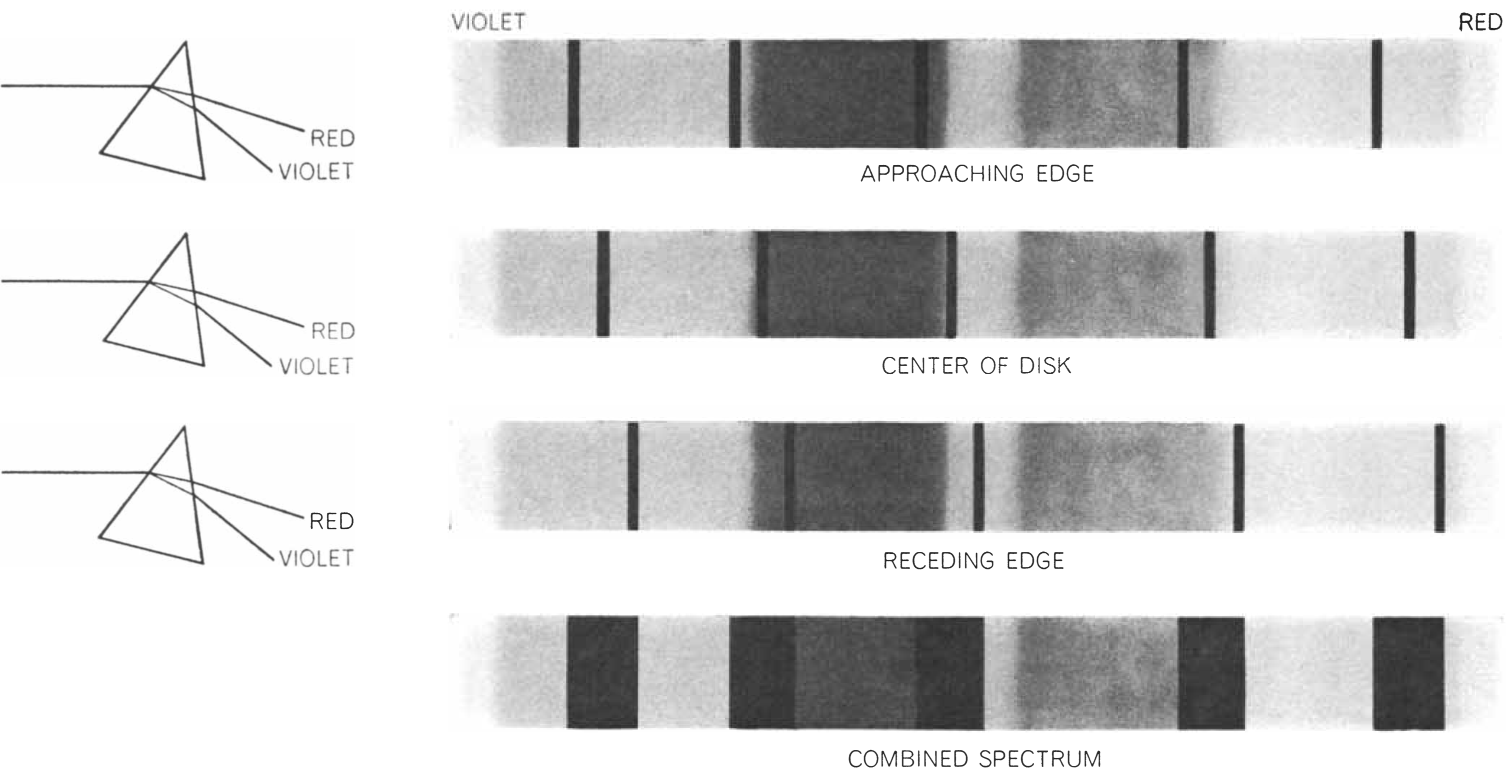
DIRECTION OF AXIS of rotation of a star influences width of spectral lines. If axis is at or near a right angle to line of



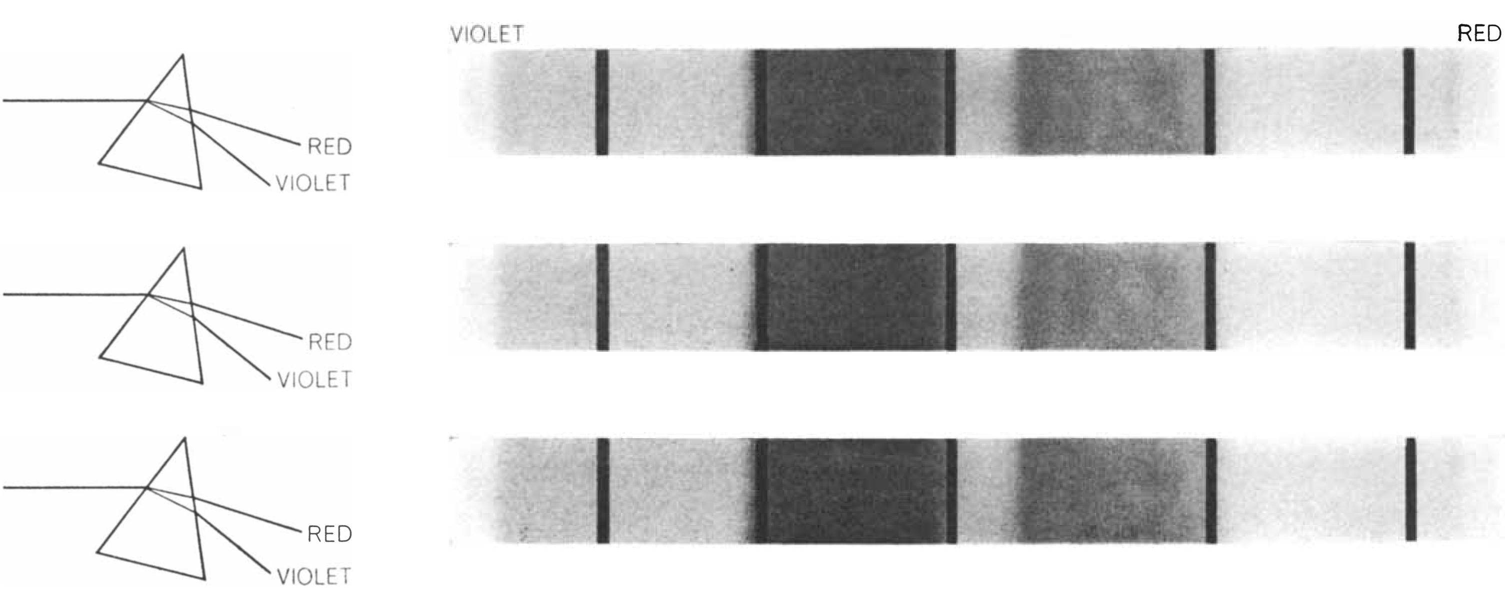
AXIS PARALLEL to line of sight gives narrow spectral lines no matter how fast star curve; if the Ursa Major stars are removed from the sample, the dip disappears. Similarly, the dip at 10 solar masses is probably due to stars from other clusters having unusual mass-rotation characteristics.

There remains for speculation the question of whether the stars of low mass that rotate slowly do so because they have planets. At present the question is one for speculation only, because planets would be utterly invisible at the distances of even the nearest stars.

By various stratagems students of stellar rotation have extracted from their data some idea of the internal structure of individual stars. In general, stars have exterior temperatures between 2,000 and 100,000 degrees Kelvin; the temperatures increase toward their centers to a maximum of at least 10 million degrees. These high temperatures result from the high pressures produced by the inward pressure of the stellar mass, and the heat maintains the thermonuclear reactions that produce the energy given off by the stars. At most stellar temperatures all material is vaporized and many atoms, even in the outer parts, have lost electrons. Thus a star is simply a large, roughly spherical ball of ionized gas. Since it contains no solids, it has no surface in the ordinary sense of the term. The "surface" of the sun is the depth to which man's vision penetrates the gas;



sight from earth, as here, width of absorption lines indicates speed of rotation. Lines from approaching edge are shifted toward violet; those from center of disk are not shifted; those from receding edge are shifted toward red. As seen from earth, all shifts of each line are superimposed on one another on the photographic plate, producing the broad lines shown in the bottom schematic spectrum.



is really rotating. There is no rotation toward or away from the observer to produce shifts in the absorption lines. As a result the astronomer usually cannot determine whether any particular star with narrow spectral lines is actually rotating slowly or rapidly.

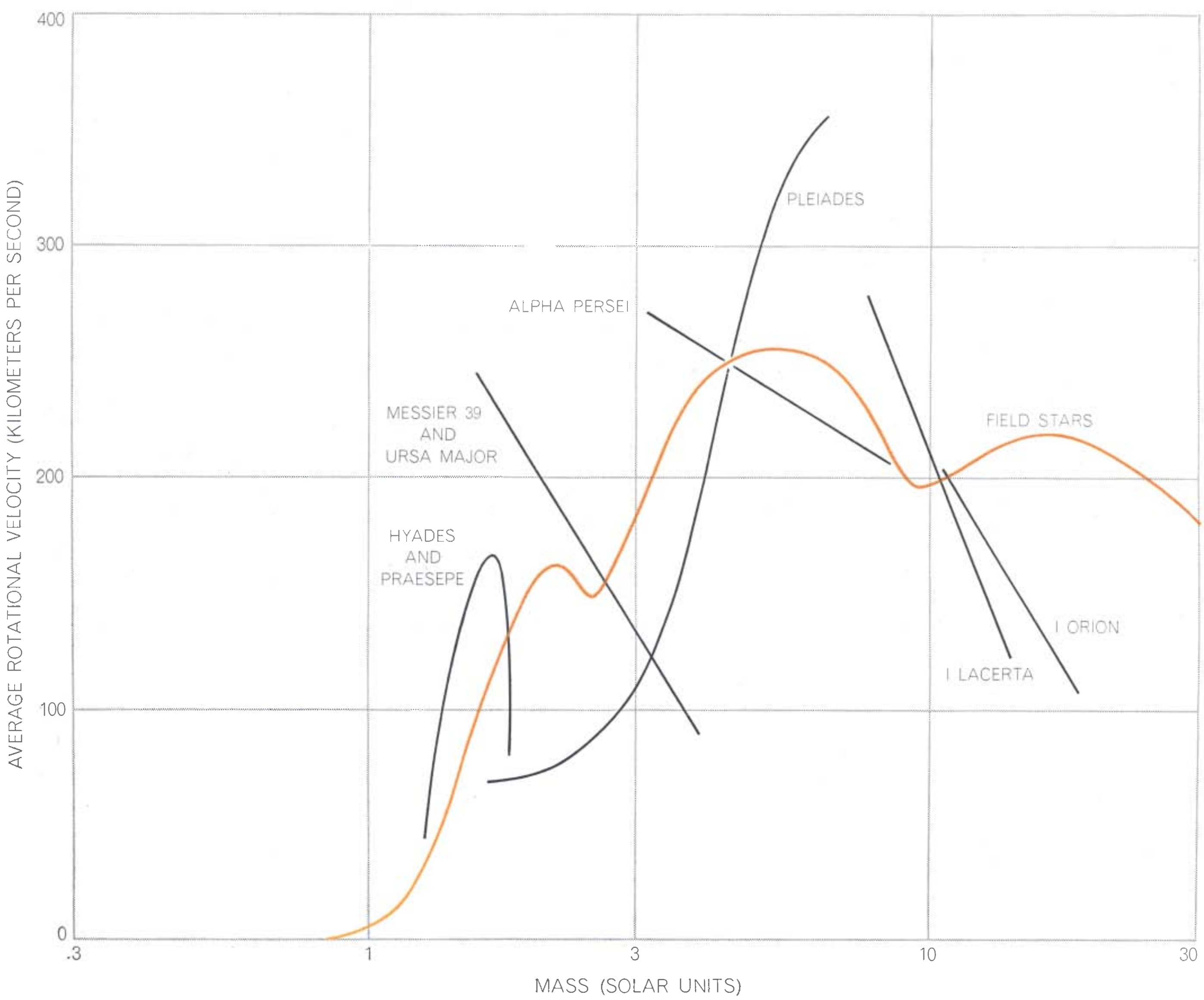
the gas outside is the stellar atmosphere.

There is no reason why a star should rotate as a solid body, since it is entirely gaseous. The core, for example, may be able to rotate more rapidly than the outer layers. Strong interior magnetic fields would tend to hold the ionized gas in a rigid mass, but although some stars are known to have strong magnetic fields near their surfaces, it is not certain that their interior magnetic fields are strong enough to do so.

Some slippage, or differential rotation, does occur in the sun. Sunspots at different latitudes can be seen to cross the disk at different speeds. Doppler shifts at various places on the solar disk show that the period of rotation 75 degrees north or south of the solar equator is 33.1 days, and at the equator it is only 24.6 days. The high-latitude regions, therefore, lag behind the equatorial regions. These observations, however, refer only to the outer parts of the sun, where the gas is tenuous and differential rotation may be unusually large.

The sun is a somewhat small (in mass) but otherwise normal example of all unevolved stars, on which Slettebak made his observations. In the case of these stars there is no explicit evidence that the stellar interior is rotating at a different rate from that of the outer layers. Such stars have contracted fully from nebulae and are producing energy by converting hydrogen into helium in thermonuclear reactions. They will continue to maintain nearly the same size and surface temperature until their interiors are depleted of hydrogen. The length of time this takes depends on the amount of hydrogen they contain and the rate at which it is being converted to helium. For the sun this evolutionary stage will take about 12 billion years, of which five billion have already passed. The most massive stars, in contrast, have the highest central pressures and temperatures and are therefore converting hydrogen to helium at much more rapid rates. Even though they started with 100 times more material than the sun, they are using it up a million times faster, which gives them only a ten-thousandth as long to go through the hydrogen-burning stage as the sun, or about a million years. Any such stars now visible must be less than a million years old.

Once the supply of hydrogen has been depleted the core of the star collapses, the central temperature quickly increases and the star begins to convert helium to carbon. Meanwhile the outer



SPEED OF ROTATION of stars plotted against stellar mass shows that among unevolved, or main-sequence, field stars (*colored curve*) only those more massive than the sun have appreciable speeds of rotation. The relation between velocity of rotation and stellar mass is quite different for many stars in clusters (*black curves*). The relative frequency of binaries may account for this.

parts of the star expand drastically. During this phase, and later ones, the distribution of density in the interior changes radically. The changes at each phase can be computed by employing the mathematics of thermodynamics, nuclear physics and astrophysics.

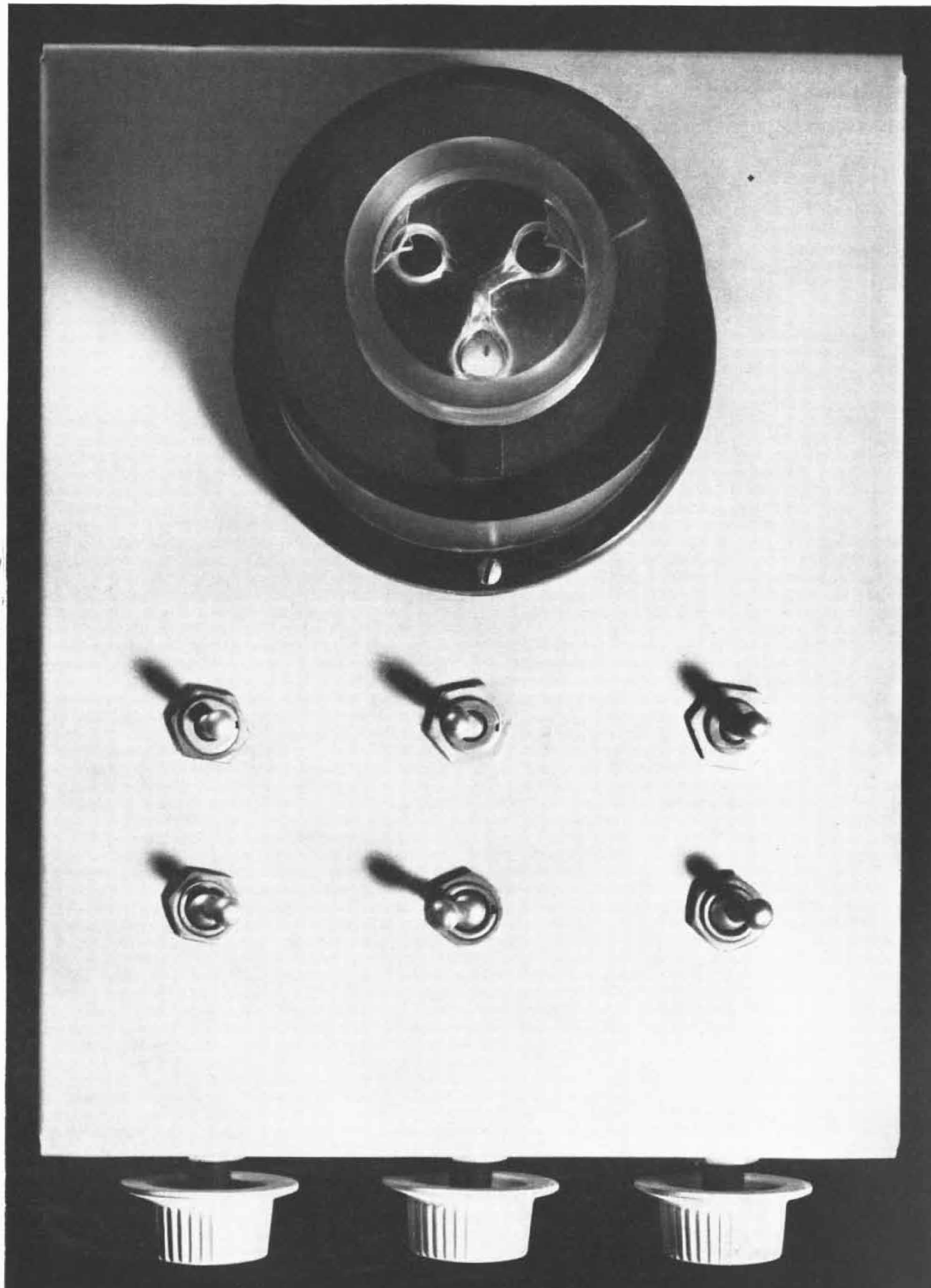
During the expansion of an evolving star its total amount of angular momentum cannot increase, and probably it remains constant. The total angular momentum is the product of the mass, distance from the axis of rotation and rotational velocity of each part of the star, summed together. The mass stays constant; therefore as the radius increases, the outside equatorial rotational velocity must decrease. If one assumes complete slippage between the interior and exterior, each part of the star can be considered alone. In particular, if the star becomes 10 times larger in radius, its rotational velocity should become 10 times smaller. At the other extreme, if the star is bound together by a strong magnetic field and so is caused to rotate as a solid body at each phase during its evolution, there will have to be a transfer of angular momentum within the star. The amount of transfer depends on the changes in the internal distribution of density. Detailed calculations indicate that stars of, say, five solar masses that increase 10 times in radius will rotate only five times slower.

Many stars in the sky are currently expanding, having depleted their internal hydrogen. Of course they cannot actually be seen to grow, because most (although not all) evolutionary changes in stars occur slowly compared with human lifetimes. They can be recognized as expanding stars, however, because they are already much too large for their masses. Well-known giants or supergiants of this type are Rigel and Betelgeuse in Orion; Deneb, the brightest star in Cygnus; the brightest star (Alpha) in Perseus; and Arcturus, the brightest star in Boötes.

Today the rotational velocities of these stars can be calculated from the width of their absorption lines and compared with the rotational velocities of stars of similar masses that have not yet started to expand. So far the results indicate that the giant stars do not rotate as solid bodies. These expanding stars have rapidly rotating cores and more slowly rotating outer layers. Thus the observed rotation of stars reveals something about their internal structure, even though the stars themselves are visible as nothing more than pinpoints of light.

GREAT NEBULA IN ORION is an example of a turbulent mass of gas condensing into stars. Angular momentum of cloud may be conserved in rotation and orbital motion of stars that condense out of it. Photograph was made with 100-inch telescope on Mount Wilson.

PRAESEPE CLUSTER in constellation Cancer is a group of stars that have condensed out of a single mass of gas. Conservation of original angular momentum of the gas cloud has given the rotation of the stars a mass-to-speed relation characteristic of the cluster.



TRAINING APPARATUS for planarian worms, which also appears on the cover of this issue, consists of a plastic chamber containing three wells connected by a Y-shaped tunnel. The wells can be illuminated individually with a light of variable intensity.

PROTOPSYCHOLOGY

The term is applied to subtle types of behavior recently observed in a primitive worm. Heretofore such behavior had been associated only with animals standing much higher in the evolutionary scale

by Jay Boyd Best

It is generally accepted that the behavior exhibited by an animal, from the most primitive to the most advanced, arises from its brain. But how highly evolved a brain does it take to manifest those psychological attributes that we have come to associate with sentient behavior, as opposed to "mindless" or "automatic" behavior? The main structures found in the brains of men and monkeys are present in all vertebrate brains. The basic plan of this brain may have been laid down as long as 400 million years ago with the appearance of sharks in the Devonian period. Is this plan a prerequisite for anthropomorphic, or even "vertebramorphic," behavior? Is the hypothalamus necessary for hunger? Is the region of the midbrain known as the limbic system needed for fear and pleasure? Is the cerebral cortex required for pattern recognition and "complex" behavior?

When a group of us at the University of Chicago were considering such problems in 1954, it seemed to us that planarian worms might provide clues to these related riddles. The fresh-water planarian is a primitive animal that has bilateral symmetry, a rudimentary central nervous system and a distinct head end that exerts control over the rest of its body. A member of the phylum of flatworms, it has a blind-ended gut and no circulatory system. Planarians are the contemporary representatives of what must have been a very ancient form of animal, from which many higher forms of invertebrates and also the vertebrates presumably evolved.

We were aware that fresh-water planarian worms can grow a new brain, if the original one is removed, and that they will accept tissue transplants from other planarians. It seemed to us that an animal with a brain that could be regenerated and transplanted might lend itself—if it could also learn something—to experiments not possible with higher animals such as rats. What, if anything, planarians could learn was not clear. This in itself was a question of some importance.

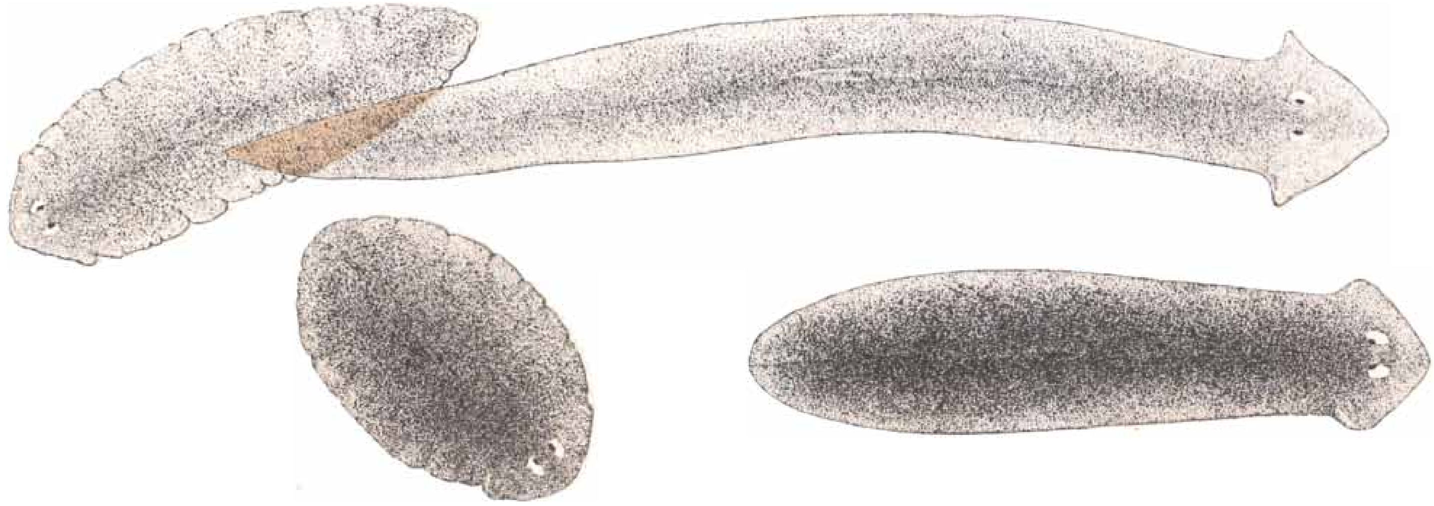
About 40 years ago, when many workers were studying the "conditioned reflexes" first described by the Russian physiologist I. P. Pavlov, a number of conditioning experiments were performed with planarians and other kinds of worms. These early investigators were largely unaware, however, of the unlearned modifications in behavior, called pseudo-conditioning, that can be produced simply by barraging the nervous system of an animal with nonspecific stimuli. Many of their results were therefore difficult to interpret and not up to the standards of rigor currently demanded of studies of this sort. As the concepts of experimental psychology became more sophisticated and its experimentation more refined, attention was largely focused on such animals as pigeons, rats and monkeys. Between 1956 and 1959 fewer than 3 per cent of all animal-behavior experiments were performed on invertebrates, although invertebrates constitute 12 of the 13 animal phyla.

Just prior to that period Robert Thompson and James V. McConnell, working at the University of Texas, performed a classical conditioning experiment with planarians that was better controlled than any up to that time. Classical conditioning experiments are learning experiments similar to those undertaken by Pavlov. In these experiments some stimulus, such as food, acts as the "unconditioned stimulus." This is a stimulus that normally, and without training, evokes a response from the animal. For example, in a dog the normal response to food is salivation. Shortly before the unconditioned stimulus is presented, the animal is exposed to a "conditioned stimulus," such as the sound of a buzzer. The conditioned stimulus normally produces no response, or a response different from that evoked by the unconditioned stimulus. After a number of trials the conditioned stimulus evokes a response resembling that normally evoked by the unconditioned stimulus. Thus the dog will begin to salivate on hearing a buzzer that alerts him to the fact that food is coming.

In the Thompson and McConnell experiment a conditioning trial consisted of suddenly shining a strong light on a planarian. Several seconds after the light was turned on, the planarian received a mild electric shock. The planarian's normal response to the light alone was to stretch itself. When it received the shock, it contracted or turned its head. After 100 or so conditioning trials, in which shock followed light, the normal response to the onset of light became modified into a response resembling that originally evoked by the shock.

These conditioning trials were repeated until a certain training criterion was attained; for instance, a worm was considered trained when the modified response was evoked in 23 out of 25 successive trials. If a trained animal is not exposed periodically to the experimental conditions, it tends to forget what it has learned. If it can be retrained with fewer trials than were originally required to reach a certain criterion, however, one can assume that the animal has not completely forgotten what it once knew. The amount of retention, as measured by the reduction in training trials, is referred to as a savings.

Later McConnell, Allan L. Jacobson and Daniel P. Kimble, working at the

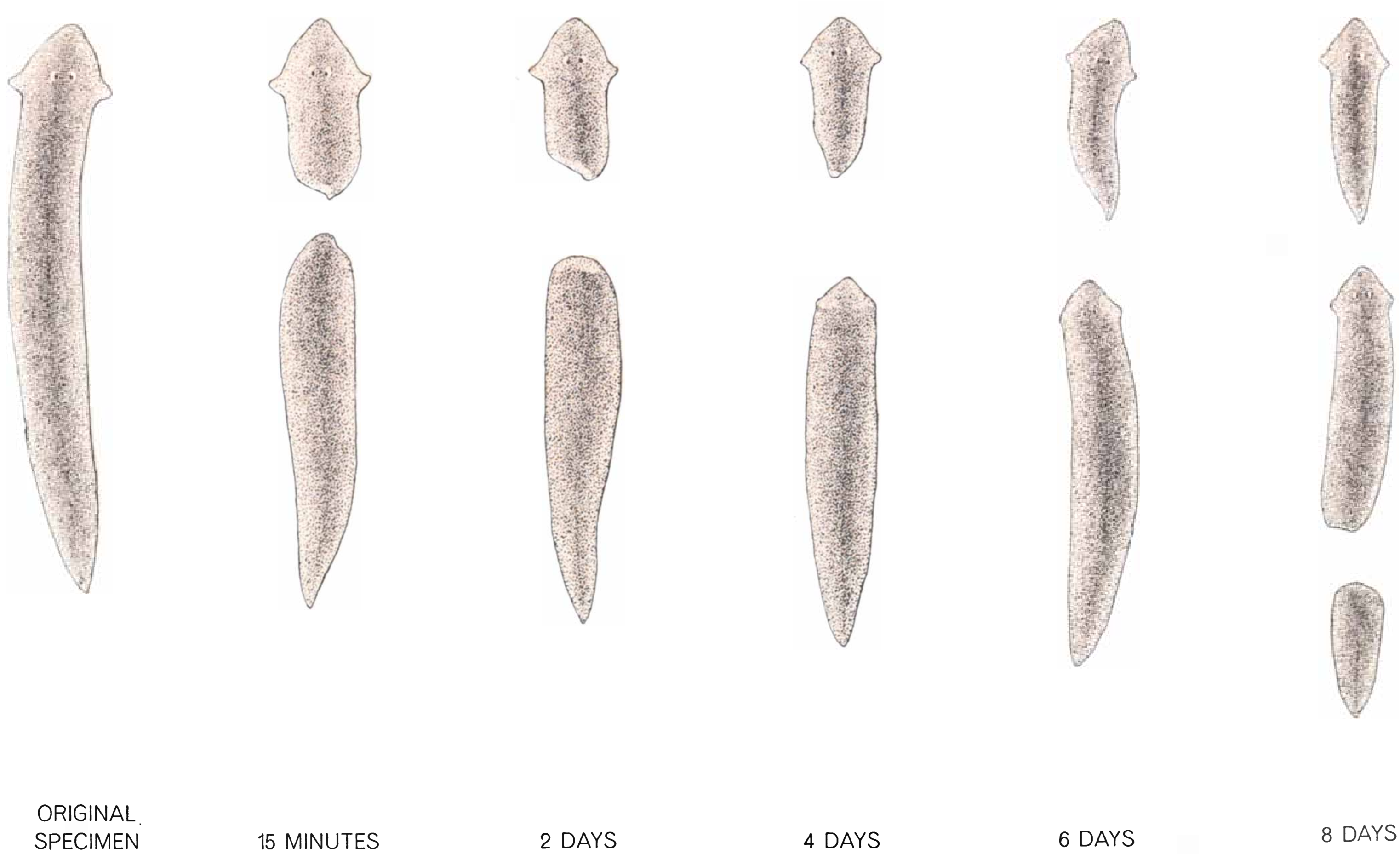


PLANARIANS USED IN STUDIES reported in this article were of two principal species: *Dugesia dorotocephela* and *Cura foremani*. *Dugesia* is represented as it looks when moving (*upper right*) and when quiescent (*upper left*). *Cura* is shown below.

University of Michigan, carried the planarian conditioning experiment one step further. Worms were trained to criterion, cut in two and the two halves were allowed to regenerate. On retraining to criterion a savings was found in the worms derived from tail pieces as well as in those derived from head pieces. It appeared from this that both the tail portion and the head portion were capable of memory storage.

How is this memory stored? It is known that genetic information is stored in deoxyribonucleic acid (DNA). Conceivably information about experienced events is stored in nerve cells in a closely related giant molecule: ribonucleic acid (RNA). This hypothesis is supported by recent experiments with rabbits, performed by Holger Hydén of the University of Göteborg in Sweden [see "Satellite Cells in the Nervous System," by Holger Hydén; SCIENTIFIC AMERICAN, December, 1961]. Following this lead William C. Corning, working in E. R. John's laboratory at the University of Rochester, undertook the following experiment. Planarians were trained and cut in the same way as they had been in the Michigan experiment except that the pieces were allowed to regenerate in a solution of ribonuclease instead of the usual spring water. Ribonuclease is an enzyme that specifically destroys RNA. On retraining the regenerated worms Corning found a savings for those derived from head pieces but not for those from tail pieces.

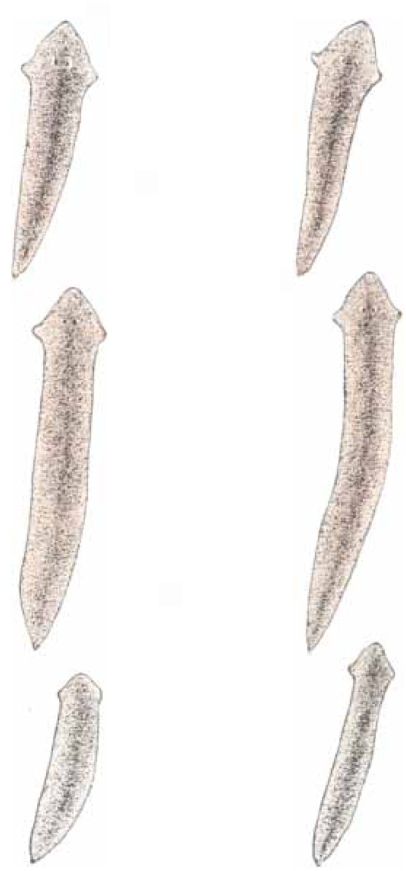
What do these interesting results



REGENERATION OF PLANARIANS takes place when a specimen is cut in half as well as when spontaneous fission occurs. The drawings show the stages of recovery after a specimen was cut in half. Tail section underwent spontaneous fission on seventh day.

mean? Failure of ribonuclease to obliterate the memory of the head piece may mean that the memory storage in the head is not coded into RNA or, more likely, that the large protein molecule of ribonuclease cannot get into the head to attack the RNA and attacks only the RNA of regenerated tissue. Since the head controls the worm, a worm whose head contained the memory would show savings. One whose head did not contain the memory—even though its tail did—would not show savings. It does not seem likely that the ribonuclease specifically obliterates memory-containing RNA in the tail piece. Since RNA is known to be involved in protein synthesis, ribonuclease may nonspecifically disrupt an entire complex of processes involved in transmitting the memory from the tail to the regenerated head. In support of this idea is the observation by Corning and John that ribonuclease concentrations only slightly higher than those employed in the basic experiment produced many deformities in the regenerated heads. Weighing against the notion of nonspecific damage, however, is the fact that worms derived from ribonuclease-treated tails could be retrained in approximately the same number of trials as the original worms.

Meanwhile, back at the Michigan laboratory, a simple experiment was done that yielded an incredible result. McConnell, Jacobson and Barbara Humphries trained planarians to criterion using the same classical conditioning procedure described above. The trained planarians were chopped into pieces and fed to a group of untrained planarians. A second group of untrained planarians was fed pieces of other untrained planarians. The cannibals that had eaten the trained planarians yielded a higher proportion of conditioned responses than those that had eaten untrained ones!



Experiments show learned behavior is "remembered" by both head and tail sections.

Does this perhaps mean that human cannibals were right in believing they would acquire the personality traits of some respected person if they ate him? Probably not. The planarian digestive tract, unlike the human, does not seem to carry out digestion by extracellular enzymes that break down the large molecules of protein, nucleic acid and polysaccharide. Instead it contains amoeba-like cells that engulf food particles by a process resembling the ingestion of a bacterium by a white blood cell. It is quite likely that in the planarian large molecular units, and perhaps whole cells, are taken up undegraded.

Two other features of planarians point toward yet another possibility. First, planarians do not show the exacting immunological specificity found in humans or other mammals, since transplants of tissue from one planarian to another are readily accepted. Second, the cells inside the planarian seem to be rather loosely packed; this allows unspecialized cells to migrate the length of the worm. It is therefore not improbable that many cells of the eaten planarian, escaping detection because of their similarity to the cannibal's cells, infiltrate the cannibal and migrate to appropriate sites in its tissues.

All the experiments performed by the Michigan and Rochester groups rest on the classical conditioning regime of Thompson and McConnell. Is this learning in the conventional sense one applies to higher animals? Or is it, in spite of the controls, a complex trick of nature like pseudo-conditioning or the speech of a parrot, which yields only a mimicry of intelligence?

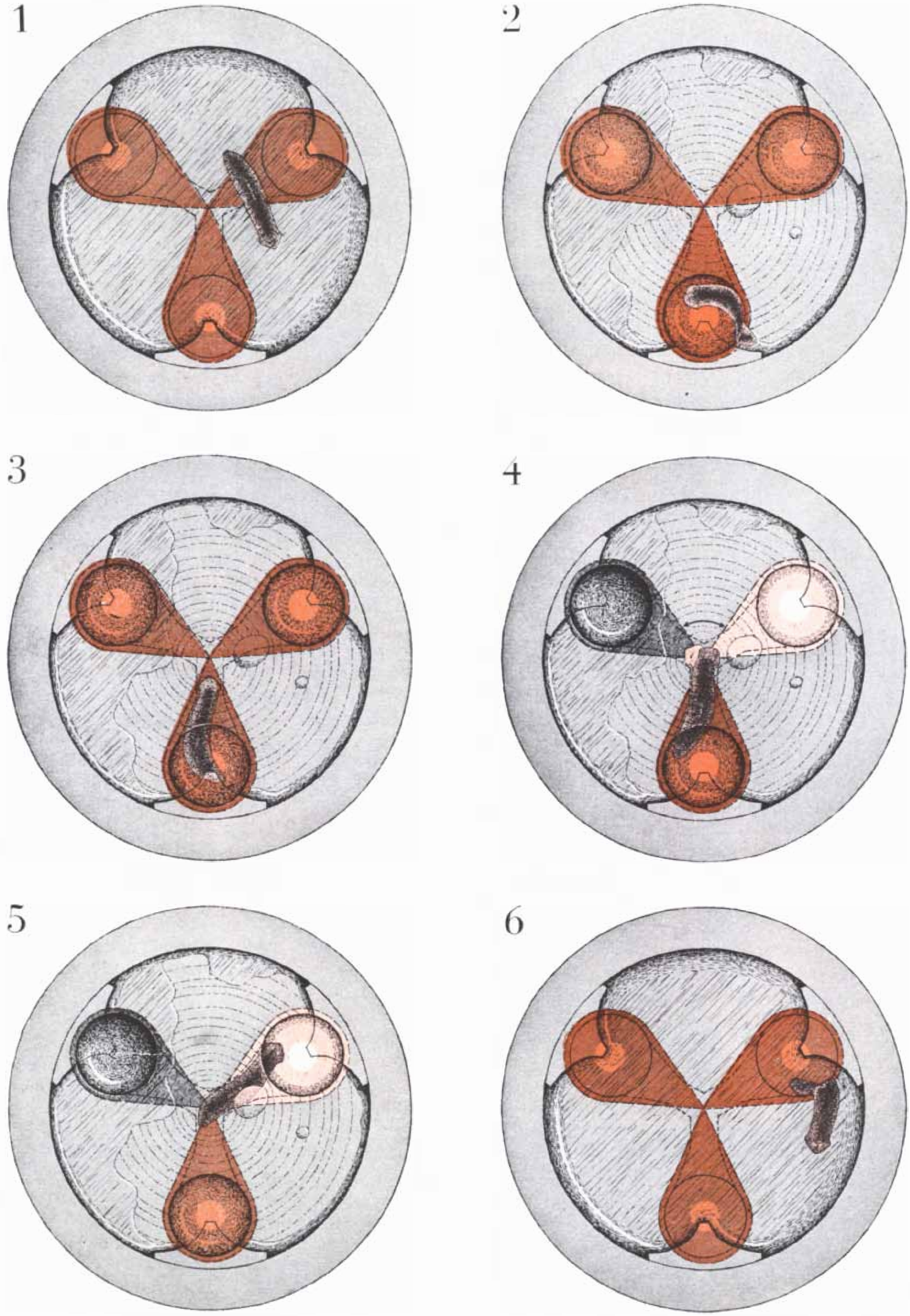
In 1958 Irvin Rubinstein and I, working at the Walter Reed Army Institute of Research in Washington and unaware of the Michigan experiments, set out to ascertain if planarians were capable of "instrumental" learning. Instrumental learning differs from classical conditioning in that the animal is trained to do something in order to get or avoid something. Thus whether the animal gets reinforced, by punishment or reward, depends on its response.

Maze learning, in which the animal is punished for making a wrong choice of alternative paths or rewarded for making the correct choice, is an example of instrumental learning. Rubinstein and I wanted a situation that would eliminate the disturbing effect produced by handling the worm between trials and provide unequivocal evidence of learning. To achieve these objectives we built a simple maze consisting of three identical cylindrical wells connected by a symmetrical Y-shaped tunnel. The entire maze was made from a block of clear acrylic plastic and was equipped with lights so that the wells could be illuminated individually. Each well could be made to appear bright, dimly lighted or dark. The maze was filled with water and a worm was placed in it [*see illustration on next page*].

For a training trial the water was withdrawn from the maze. Thereupon the worm would enter one of the wells and crawl into the Y-shaped tunnel looking for water. When the worm was securely in the tunnel, the well connecting to one fork of the Y directly ahead of the worm was brightly lighted and that connecting to the other fork was totally darkened. If the worm chose the lighted well, the maze was flooded with water. If it chose the darkened one, water was withheld and the lights were switched around so that it again had to make a choice between the branches leading to the darkened and the brightly lighted well. Following a correct choice, all the wells were switched to dim illumination and the worm was allowed to remain in the water-filled maze undisturbed for 15 minutes. It would then be put through another trial in the same way.

To eliminate any systematic coincidence of right-left choice between worm and experimenter, the well to be darkened and the well to be illuminated in each trial were determined by lottery. Moreover, about half of the worms in the experiment were trained to go to darkened rather than lighted wells. After 10 to 15 trials the worm was put back into a finger bowl filled with spring water, which served as its home during the period of the experiment. It was put through a training session every two days.

In the first session of trials the worms would pick the lighted well about as often as the darkened one. By the second session they would show a marked preference for the reinforced alternative. That is, the worms that received water



"INSTRUMENTAL" LEARNING takes place when a planarian is rewarded for doing something. In this case it is rewarded with water if it selects a lighted branch rather than a darkened one when it comes to a fork in a Y-shaped tunnel. The experimental apparatus is that shown in the photograph on page 54 and diagrammatically on the opposite page. At the outset (*1*) the entire maze contains water. When the water is removed (*2*), the worm enters one well in search of another supply. As it enters the tunnel (*3*) all wells are dimly lighted. When the worm is securely in the tunnel (*4*), one well is brightly illuminated and the other darkened; the planarian must choose one. If it chooses the lighted well (*5*), it is rewarded with water (*6*). Some worms are trained to go to darkened wells.

for choosing the lighted well chose the lighted well more often, and those that received water for choosing the darkened well chose the darkened well more often. Some of our worms continued to increase their preference for the rewarded alternative still further into the third session and a few still more in the fourth session. But an odd thing eventually happened with all of them.

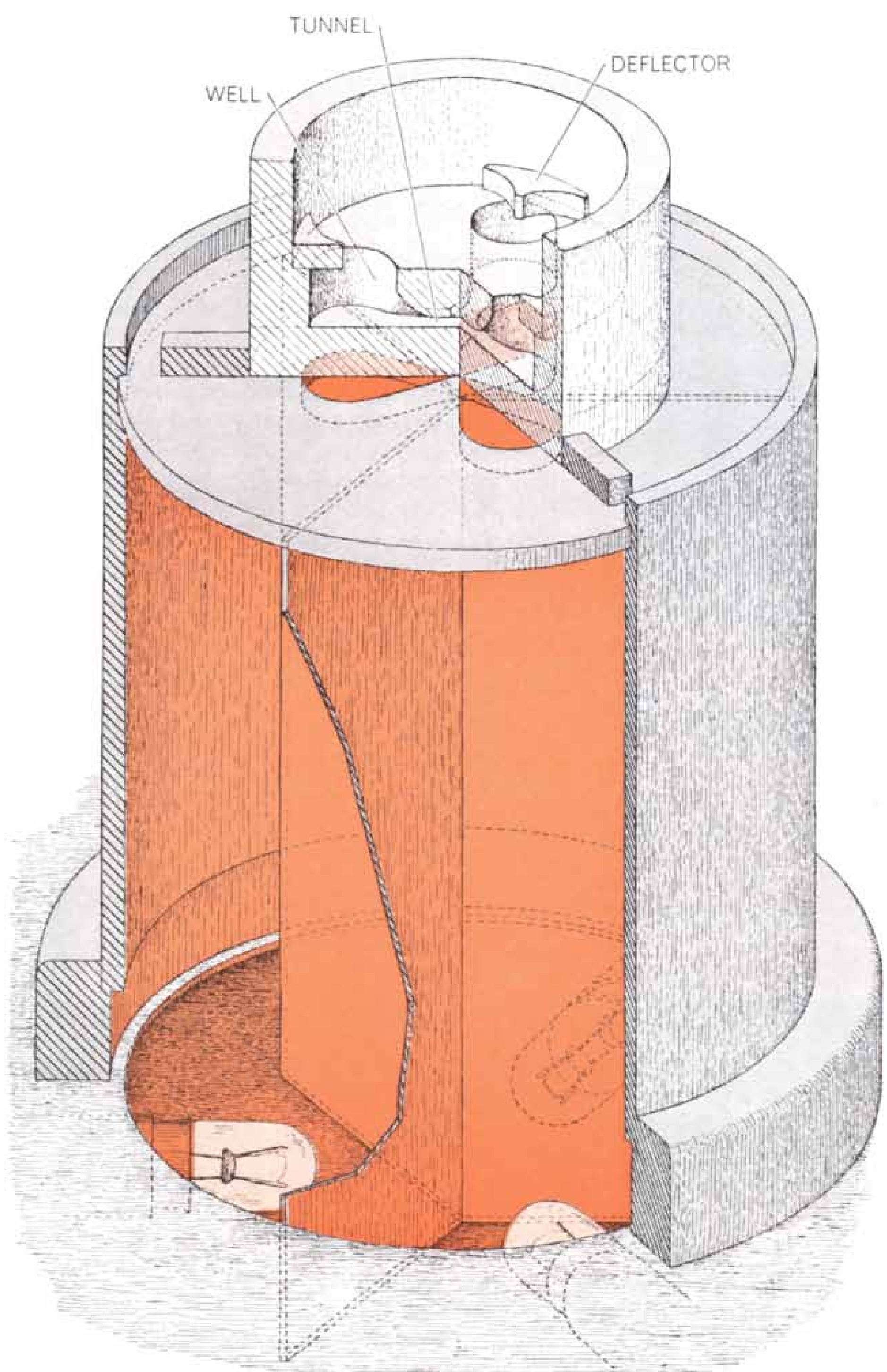
In the session following the one in which a worm showed its most marked preference for the rewarded alternative, it rejected the rewarded alternative and chose the other instead. This happened whether the worm had been trained to choose the lighted well or the darkened one. A session or two following the one in which the worm rejected the rewarded alternative it acted lethargic when placed in the maze and refused to play the game at all.

Rubinstein and I were appalled at this complex turn of events in our seemingly simple experiment. It was clear from the structure of the experiment that the switch in preference from the rewarded to the unrewarded alternative was not mere forgetting; in that session the worms did worse than they would have on a random basis and worse than they had done in their first session, when they had had no previous training. The only way a worm could perform worse than randomly in this particular experiment was to know what the correct choice was and choose the opposite. But why would it do that?

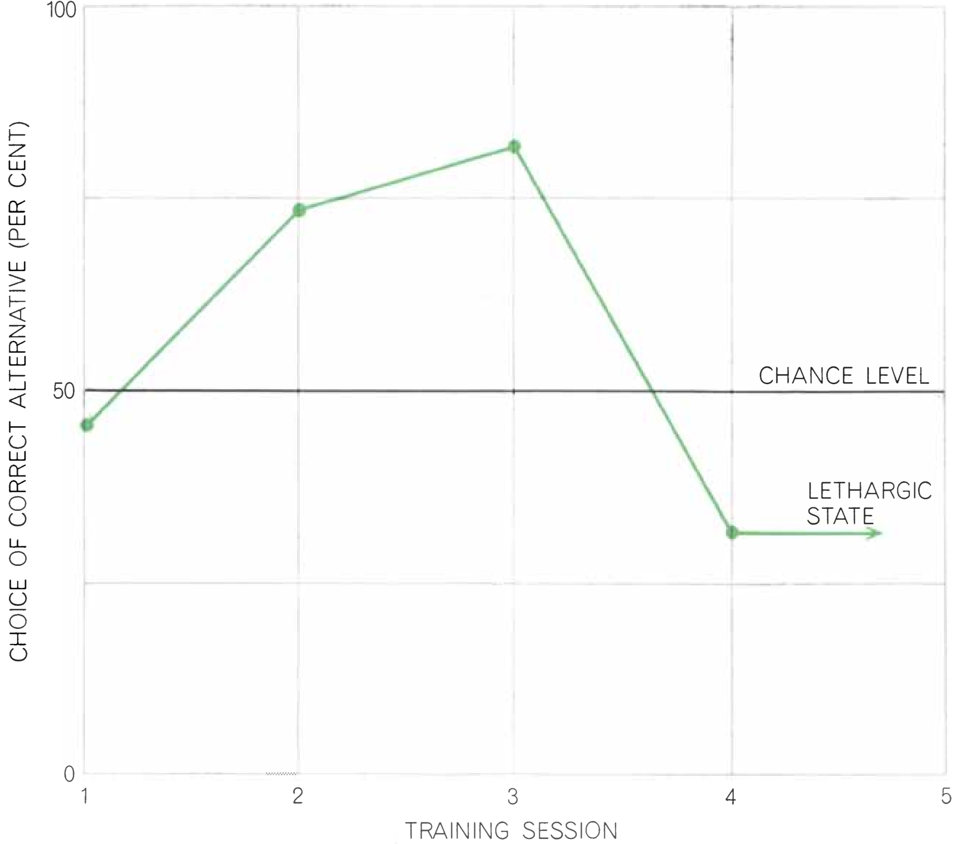
The lethargy too was baffling. If the incentive had been something to which the worms might have adapted, we would have seized on this explanation, but the worms cannot live for long without water. At first we speculated that we had driven the worms to exhaustion. Then we noticed that most of the lethargic worms exhibited normal activity in their home bowl both immediately before and immediately after the session in the maze during which they refused to perform. The lethargy thus seemed—from its context, speed of onset and speed of recovery—to be a kind of psychological state rather than exhaustion.

Higher animals, particularly cats, frequently exhibit behavior that appears to be "rebellious" or negativistic when one is attempting to train them to an avoidance task. Some investigators have reported instances in which cats would simply lie down on an electric grid and take a shock rather than try to avoid it. Increasing the shock intensity will not force some recalcitrants to perform and may ruin them as subjects for future experiments. Because neither Rubinstein nor I had had any experience in avoidance conditioning of higher animals, and because there are few published accounts of such perverse behavior, we were unaware of its existence when we first encountered the lethargic state in planarians. Only later, when we were discussing our findings with workers who were familiar with the psychological behavior of rats, cats and monkeys, did we become aware of this prevalent but poorly understood phenomenon in higher animals. Most workers agreed that it was usually evoked by overpunishment and that it represented some kind of emotional response toward the entire test situation.

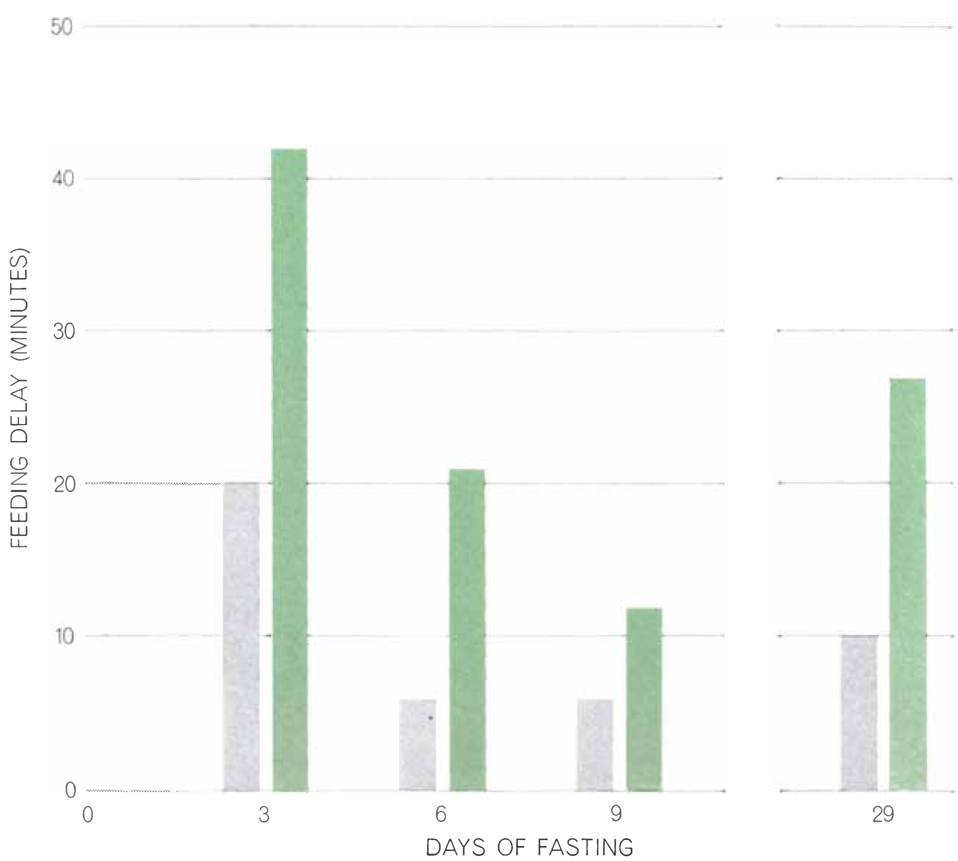
Aside from the trials themselves we could see nothing very punishing about our maze situation. We thought, however, that by linking some positive association such as feeding with the maze we might be able to offset whatever it was the worm found unpleasant about the situation. We put planarians that had fasted and had not been through any trials into water-filled maze wells that



Y MAZE was designed with a rim so that the plateau above the wells could be flooded with water. This cured the planarians' "lethargy," described in the text. The maze is constructed from clear acrylic plastic, which allows the wells to be lighted individually from below.



LEARNING CURVE for planarians shows a baffling slump after a session of high performance. The Y maze used in this experiment was similar to that shown on preceding page, except for the rim. In the rim maze, containing extra water, performance did not slump.



DELAY IN FEEDING indicates whether or not planarians remember an environment to which they have been exposed before. Hungry planarians placed in a familiar environment (*gray bars*) begin feeding sooner than planarians placed in an unfamiliar one (*colored bars*). Apparent diminution of appetite after long fasting is also seen in mammals.

contained a small piece of raw beef liver. Ordinarily a hungry planarian will eat beef liver without much hesitation; in the maze wells they would not eat at all. It occurred to us that their loss of appetite might be due to some chemical property of the acrylic plastic of which the maze was built, but when planarians were placed in large trays made of the same plastic, they ate readily.

At a loss for an explanation, I was glumly watching my cat trying to get into a closet past the closet door, which was slightly ajar. Only the day before, when I needed her out of the way briefly, I had put her into the closet with a plate of food. Instead of quietly eating, she had thrown a terrible feline tantrum, ignoring the food, yowling and scratching the door. Yet this same closet, a dungeon yesterday when escape was blocked, now, with the door ajar, became attractive. Why?

I decided to present the planarians with a situation analogous to the cat and the closet. A small piece of liver was placed in the flooded maze well as before. The entire maze block was put into the home bowl of the planarian and the water level adjusted until it was just slightly higher than the top of the maze block. The planarian could now, remaining in water, pass between the well and its home bowl at its own discretion. The "open door" stratagem succeeded. Under these circumstances the planarians climbed into the well and ate.

In higher animals such as cats and rats inhibition of the feeding response in a hungry animal is frequently used as a behavioral indicator of an emotional state akin to "anxiety." It is probably premature to refer to the cat-and-the-closet effect as claustrophobia, but it does suggest that confinement in the close quarters of the maze well-and-tunnel system was unpleasant to planarians. Moreover, one can conceive how this particular form of behavior might be of value to planarians in their natural habitat. One species of planarian used in our investigation lives in fresh-water streams. The other inhabits the bayous of southern Louisiana and the Mississippi delta country. Fresh-water streams become swollen and overflow their banks in times of heavy rainfall and may diminish to mere rivulets in dry weather. Bayous not only become flooded but also rise and fall with the tide. As either flood or tidal waters recede they leave small pools that may dry up and kill a planarian trapped in them. A small pool with an escape route to a larger pool is not so dangerous as a small pool with no such escape. Natural selection is apt to be hard on animals that do not manifest the appropriate anxiety in the face of frequently encountered dangerous situations.

With this in mind we built a maze of the same kind and dimensions as before but with a rim extending above the maze block. When filled with water, this produced a larger chamber into which the worm could crawl from the maze wells. A trial was the same as before except that between trials the worm could now crawl out of the cramped quarters of the maze wells and use the more spacious quarters provided by the upper chamber. The worms did in fact use the upper chamber nearly every time it was made available to them. The choice point and the geometry of the tunnels in which the decision was actually made were the same as before.

In this rim maze the planarians never perversely rejected the choice (light or dark) that was rewarded with water, nor did they refuse to run through the tunnel. These results seemed consistent with the idea that the rejection of the reinforced choice and the lethargy were produced by unpleasant aspects of the over-all situation in the maze.

Closely associated with this behavior pattern is one that seems to occur widely throughout the animal kingdom. A good example of such behavior is exhibited by a single-celled, trumpet-shaped aquatic animal, the stentor. The stentor ordinarily lives with the mouthpiece of its trumpet anchored to a water plant or some other stable object. If it is disturbed by some stimulus such as a jet of water, the stentor will twist or bend on its anchor to avoid the jet. If, however, this is repeated a number of times, the stentor will detach its grip and seek a new location. In shifting to this new response the stentor is reacting to the entire sequence in which the irritating stimulus keeps recurring.

When we reconsidered the planarian's behavior, we conjectured that perhaps it included a counterpart to the behavioral program of the stentor: "If the situation continues to be unpleasant, try something different." We had found in our original maze experiments that, when only two choices are available to the planarian, it first responds at random, then it learns to respond correctly, then it responds incorrectly and finally it does not respond at all. We wondered what would happen if the planarian were given a situation allowing a greater range of response within the basic framework of the same learning situation.

By way of a test a planarian was trained in the original Y maze to choose the lighted alternative whether it occurred on the right or on the left. When we reached the stage of the experiment at which the worm began to reject the lighted alternative, we switched it into a second Y maze. The second maze was identical with the first except that the walls of its wells were scored with a gridwork of scratches in the plastic; the well walls of the first maze were smooth. From this point on, in each day's session, half of the trials were conducted in the smooth maze and half in the scratched maze. In the smooth maze the planarian now had to pick the darkened alternative, in the scratched maze the lighted alternative. Clearly this was a more complex situation than the one we had set up earlier. Only one out of every three worms tested in the dual-maze situation was able to learn it; this one, however, after having rejected the correct alternative in the initial single-maze stage, began to respond correctly in the dual-maze situation. Nor did it ever show the lethargy observed in all the worms tested in the single-maze task.

When a higher animal is confronted with an experimental situation in which it must choose between alternative doors or alleyways, it tends at first to choose one without much hesitation. After a few trials in which it has been punished (or rewarded) for its choice, but before it has learned which choice to make, it behaves quite differently at the point of decision. It may now hesitate at the choice point, turning its head first toward one door, then toward the other, looking as though it were trying to make up its mind which to take. Animal psychologists refer to this as "vicarious trial-and-error" behavior.

We have seen planarians exhibit similar behavior under comparable circumstances. In the initial trials a planarian in the Y maze just chooses one of the tunnels. After 10 to 15 trials in which it has received water or had it withheld, depending on its choice, it will now hesitate at the choice point, turning its head first one way and then the other. Sometimes it seems unable to decide at all and may crawl back to the starting well and begin over again. Although there has been much speculation about the nerve mechanisms responsible for decision making, no one really knows what goes on in the head of a planarian or any other animal trying to make up its "mind" between alternative courses of action. What is striking, we think, is that vicarious trial-and-error behavior—common enough in higher animals—has its counterpart in the primitive planarian worm.

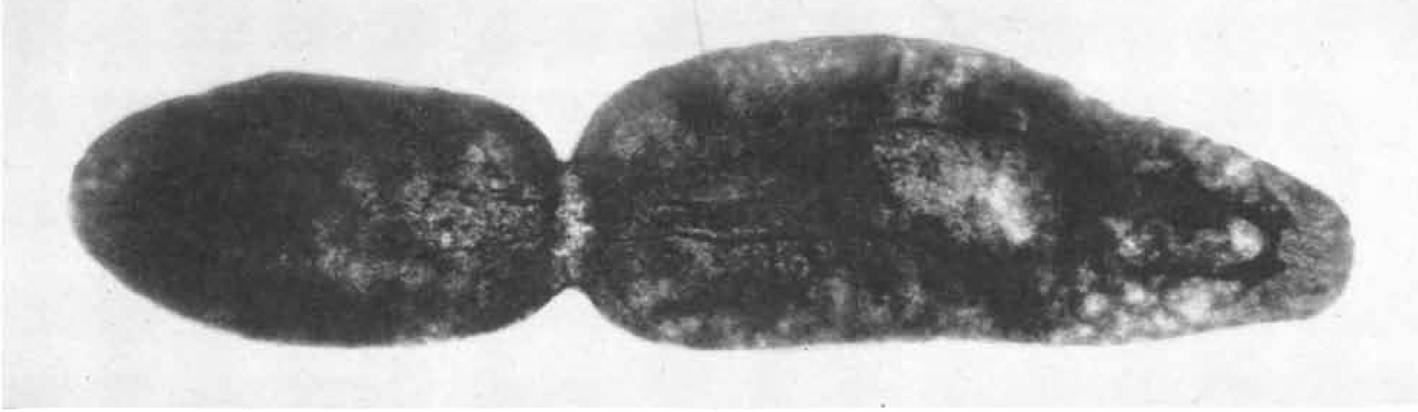
I shall give one more example in which planarian behavior parallels that found in much higher animals. When an animal such as a rat is offered food in a strange environment, it refuses to eat at first, even though it may be hungry. But if the environment is familiar, the animal will usually eat with little hesitation, even though it has never received food there before.

An animal's reluctance to eat in a strange environment provides a simple means of demonstrating whether or not the animal "recognizes" an environment to which it may have been previously exposed. Such recognition does not necessarily imply that the animal possesses cognitive memory of the environment itself. Animals often leave a mark or spoor of some kind, which they detect on revisiting the locale. To demonstrate that an animal has cognitive memory, one must devise an experiment in which spoors play no role. If this is done, one can use feeding delay as behavioral evidence of the strangeness of an environment. Without markers or memory all environments must be alien.

Rubinstein and I devised the following experiment to test the delayed feeding effect on planarians. Worms that had fasted varying lengths of time were divided into two groups. Members of one group were given a familiarization period in a small plastic receptacle. After they had been taken from the receptacle it was washed to remove any marker spoors they might have left. After an interval of 25 minutes the familiarized worms were returned to the receptacle and given a small piece of liver. The length of time until they began to eat was measured. Worms that had never been in the receptacle before were similarly tested. The familiarized worms ate sooner than the controls, indicating that planarians do show the delayed-feeding effect [*see bottom illustration on opposite page*].

Does this feeding delay mean that planarians are exhibiting some sort of "anxiety" or "caution" in the strange environment, as this behavior is usually interpreted when it is observed in higher animals? The question is difficult to answer. One can, however, devise further experiments to see if the feeding delay regularly appears in situations comparable to those that produce "anxiety" in rats and humans.

If the delay in feeding is a manifestation of a primitive anxiety pattern, one would expect an even longer delay in feeding for planarians in an environment that had proved to be dangerous in the



PRIMITIVE NERVOUS SYSTEM OF PLANARIAN is made visible by staining. The animal is undergoing fission. The dark, bat-shaped patch at the extreme right is the head ganglion, or brain. The two dark threads running the length of the animal are the ventral nerve cords. The cords continue through the cleavage region, showing that the head ganglion of the tail piece does not form until fission is complete. The photograph was made by Teiichi Betchaku of Wabash College in Crawfordsville, Ind.

past. A preliminary study suggests that this is true. Planarians that had fasted were placed in a plastic receptacle and given brief electric shocks. Tested later in the same receptacle with a piece of liver and without being shocked, they delayed feeding much longer than those that had not been shocked.

In doing studies of the sort described here one must be constantly on the watch for covert behavior patterns that could invalidate one's observations. For example, I discovered quite by accident that at least one species of planarian has a strong time sense. Very late one night I placed a planarian of the species *Dugesia tigrina* in a bowl with several *Cura foremani*. The *tigrina* quickly attacked the *foremani*. When I tried to repeat the experiment the next afternoon, I found that the two species completely ignored each other. Subsequently I learned that the *tigrina* would attack the *foremani* only at night. Moreover, the behavior remained on a fixed daily schedule even when the two species were maintained under constant illumination for an extended period.

Many questions are raised by these investigations. If one finds that planarian behavior resembles behavior that in higher animals one calls boredom, interest, conflict, decision, frustration, rebellion, anxiety, learning and cognitive awareness, is it permissible to say that planarians also display these attributes? The question can only be answered obliquely. All one knows of the "mind" of another organism is inferred from its behavior and its similarity to one's own. To indicate that these behavioral programs of primitive animals may be precursors of the psychological patterns of rats and men, one perhaps should speak of protoboredom, protointerest, protorebellion and protoanxiety.

Planarian worms are very primitive. Their nervous system is so rudimentary that its nerve cells can scarcely be distinguished from the surrounding tissue. Completely absent is the intricate meshwork of nerve circuitry that is found in the vertebrate brain and that is considered necessary for the behavior ordinarily identified with higher psychologies. Suppose the apparent similarity between the protopsychological patterns of planarians and the psychological patterns of rats and men turns out to be more than superficial. This would indicate that psychological characteristics are more ancient and widespread than the neurophysiological structures from which they are thought to have arisen. Perhaps it is time to recognize, in any case, that there is only limited evidence for the common belief that complex psychological behavior has its origin in the particular anatomy and physiology of the vertebrate brain. A probable reason for this belief is that more investigations of animal behavior have been conducted with birds and mammals. Quite possibly the world of lower animal life is a psychological wasteland only because it has not been studied.

Another reason for this belief is that investigators have become accustomed to thinking that invertebrate behavior must be primitive and therefore have tended to look only for relatively simple responses to simple stimuli. For example, if one of the eyes of a honeybee is blinded, the bee will travel in a circle. Similarly, an intact bee will orient with respect to an artificial light source. From such studies one might conclude that the bee is a simple automaton, the behavior of which is governed largely by asymmetric stimulation to a pair of photoelectric cells in its head. Yet the amazing work of Karl von Frisch of Austria has shown that bees possess a language for communicating precise navigational information [see "Dialects in the Language of the Bees," by Karl von Frisch; SCIENTIFIC AMERICAN, August, 1962].

If the major psychological patterns are not unique to the vertebrate brain but can be produced even by such primitive animals as planarians, two possibilities suggest themselves. Such patterns may stem from some primordial properties of living matter, arising from some cellular or subcellular level of organization rather than nerve circuitry. These protopsychological properties may in turn serve as the building blocks of vertebrate psychology in the way electronic computer subroutines enter as parts of a larger program.

An alternative possibility is that the behavioral programs may have arisen independently in various species by a kind of convergent evolution. In other words, the psychology of animals may evolve in response to compelling considerations of optimal design in the same way that whales and other cetacean mammals have evolved a fishlike shape. Both possibilities seem likely and do not exclude each other.

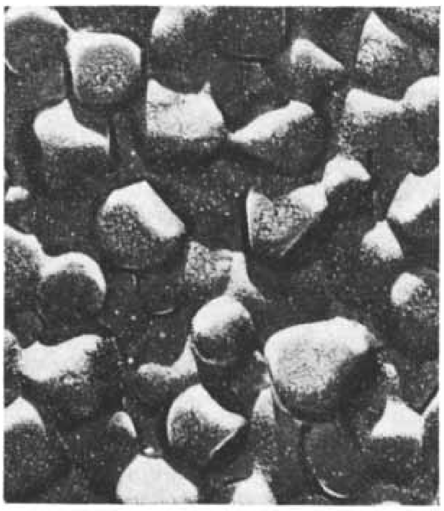
There are great difficulties in working with a truly alien species. Nearly any experiment in learning is simultaneously an experiment in perception; conversely, almost all experiments on the perception of another animal are done by teaching it some kind of discrimination. When one does not know how an animal perceives the world, it is difficult to know whether an animal's failure to learn a task set by the experimenter arises from incapacity or communication failure.

We are encouraged to believe as a result of our experiments with planarians that the strange, little-explored domain of protopsychology will shed new light on the ultimate nature of the human brain.

Kodak reports on:

how to look around in the tunnel... naked-eye colorimetry in paper chromatography... showing right from wrong

Cosmic film from France



The cobblestones seen in this electron micrograph are grains of silver halide sticking up out of a gelatin matrix. Very smart for extra-terrestrial use. Bear in mind the photographic conditions out there.

During the earthbound childhood of our race, we have been saying "ultraviolet" for radiation shorter in wavelength than what our particular natural-born sensing device happens to be tuned to. When at last we venture out from under the air blanket and note the ambience of the universe, we see what a special case is the life we have led. The color of the cosmos is not confined to an octave centered about the dominant hue of green cheese.

Even as we sing out in exultation, however, we must remind ourselves that all matter is opaque below about 2000Å and that the tunnel is long and dark all the way to x-rayland; for everything animal, vegetable, mineral, or gaseous is prone to electron transitions.

The light in your eyes, of course, goes out at around 3800Å, but any silver halide photographic material will get you down to 2500Å. The next 500Å is sticky: you spread a fluorescent oil over the emulsion to convert the energy to a wavelength long enough to penetrate the gelatin. Below 2000Å this stratagem poops out because even the oil robs you. At this point many years ago a spectroscopist named Victor Schumann had the bright idea of eroding gelatin away with H_2SO_4 to uncover the halide crystals. This worked fine. Schumann plates also proved useful for registering the focused ions in Aston's early mass spectrographs.

About 15 years ago we improved on Schumann plates by a technique that left only enough gelatin to keep the grains apart, as seen at left. We call the product KODAK SWR Plates and still recommend it unless you need high sensitivity so desperately that neither granularity nor price can stand in your way. In that event we can arrange to import for you some 180mm x 35mm strips of film from Kodak-Pathé. Our clever French cousins have developed a very tricky centrifugal coating technique that permits them to paste down much larger halide crystals than the SWR kind, resulting in *le film TYPE SC5 (environ 10 fois la sensibilité du film S.W.R. vers 1200Å)*.

If $108 for 24 such strips is not out of scale with the magnitude of your thinking, get in touch on this matter with Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. If you need nothing more special than a new free booklet entitled "Kodak Materials for Emission Spectrography," same address still applies.

Delicious colors with sugars

No colorimeters, no spectrophotometers are required to do paper chromatography. A ruler is the only measuring instrument. Despite the unimposing contribution that paper chromatography can make to the size of one's capital budget, the technique grows ever more popular. Now a contemptible pittance—a ridiculous $4.65—buys 25 grams of *p-Anisidine Hydrochloride* (EASTMAN 8615) and permits the purchaser to let on that he uses colorimetry (naked-eye type) in his paper chromatography.

We were going to offer with our compliments a color photograph of such a chromatogram as it looks when wet and fresh. The thought to do so came after reading the account (*J. Chem. Soc.*, *1950*, 1702) of how p-anisidine hydrochloride turned up from a systematic hunt for a universal reagent that would yield a specific color with each particular class of sugar or methylated sugar. It said that aldohexoses give "green-brown," ketohexoses "brilliant lemon yellow," methyl aldopentoses "emerald green," uronic acids "cherry red"—all delicious colors like that.

We have decided not to do it. We fear that our photography would be blamed if the colors in the photograph seemed drabber than the verbal designations. Remember that the paper chromatographers' eager pursuit of color in their working lives leaves them more impressionable in this respect than other people. Let them better order a little bottle of EASTMAN 8615 and impress themselves privately.

We also have *Aniline Hydrogen Phthalate* (EASTMAN 8608), which is also well spoken of for the same general purpose. "Excellent colours" with the methylated sugars are mentioned, with detectability down to 1-5 μg.

We also have a new catalog, List No. 43, which tells about some 4,000 other EASTMAN Organic Chemicals obtainable from Distillation Products Industries, Rochester 3, N.Y. (Division of Eastman Kodak Company).

Suggestion for teachers

Overhead projectors are great. We don't make them.

We do make VERIFAX Copiers. They are great, too. Lots of other companies also make copiers, but a VERIFAX Copier gives the best-quality single copy and the lowest-cost extra copies.

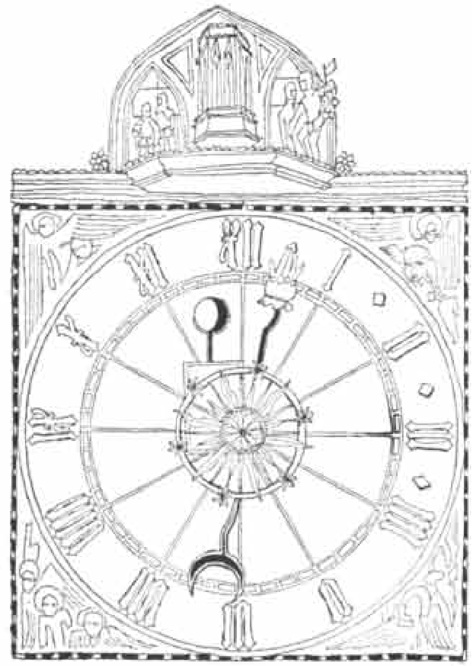
The copies need not be on paper. They can now be made on VERIFAX Transparent Sheeting. The sheet has the proper surface for writing over the copied material in the overhead projector. Superfluous to belabor the possibilities for convenience in showing the class text, tables, or complicated diagrams from all sorts of sources, including the instructor's own den at home, where it is easier to think out and write out detailed material.

We have another pedagogical suggestion, which you may think good or bad. Take a paper turned in by a student in the class and copy it on VERIFAX Transparent Sheeting, omitting his name to avoid embarrassment or jealousy as the case may be. Project it and mark it up right then and there on the projector. Brings the difference between right and wrong close to home in a convincing manner.

Eastman Kodak Company, Business Photo Methods Division, Rochester 4, N. Y. can place VERIFAX Transparent Sheeting in your hands right away. If you don't even have a VERIFAX Copier, somebody ought to look it up under "Photocopy Machines" or "Duplicating Machines" in the Yellow Pages of the telephone directory.

Prices subject to change without notice.

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



SCIENCE AND

Invulnerable and Immovable

"The positions of the nuclear powers seem immovable," said Roberto Luiz Assumpção de Araùjo, Brazilian delegate to the 17-nation disarmament conference at Geneva, as the conference adjourned in December, still deadlocked on the issue of policing a ban on underground nuclear tests. "Cosmic irresponsibility" was the comment of Matthew T. Mbu, delegate from Nigeria. With the completion of the latest cycle of tests in the U.S.S.R., however, testing also went into recess.

Meanwhile the U.S. announced the installation of the 200th intercontinental ballistic missile in firing position on its home territory; the operational missile force now includes 126 Atlas and 54 Titan liquid-fueled rockets and 20 solid-fueled Minutemen. With most of these weapons installed in hardened underground silos and with 10 nuclear-powered submarines at sea, each capable of bearing 16 intermediate-range missiles, the U.S. was in possession of a substantial "invulnerable" striking force. An additional 54 Titans, 800 Minutemen and 17 Polaris submarines are in production, and the Administration now appears disposed to reduce the nation's commitment to other delivery systems. Already engaged in an effort to stop further development of the "last" U.S. intercontinental bomber—the B-70, RB-70 or RS-70 in its various incarnations—Secretary of Defense Robert S. McNamara called a halt to Skybolt, an air-to-ground missile designed for launching from a bomber at a range of up to 1,000 miles.

The Skybolt announcement brought immediate protest from the United Kingdom. By prior agreement the missile was supposed to be carried aboard Britain's supersonic Vulcan bomber and thus to serve as the delivery vehicle for that nation's "independent deterrent." Following a conference between President Kennedy and Prime Minister MacMillan in Nassau, the Administration was urging Britain to join instead with other members of the North Atlantic Treaty Organization in accepting a squadron of Polaris submarines for operation under Allied command.

First News from Venus

The rich stream of information from *Mariner II* finally ended January 3, when radio contact with the 447-pound spacecraft was lost at a distance of 54 million miles from the earth and 5.7 million miles beyond Venus. Earlier, on December 14, *Mariner II* had attained its primary goal when it passed 21,594 miles above the sunlit side of Venus after traveling 180.2 million miles in 109 days. Although the data on surface and atmospheric temperatures collected when the craft scanned the planet for 42 minutes in its historic fly-by have not yet been fully analyzed, three significant findings have been reported.

First, *Mariner II*'s magnetometer reported no evidence of a Venusian magnetic field. The finding is consistent with radar observations indicating that Venus may rotate on its axis only once in about 200 days. It is believed that the earth's magnetic field arises because the earth is rotating fairly rapidly, producing a dynamo-like action in its molten core. It is possible, however, that a weak magnetic field exists on Venus but that it was depressed below the altitude of *Mariner II* by the pressure of the solar "wind"—electrically charged particles streaming from the sun.

A second observation, consistent with the first, is that no magnetically trapped particles were detected 22,000 miles from Venus. At the same height above the earth *Mariner II*'s instruments would have counted several thousand particles per second. On the fly-by the count averaged only one particle per second, the rate observed during most of the trip.

A third set of observations permitted an extremely accurate computation of the mass of Venus. The best previous estimate showed Venus to have .8148 times the mass of the earth, with a probable error of .05 per cent. As *Mariner II* approached Venus it was traveling about 40,000 miles per hour with respect to the earth. Venus increased the velocity some 3,000 m.p.h., thereby providing the data for a new computation of Venus' gravitational field. The new determination assigns Venus a mass .81485 times that of the earth, with a probable error of .015 per cent.

Three other sets of observations made by *Mariner II* deal with characteristics of interplanetary space. One showed that the cosmic ray intensity was approximately constant during the whole trip, as was expected. A second showed marked fluctuations in the solar wind, correlating in some cases with observed solar flares. Solar-wind particles were found to be a billion times more numerous than cosmic ray particles. The latter, however, are individually far more energetic. Finally, a radiation meter inside the spacecraft showed that a total radiation "dose" of about three roentgens penetrated the hull on the trip to Venus. This is roughly equal to the dose provided at the surface of the earth by normal background radiation over a 30-year period.

The National Aeronautics and Space Administration announced that *Mariner II* was so successful it had canceled plans to repeat the Venus mission in 1964 in order to concentrate on sending a spacecraft to Mars.

Pregalactic Stars

A study of the motions of dwarf stars in the vicinity of the sun has provided an unexpected glimpse of conditions during the formation of our galaxy some 10 billion years ago. Evidently the galaxy was then at least 10 times its present diameter and had not yet collapsed into its present flat pinwheel configuration. The study, reported in *The Astrophysical Journal*, was made by Olin J. Eggen, D. Lynden-Bell and Allan R. Sandage of the Mount Wilson and Palomar Observatories.

To obtain information about the early state of the galaxy the Mount Wilson and Palomar workers computed the galactic orbits of 221 dwarf stars whose positions have been observed to shift slightly against the background of other stars. Stars showing such a shift are said to exhibit proper motions. Because proper motions are often extremely small it was necessary to use observations dating back as much as 200 years. Over this period many of the stars in the group had shown an angular displacement of less than half a second of arc. This is less than 1/3,600th of the apparent diameter of the moon.

Proper motions provided only part of the information needed to compute the galactic orbits of the 221 dwarf stars. Also needed were their distances and the velocities of their motion toward or away from the sun. Much of this last information has only recently been collected with the 200-inch telescope on Palomar Mountain.

The galactic orbits were found to fall into two broad groups. The slowest moving stars travel in approximately circular orbits around the center of the galaxy and in the plane of the galactic disk. The fastest moving dwarfs tend to have highly elliptical, or eccentric, orbits that swing close to the galactic center and far out toward the edge of the disk. In addition, many of the eccentric orbits sweep far above and below the plane of the disk.

Dwarf stars were picked for the study because they are believed to be the oldest stars in the galaxy. Very old stars contain only traces of elements heavier than helium. According to present theories of stellar evolution, heavier elements are formed abundantly, in a brief time, during the catastrophic explosions of supernovae. The heavy elements are blown into space and are then incorporated, along with hydrogen, into new stars. When the dwarf stars were classified according to their content of heavy elements, it was found that those with the lowest content—the first-generation stars—had the most eccentric orbits. The second-generation dwarfs, with a higher content of heavy elements, had approximately circular orbits.

The Mount Wilson and Palomar workers conclude that the oldest dwarfs were formed while the galaxy was in its initial gravitational contraction from a larger protogalaxy. They have eccentric orbits because they were formed from gas falling generally toward the center of the galactic mass. The collapsing gas that did not become trapped in first-generation stars collided with other streams of gas, thereby losing its kinetic energy, and within the relatively brief time of about 100 million years had acquired a circular orbit in the galactic plane. Because the second generation of dwarf stars was formed after the collapse was completed and galactic rotation had begun, their orbits are circular.

Ribosomes at Work

The electron microscope has provided a direct and remarkable view of cellular particles—ribosomes—in the act of synthesizing the protein hemoglobin. Ribosomes are tiny particles composed of protein and ribonucleic acid (RNA), which appear approximately spherical in electron micrographs. It had been thought that protein synthesis took

MESSENGER RNA (ribonucleic acid) is thread at lower left joining ribosomal units (*balls*) of a disintegrated polysome. Electron micrograph magnification is 135,000 diameters.

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3. Get to know at least one of the bank's officers so that you know where you stand financially right now. A good way to do this is to fill out a Personal Financial Statement for his files.

4. When you need some extra money, borrow it from the bank instead of taking it from your savings. This way, you'll keep your savings account intact, and you'll also build a solid credit reputation with the bank.

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place in, or on, a single ribosome. Micrographs made at the Massachusetts Institute of Technology by Jonathan R. Warner, Alexander Rich and Cecil E. Hall now show that several ribosome particles are linked together at the time of synthesis. The particles appear to be held together by a long-chain molecule that is probably "messenger" RNA. This is the species of RNA that carries the code for protein structure from the genetic material, deoxyribonucleic acid (DNA), to the site of synthesis.

The M.I.T. workers showed by using radioactive tracers that newly synthesized hemoglobin is associated with the heavier of two ribosome fractions obtained by ultracentrifugation. When the heavier fraction was examined in the electron microscope, it was found to consist predominantly of clusters of five ribosomes. About 10 per cent of the clusters contain four ribosomes and another 10 per cent six ribosomes. The clusters have been named polysomes.

Although the first micrographs showed polysomes in clumps, further studies revealed that they could be obtained in a linear array connected by a thread with the approximate dimensions of a messenger RNA molecule [*see illustration on page 66*]. Writing in *Science,* the M.I.T. investigators propose that the ribosome attaches to the messenger RNA at one end and travels across to the other end. In the process the ribosome synthesizes hemoglobin according to the code it reads off the RNA molecule. At any given time four, five or six ribosome particles are making their way along the messenger RNA chain. Prior to these observations there was no good hypothesis to explain how messenger RNA and the ribosome collaborate physically to produce protein.

Older Man; Longer Pleistocene

A controversy over the age of *Zinjanthropus,* the Australopithecine hominid from Olduvai Gorge in East Africa, has ended with agreement that he and related early Australopithecine hominids from South Africa lived nearly two million years ago. The date not only stretches out the evolution of man but also promises to push back the beginning of the Pleistocene, the geological epoch of the ice ages, to three million years ago.

In 1961 L. S. B. Leakey, the British prehistorian who had found the bones of *Zinjanthropus* two years earlier, and J. F. Evernden and G. H. Curtis of the University of California estimated the age of *Zinjanthropus* at 1.75 million years on the basis of potassium-argon dating tests of volcanic rock from the stratum in which the bones were found. Their date was in conflict with accepted ideas on both human evolution and the duration of the Pleistocene. Man has traditionally been regarded as a child of the Pleistocene, and the Pleistocene (including a preliminary period of cooling before the appearance of the first continental ice sheets) has been considered to have lasted about a million years. A sharp controversy ensued when G. H. R. von Koenigswald, an eminent Dutch authority on human evolution, reported altogether different results from potassium-argon tests on other Olduvai specimens carried out at the Max Planck Institute for Nuclear Physics in Heidelberg. The dispute grew to include the character of the fossil mammals at Olduvai and the over-all geological history of the gorge.

The resolution came in a symposium on the dating of man and the Pleistocene at the December meeting of the American Association for the Advancement of Science in Philadelphia. Evernden and Curtis reported additional potassium-argon studies clarifying and confirming the 1.75-million-year date. The latter was immediately accepted by participants in the symposium, including von Koenigswald. It was also agreed that the fossil mammals in the *Zinjanthropus* stratum belong to a period called the Upper Villafranchian. Similar fossils have been found in association with the earliest South African Australopithecine hominids. Thus the South African hominids also date back almost two million years.

In addition, an earlier period known as the Lower Villafranchian has been regarded as the start of the Pleistocene. As noted separately by Evernden and Curtis, by von Koenigswald and by Cesare Emiliani of the University of Miami, a 1.75-million-year date for the Upper Villafranchian must move the Lower Villafranchian, and the start of the geological era that brought both ice and man, back to at least three million years ago and perhaps earlier.

Living with the Bomb

How is it that Americans and other peoples living under the constant threat of annihilation in a thermonuclear war can go about their daily affairs apparently undisturbed? They erect mental barriers and actively employ other psychological mechanisms in order to avoid accepting the threat and the concomitant unmanageable anxieties, according to

participants in a symposium on reactions to nuclear threat, held at the December meeting of the American Association for the Advancement of Science in Philadelphia.

Lester Grinspoon, psychiatrist at the Harvard Medical School, cited the reluctance to contemplate one's own inevitable death or to acknowledge the presence of a fatal disease as typical examples of denial, one of the most primitive and most important mechanisms by which people reject unacceptable facts. Other mechanisms include isolation, in which they speak of death of self, of loved ones and of millions of others as an abstraction; displacement or the transfer of the anxieties from the threat of nuclear war to some other object, as in the hyperpatriot's concern about "the enemy"; rationalization, typically expressed as "No one's going to be mad enough to start an H-bomb war" or "It will be God's will"; intellectualization, the mechanism employed particularly by those involved in preparing for war and also those involved in peace research. Such mechanisms are being widely used in the U.S. today, Grinspoon said, citing a recent national survey on reasons for unhappiness, in which only 4 per cent of the respondents mentioned world tension and the possibility of war.

Stephen B. Withey, psychologist at the University of Michigan, indicated that the population, under the threat of nuclear war, has been exhibiting the first of a series of responses observed in people caught in natural disasters. In the early stages there is a tendency to disbelieve a warning, to distort later information, then to accept the threat but underrate its seriousness. A basic problem of chronic exposure to the hazard of nuclear war is that the threat does not stay steady and adjustment to it must vary accordingly.

At least one group of people in the world does accept the threat of thermonuclear war and live with the anxieties: the 90,000 Hiroshima residents who survived the first atomic bomb. According to Robert J. Lifton, Yale University psychiatrist who recently spent several months in Hiroshima interviewing survivors, they have lived with death and the threat of death for so long that it is an obsession. Their fear of a nuclear war is intense. Although they are functioning, productive members of society, they are troubled by many other problems, among them feelings of guilt and futility because they have concluded that their terrible experience has no meaning for anyone else, that the world has learned nothing from it.

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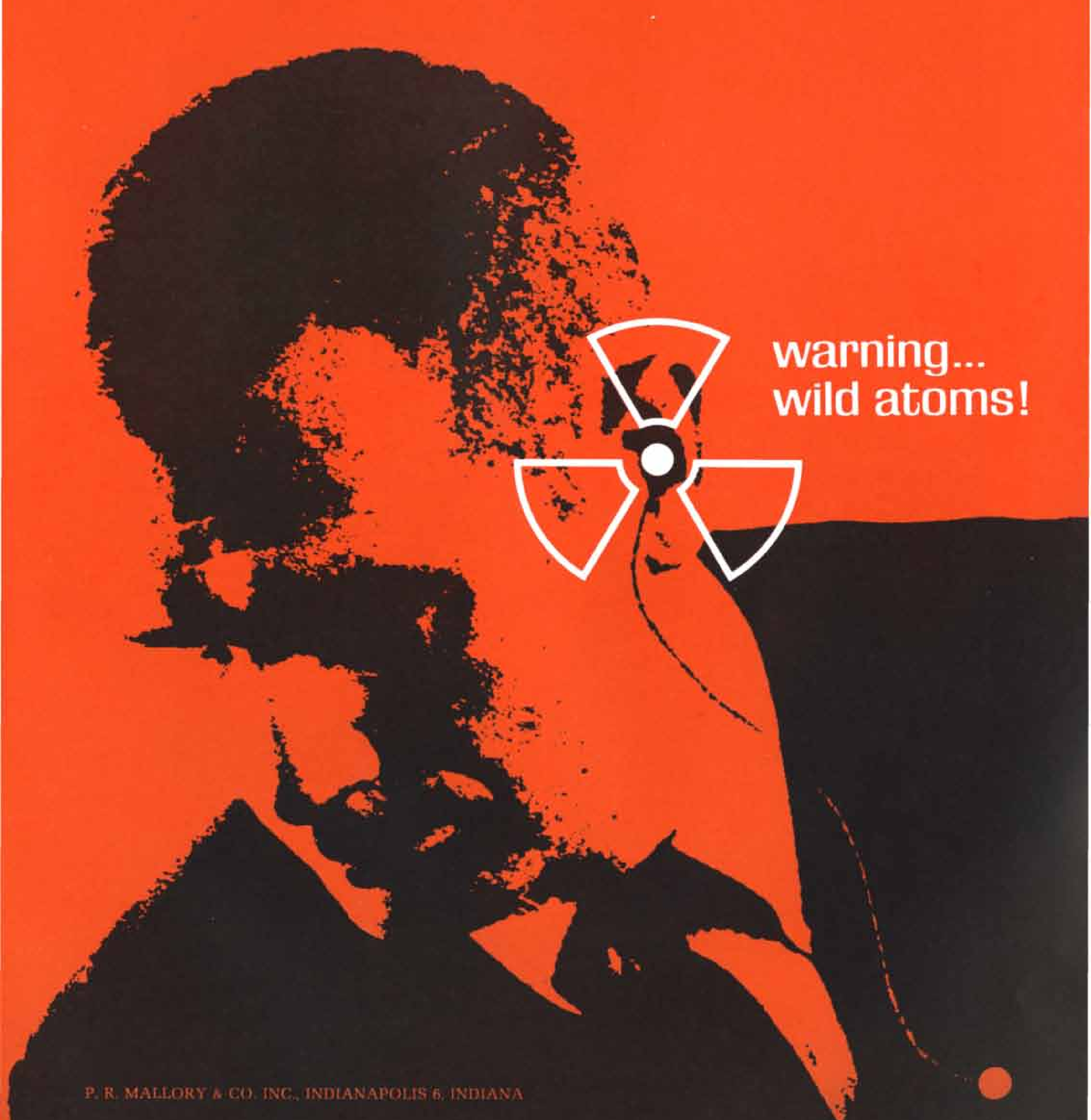

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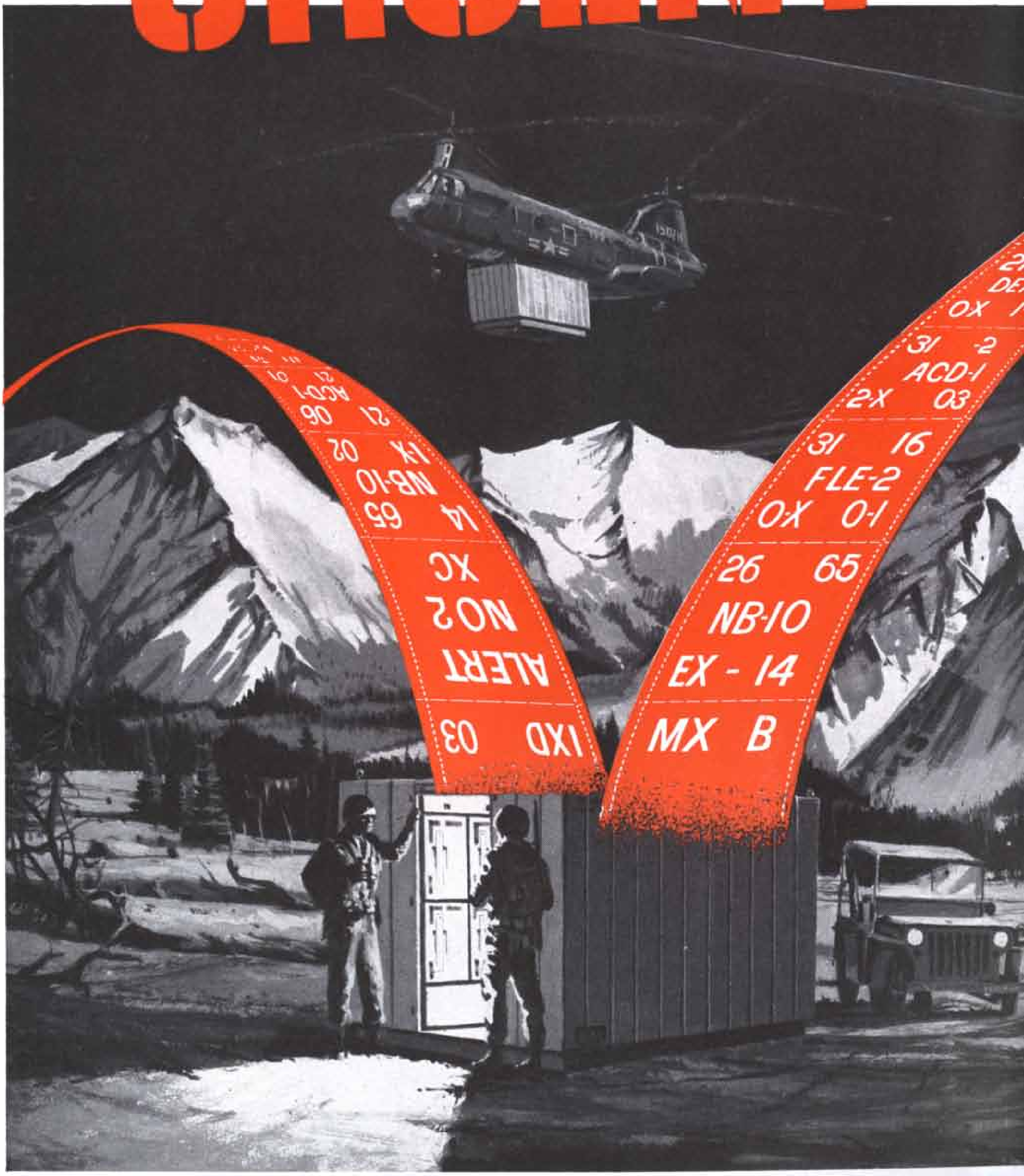

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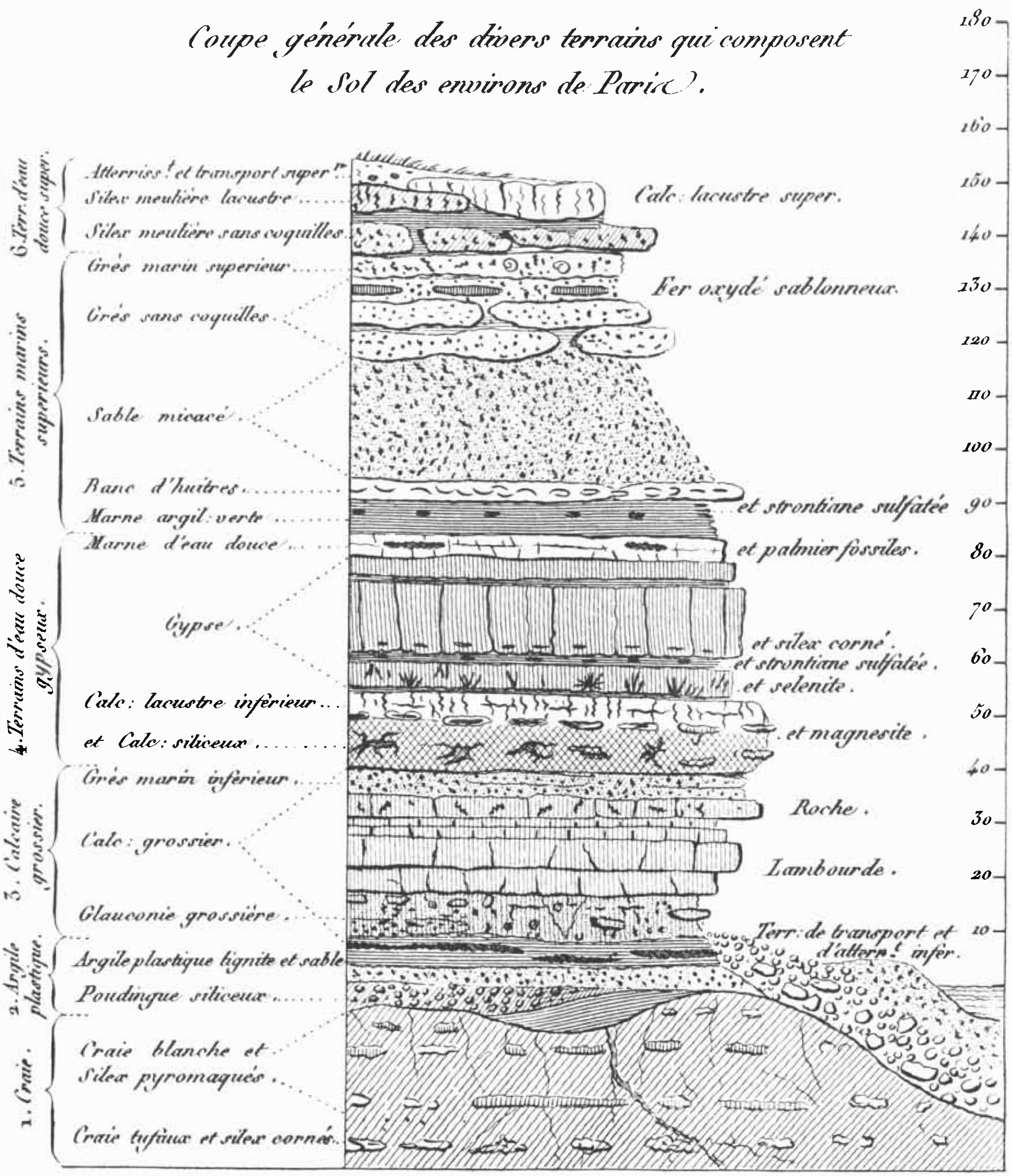


"EVIDENCE" FOR CATASTROPHISM was adduced by the French naturalist Baron Georges Cuvier from his study of the Paris basin. He and Alexandre Brongniart published this diagram in 1822. Cuvier believed that the abrupt changes in the strata bespoke the occurrence of cataclysms. Although his observations were accurate, his conclusions are no longer generally accepted.

CRISES IN THE HISTORY OF LIFE

How is it that whole groups of animals have simultaneously died out? Paleontologists are returning to an earlier answer: natural catastrophe. The catastrophes they visualize, however, are not sudden but gradual

by Norman D. Newell

The stream of life on earth has been continuous since it originated some three or four billion years ago. Yet the fossil record of past life is not a simple chronology of uniformly evolving organisms. The record is prevailingly one of erratic, often abrupt changes in environment, varying rates of evolution, extermination and repopulation. Dissimilar biotas replace one another in a kind of relay. Mass extinction, rapid migration and consequent disruption of biological equilibrium on both a local and a world-wide scale have accompanied continual environmental changes.

The main books and chapters of earth history—the eras, periods and epochs—were dominated for tens or even hundreds of millions of years by characteristic groups of animals and plants. Then, after ages of orderly evolution and biological success, many of the groups suddenly died out. The cause of these mass extinctions is still very much in doubt and constitutes a major problem of evolutionary history.

The striking episodes of disappearance and replacement of successive biotas in the layered fossil record were termed revolutions by Baron Georges Cuvier, the great French naturalist of the late 18th and early 19th centuries. Noting that these episodes generally correspond to unconformities, that is, gaps in the strata due to erosion, Cuvier attributed them to sudden and violent catastrophes. This view grew out of his study of the sequence of strata in the region of Paris. The historic diagram on the opposite page was drawn by Cuvier nearly 150 years ago. It represents a simple alternation of fossil-bearing rocks of marine and nonmarine origin, with many erosional breaks and marked interruptions in the sequence of fossils.

The objection to Cuvier's catastrophism is not merely that he ascribed events in earth history to cataclysms; many normal geological processes are at times cataclysmic. The objection is that he dismissed known processes and appealed to fantasy to explain natural phenomena. He believed that "the march of nature is changed and not one of her present agents could have sufficed to have effected her ancient works." This hypothesis, like so many others about extinction, is not amenable to scientific test and is hence of limited value. In fairness to Cuvier, however, one must recall that in his day it was widely believed that the earth was only a few thousand years old. Cuvier correctly perceived that normal geological processes could not have produced the earth as we know it in such a short time.

Now that we have learned that the earth is at least five or six billion years old, the necessity for invoking Cuverian catastrophes to explain geological history would seem to have disappeared. Nevertheless, a few writers such as Immanuel Velikovsky, the author of *Worlds in Collision,* and Charles H. Hapgood, the author of *The Earth's Shifting Crust,* continue to propose imaginary catastrophes on the basis of little or no historical evidence. Although it is well established that the earth's crust has shifted and that climates have changed, these changes almost certainly were more gradual than Hapgood suggests. Most geologists, following the "uniformitarian" point of view expounded in the 18th century by James Hutton and in the 19th by Charles Lyell, are satisfied that observable natural processes are quite adequate to explain the history of the earth. They agree, however, that these processes must have varied greatly in rate.

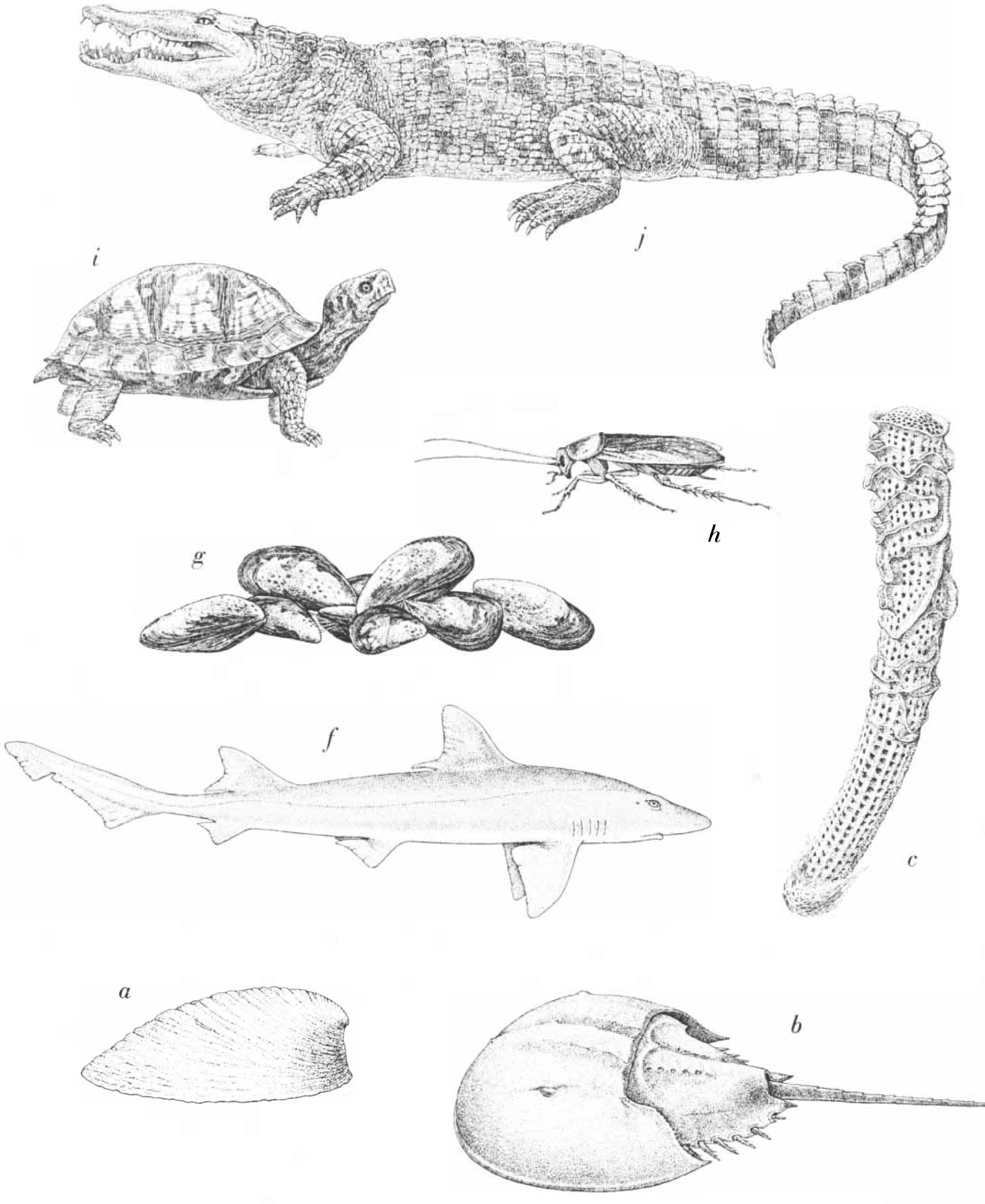
Charles Darwin, siding with Hutton and Lyell, also rejected catastrophism as an explanation for the abrupt changes in the fossil record. He attributed such changes to migrations of living organisms, to alterations of the local environment during the deposition of strata and to unconformities caused by erosion. Other important factors that are now given more attention than they were in Darwin's day are the mass extinction of organisms, acceleration of the rate of evolution and the thinning of strata due to extremely slow deposition.

The Record of Mass Extinctions

If we may judge from the fossil record, eventual extinction seems to be the lot of all organisms. Roughly 2,500 families of animals with an average longevity of somewhat less than 75 million years have left a fossil record. Of these, about a third are still living. Although a few families became extinct by evolving into new families, a majority dropped out of sight without descendants.

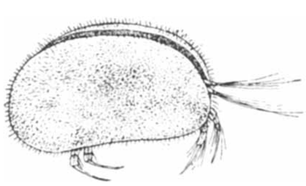
In spite of the high incidence of extinction, there has been a persistent gain in the diversity of living forms: new forms have appeared more rapidly than old forms have died out. Evidently organisms have discovered an increasing number of ecological niches to fill, and by modifying the environment they have produced ecological systems of great complexity, thereby making available still more niches. In fact, as I shall develop later, the interdependence of living organisms, involving complex chains of food supply, may provide an important key to the understanding of how relatively small changes in the environment could have triggered mass extinctions.

The fossil record of animals tells more about extinction than the fossil record of plants does. It has long been known



GALLERY OF HARDY ANIMALS contains living representatives of 11 groups that have weathered repeated crises in evolutionary history. Four of the groups can be traced back to the Cambrian period: the mollusk *Neopilina* (*a*), the horseshoe crab (*b*), the Venus's-flower-basket, *Euplectella* (*c*) and the brachiopod *Lingula* (*d*). One animal represents a group that goes back to the Ordovician period: the ostracode *Bairdia* (*e*). Two arose in the Devonian period: the shark (*f*) and the mussel (*g*). The cockroach

e



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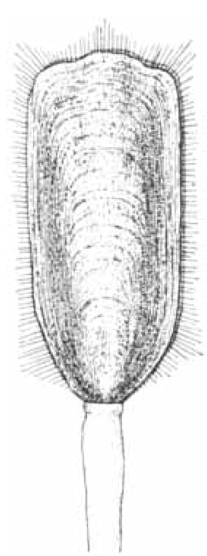


(*h*) goes back to the Pennsylvanian period. Two arose in the late Triassic: the turtle (*i*) and the crocodile (*j*). The opossum (*k*) appeared during the Cretaceous period.

that the major floral changes have not coincided with the major faunal ones. Each of the three successive principal land floras—the ferns and mosses, the gymnosperms and angiosperms—were ushered in by a short episode of rapid evolution followed by a long period of stability. The illustration on page 81 shows that once a major group of plants became established it continued for millions of years. Many groups of higher plants are seemingly immortal. Since green plants are the primary producers in the over-all ecosystem and animals are the consumers, it can hardly be doubted that the great developments in the plant kingdom affected animal evolution, but the history of this relation is not yet understood.

Successive episodes of mass extinction among animals—particularly the marine invertebrates, which are among the most abundant fossils—provide world-wide stratigraphic reference points that the paleontologist calls datums. Many of the datums have come to be adopted as boundaries of the main divisions of geologic time, but there remains some uncertainty whether the epochs of extinction constitute moments in geologic time or intervals of significant duration. In other words, did extinction occur over hundreds, thousands or millions of years? The question has been answered in many ways, but it still remains an outstanding problem.

A good example of mass extinction is provided by the abrupt disappearance of nearly two-thirds of the existing families of trilobites at the close of the Cambrian period. Before the mass extinction of these marine arthropods, which are distantly related to modern crustaceans, there were some 60 families of them. The abrupt disappearance of so many major groups of trilobites at one time has served as a convenient marker for defining the upper, or most recent, limit of the Cambrian period [*see illustration on page 82*].

Similar episodes of extinction characterize the history of every major group and most minor groups of animals that have left a good fossil record. It is striking that times of widespread extinction generally affected many quite unrelated groups in separate habitats. The parallelism of extinction between some of the aquatic and terrestrial groups is particularly remarkable [*see illustration on page 84*].

One cannot doubt that there were critical times in the history of animals. Widespread extinctions and consequent revolutionary changes in the course of animal life occurred roughly at the end of the Cambrian, Ordovician, Devonian, Permian, Triassic and Cretaceous periods. Hundreds of minor episodes of extinction occurred on a more limited scale at the level of species and genera throughout geologic time, but here we shall restrict our attention to a few of the more outstanding mass extinctions.

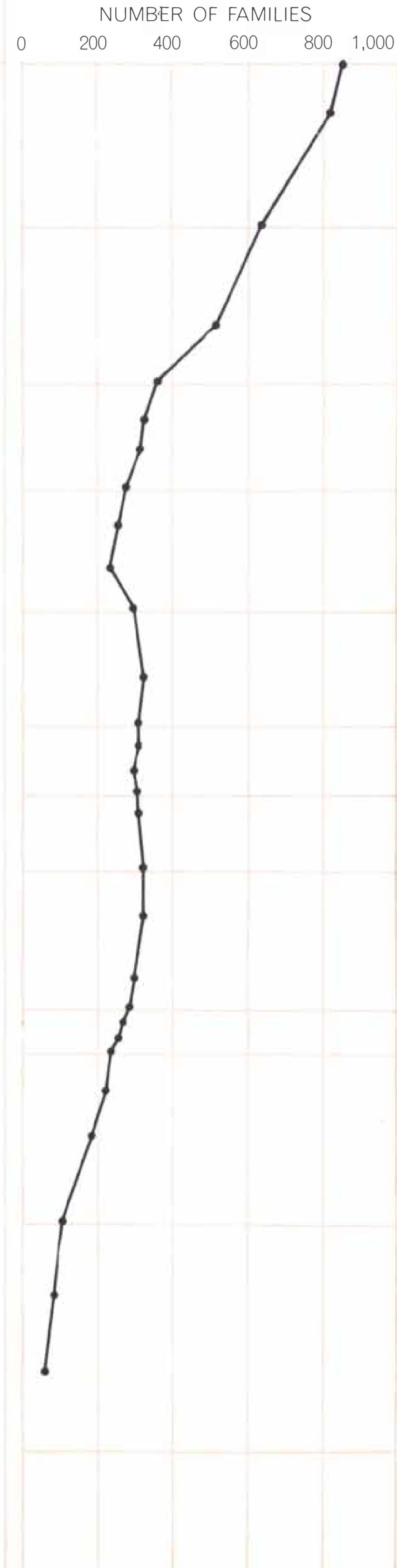
At or near the close of the Permian period nearly half of the known families of animals throughout the world disappeared. The German paleontologist Otto Schindewolf notes that 24 orders and superfamilies also dropped out at this point. At no other time in history, save possibly the close of the Cambrian, has the animal world been so decimated. Recovery to something like the normal variety was not achieved until late in the Triassic period, 15 or 20 million years later.

Extinctions were taking place throughout Permian time and a number of major groups dropped out well before the end of the period, but many more survived to go out together, climaxing one of the greatest of all episodes of mass extinction affecting both land and marine animals. It was in the sea, however, that the decimation of animals was particularly dramatic. One great group of animals that disappeared at this time was the fusulinids, complex protozoans that ranged from microscopic sizes to two or three inches in length. They had populated the shallow seas of the world for 80 million years; their shells, piling up on the ocean floor, had formed vast deposits of limestone. The spiny productid brachiopods, likewise plentiful in the late Paleozoic seas, also vanished without descendants. These and many other groups dropped suddenly from a state of dominance to one of oblivion.

By the close of the Permian period 75 per cent of amphibian families and more than 80 per cent of the reptile families had also disappeared. The main suborders of these animals nonetheless survived the Permian to carry over into the Triassic.

The mass extinction on land and sea at the close of the Triassic period was almost equally significant. Primitive reptiles and amphibians that had dominated the land dropped out and were replaced by the early dinosaurs that had appeared and become widespread before the close of the period. It is tempting to conclude that competition with the more successful dinosaurs was an important factor in the disappearance of these early land animals, but what bearing could this have had on the equally impressive and

ERA	SYSTEM AND PERIOD	SERIES AND EPOCH	DISTINCTIVE FEATURES	YEARS BEFORE PRESENT
CENOZOIC	QUATERNARY	RECENT	Modern man	11 THOUSAND
		PLEISTOCENE	Early man; northern glaciation	.5 TO 3 MILLION
	TERTIARY	PLIOCENE	Large carnivores	13 ± 1 MILLION
		MIOCENE	First abundant grazing mammals	25 ± 1 MILLION
		OLIGOCENE	Large running mammals	36 ± 2 MILLION
		EOCENE	Many modern types of mammals	58 ± 2 MILLION
		PALEOCENE	First placental mammals	63 ± 2 MILLION
MESOZOIC	CRETACEOUS		First flowering plants; climax of dinosaurs and ammonites, followed by extinction	135 ± 5 MILLION
	JURASSIC		First birds, first mammals; dinosaurs and ammonites abundant	180 ± 5 MILLION
	TRIASSIC		First dinosaurs. Abundant cycads and conifers	230 ± 10 MILLION
PALEOZOIC	PERMIAN		Extinction of many kinds of marine animals, including trilobites. Glaciation at low latitudes	280 ± 10 MILLION
	CARBON-IFEROUS	PENNSYLVANIAN	Great coal forests, conifers. First reptiles	310 ± 10 MILLION
		MISSISSIPPIAN	Sharks and amphibians abundant. Large and numerous scale trees and seed ferns	345 ± 10 MILLION
	DEVONIAN		First amphibians and ammonites; fishes abundant	405 ± 10 MILLION
	SILURIAN		First terrestrial plants and animals	425 ± 10 MILLION
	ORDOVICIAN		First fishes; invertebrates dominant	500 ± 10 MILLION
	CAMBRIAN		First abundant record of marine life; trilobites dominant, followed by extinction of about two-thirds of trilobite families	600 ± 50 MILLION
	PRE-CAMBRIAN		Fossils extremely rare, consisting of primitive aquatic plants. Evidence of glaciation. Oldest dated algae, over 2,600 million years.	



GEOLOGICAL AGES can be dated by comparing relative amounts of radioactive elements remaining in samples of rock obtained from different stratigraphic levels. The expanding curve at the right indicates how the number of major families of fossil animals increased through geologic time. The sharp decline after the Permian reflects the most dramatic of several mass extinctions.

simultaneous decline in the sea of the ammonite mollusks? Late in the Triassic there were still 25 families of widely ranging ammonites. All but one became extinct at the end of the period and that one gave rise to the scores of families of Jurassic and Cretaceous time.

The late Cretaceous extinctions eliminated about a quarter of all the known families of animals, but as usual the plants were little affected. The beginning of a decline in several groups is discernible near the middle of the period, some 30 million years before the mass extinction at the close of the Cretaceous. The significant point is that many characteristic groups—dinosaurs, marine reptiles, flying reptiles, ammonites, bottom-dwelling aquatic mollusks and certain kinds of extinct marine plankton—were represented by several world-wide families until the close of the period. Schindewolf has cited 16 superfamilies and orders that now became extinct. Many world-wide genera of invertebrates and most of the known species of the youngest Cretaceous period drop out near or at the boundary between the Cretaceous and the overlying Paleocene rocks. On the other hand, many families of bottom-dwelling sea organisms, fishes and nautiloid cephalopods survived with only minor evolutionary modifications. This is also true of primitive mammals, turtles, crocodiles and most of the plants of the time.

In general the groups that survived each of the great episodes of mass extinction were conservative in their evolution. As a result they were probably able to withstand greater changes in environment than could those groups that disappeared, thus conforming to the well-known principle of "survival of the unspecialized," recognized by Darwin. But there were many exceptions and it does not follow that the groups that disappeared became extinct simply because they were highly specialized. Many were no more specialized than some groups that survived.

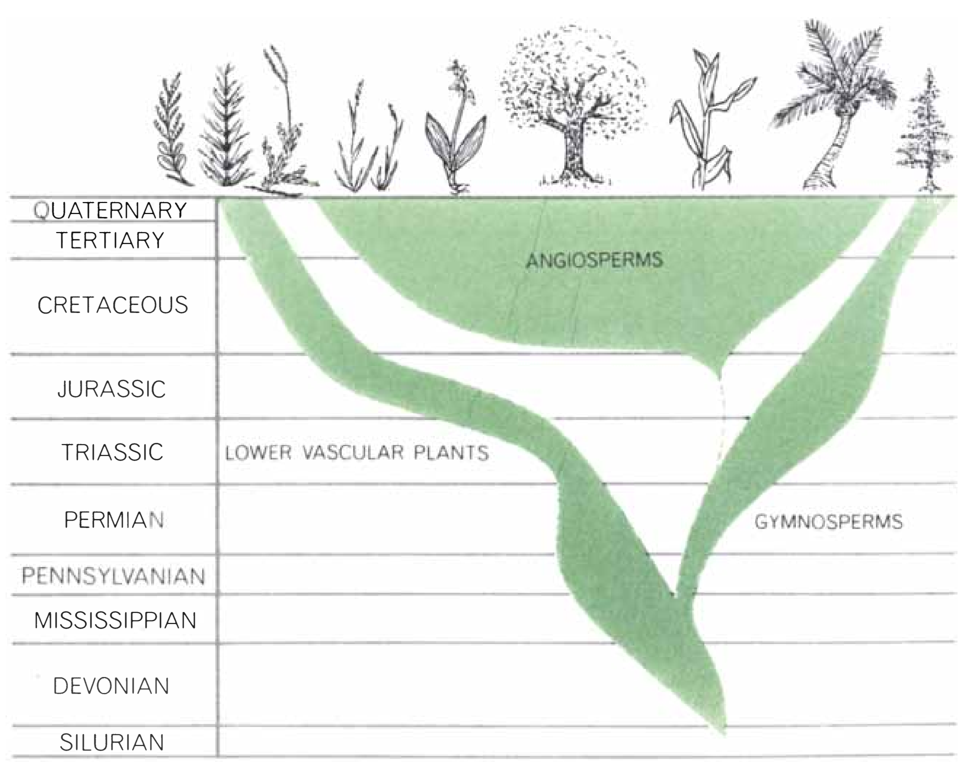
The Cretaceous period was remarkable for a uniform and world-wide distribution of many hundreds of distinctive groups of animals and plants, which was probably a direct result of low-lying lands, widespread seas, surprisingly uniform climate and an abundance of migration routes. Just at the top of the Cretaceous sequence the characteristic fauna is abruptly replaced by another, which is distinguished not so much by radically new kinds of animals as by the elimination of innumerable major groups that had characterized the late Cretaceous. The geological record is somewhat obscure at the close of the Cretaceous, but most investigators agree that there was a widespread break in sedimentation, indicating a brief but general withdrawal of shallow seas from the area of the continents.

Extinctions in the Human Epoch

At the close of the Tertiary period, which immediately preceded the Quaternary in which we live, new land connections were formed between North America and neighboring continents. The horse and camel, which had evolved in North America through Tertiary time, quickly crossed into Siberia and spread throughout Eurasia and Africa. Crossing the newly formed Isthmus of Panama at about the same time, many North American animals entered South America. From Asia the mammoth, bison, bear and large deer entered North America, while from the south came ground sloths and other mammals that had originated and evolved in South America. Widespread migration and concurrent episodes of mass extinction appear to mark the close of the Pliocene (some two or three million years ago) and the middle of the Pleistocene in both North America and Eurasia. Another mass extinction, particularly notable in North America, occurred at the very close of the last extensive glaciation, but this time it apparently was not outstandingly marked by intercontinental migrations. Surprisingly, none of the extinctions coincided with glacial advances.

It is characteristic of the fossil record that immigrant faunas tend to replace the old native faunas. In some cases newly arrived or newly evolved families replaced old families quite rapidly, in less than a few million years. In other cases the replacement has been a protracted process, spreading over tens of millions or even hundreds of millions of years. We cannot, of course, know the exact nature of competition between bygone groups, but when they occupied the same habitat and were broadly overlapping in their ecological requirements, it can be assumed that they were in fact competitors for essential resources. The selective advantage of one competing stock over another may be so slight that a vast amount of time is required to decide the outcome.

At the time of the maximum extent of the continental glaciers some 11,000 years ago the ice-free land areas of the Northern Hemisphere supported a rich



HISTORY OF LAND PLANTS shows the spectacular rise of angiosperms in the last 135 million years. The bands are roughly proportional to the number of genera of plants in each group. Angiosperms are flowering plants, a group that includes all the common trees (except conifers), grasses and vegetables. Lower vascular plants include club mosses, quillworts and horsetails. The most familiar gymnosperms (naked-seed plants) are the conifers, or evergreens. The diagram is based on one prepared by Erling Dorf of Princeton University.

and varied fauna of large mammals comparable to that which now occupies Africa south of the Sahara. Many of the species of bears, horses, elks, beavers and elephants were larger than any of their relatives living today. As recently as 8,000 years ago the horse, elephant and camel families roamed all the continents but Australia and Antarctica. Since that time these and many other families have retreated into small regions confined to one or two continents.

In North America a few species dropped out at the height of the last glaciation, but the tempo of extinction stepped up rapidly between about 12,000 and 6,000 years ago, with a maximum rate around 8,000 years ago, when the climate had become milder and the glaciers were shrinking [*see illustration on page 88*]. A comparable, but possibly more gradual, loss of large mammals occurred at about the same time in Asia and Australia, but not in Africa. Many of the large herbivores and carnivores had been virtually world-wide through a great range in climate, only to become extinct within a few hundred years. Other organisms were generally unaffected by this episode of extinction.

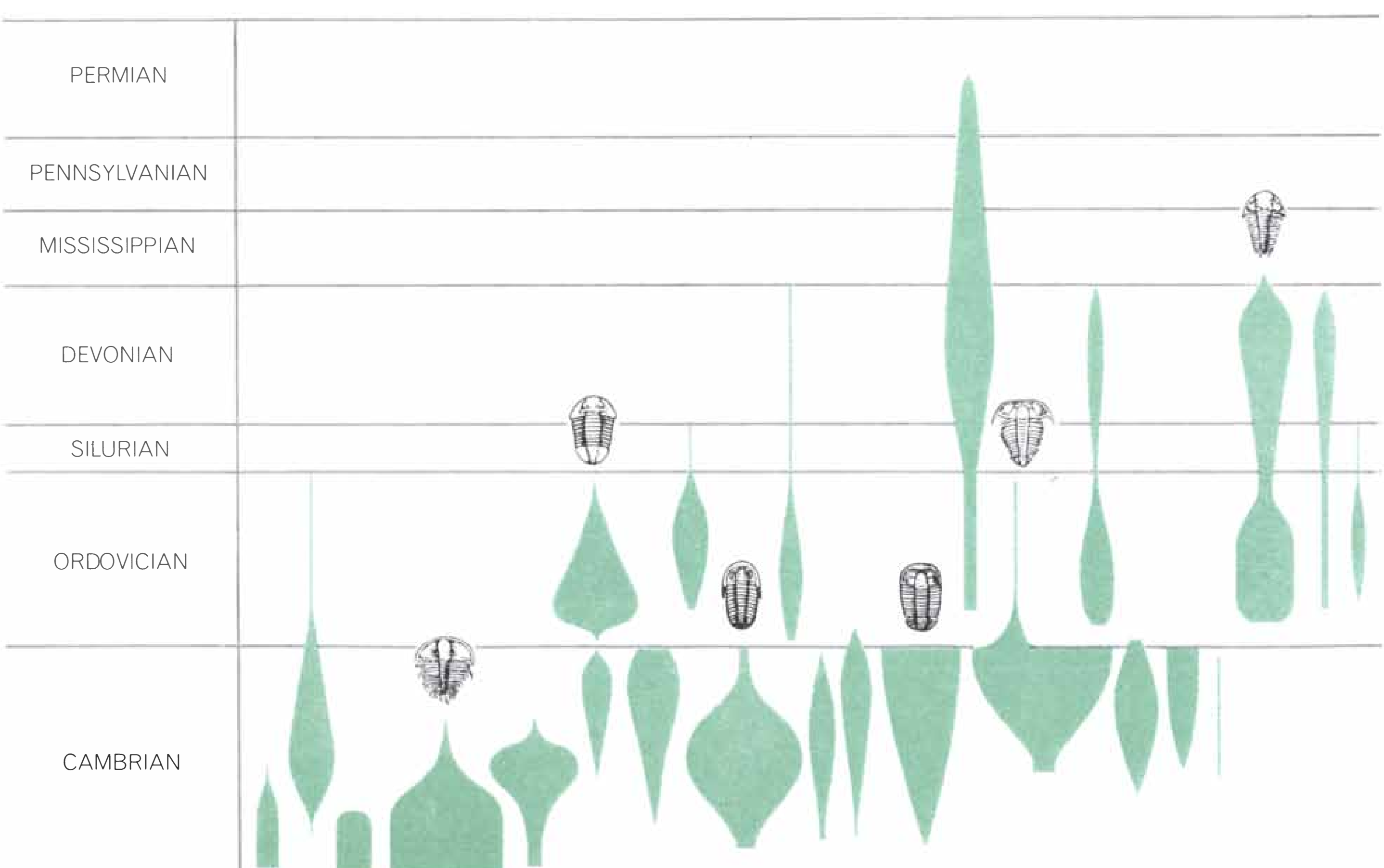
On the basis of a limited series of radiocarbon dates Paul S. Martin of the University of Arizona has concluded that now extinct large mammals of North America began to disappear first in Alaska and Mexico, followed by those in the Great Plains. Somewhat questionable datings suggest that the last survivors may have lived in Florida only 2,000 to 4,000 years ago. Quite recently, therefore, roughly three-quarters of the North American herbivores disappeared, and most of the ecological niches that were vacated have not been filled by other species.

Glaciation evidently was not a significant agent in these extinctions. In the first place, they were concentrated during the final melting and retreat of the continental glaciers after the entire biota had successfully weathered a number of glacial and interglacial cycles. Second, the glacial climate certainly did not reach low latitudes, except in mountainous areas, and it is probable that the climate over large parts of the tropics was not very different from that of today.

Studies of fossil pollen and spores in many parts of the world show that the melting of the continental glaciers was accompanied by a change from a rainy climate to a somewhat drier one with higher mean temperatures. As a result of these changes forests in many parts of the world retreated and were replaced by deserts and steppes. The changes, however, probably were not universal or severe enough to result in the elimination of any major habitat.

A number of investigators have proposed that the large mammals may have been hunted out of existence by prehistoric man, who may have used fire as a weapon. They point out that the mass extinctions coincided with the rapid growth of agriculture. Before this stage in human history a decrease in game supply would have been matched by a decrease in human populations, since man could not have destroyed a major food source without destroying himself.

In Africa and Eurasia, where man had lived in association with game animals throughout the Pleistocene, extinctions were not so conspicuously concentrated in the last part of the epoch. There was ample opportunity in the Old World for animals to become adapted to man through hundreds of thousands of years of coexistence. In the Americas and



MASS EXTINCTION OF TRILOBITES, primitive arthropods, occurred at the close of the Cambrian period about 500 million years ago. During the Cambrian period hundreds of kinds of trilobites populated the shallow seas of the world. The chart depicts 15 superfamilies of Cambrian trilobites; the width of the shapes is roughly proportional to the number of members in each superfamily. Final extinction took place in the Permian. The chart is based on the work of H. B. Whittington of Harvard University.

Australia, where man was a comparative newcomer, the animals may have proved easy prey for the hunter.

We shall probably never know exactly what happened to the large mammals of the late Pleistocene, but their demise did coincide closely with the expansion of ancient man and with an abrupt change from a cool and moist to a warm and dry climate over much of the world. Possibly both of these factors contributed to this episode of mass extinction. We can only guess.

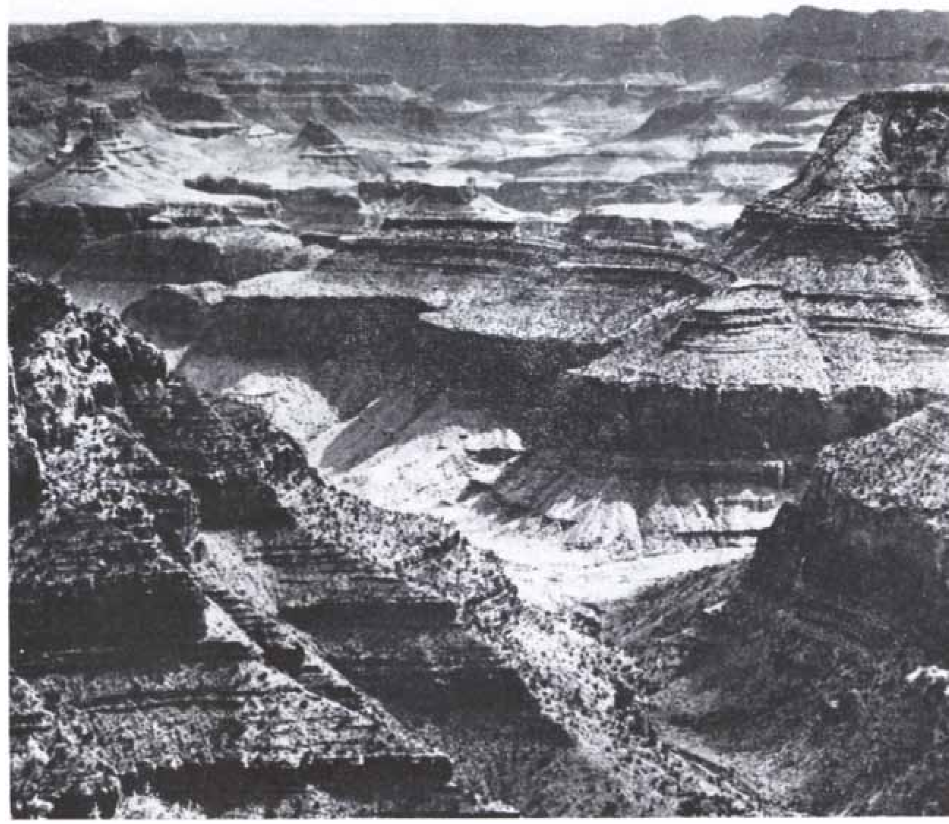
The Modern Crisis

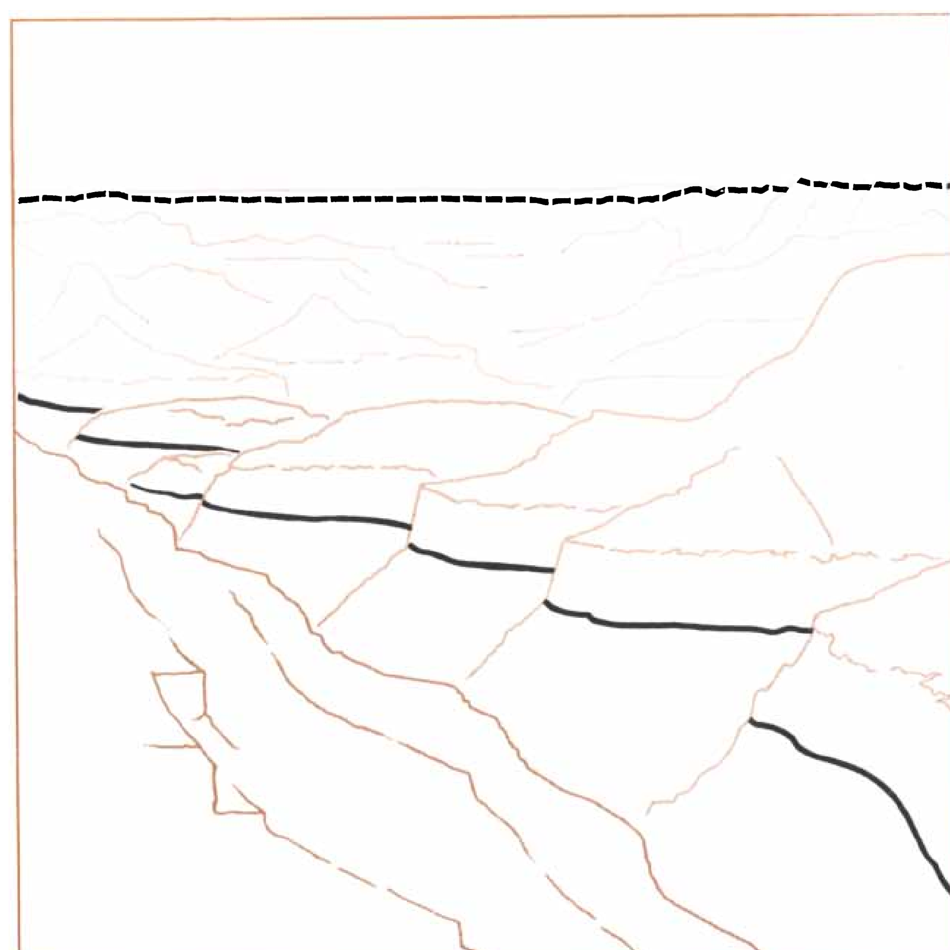
Geological history cannot be observed but must be deduced from studies of stratigraphic sequences of rocks and fossils interpreted in the context of processes now operating on earth. It is helpful, therefore, to analyze some recent extinctions to find clues to the general causes of extinction.

We are now witnessing the disastrous effects on organic nature of the explosive spread of the human species and the concurrent development of an efficient technology of destruction. The human demand for space increases, hunting techniques are improved, new poisons are used and remote areas that had long served as havens for wildlife are now easily penetrated by hunter, fisherman, lumberman and farmer.

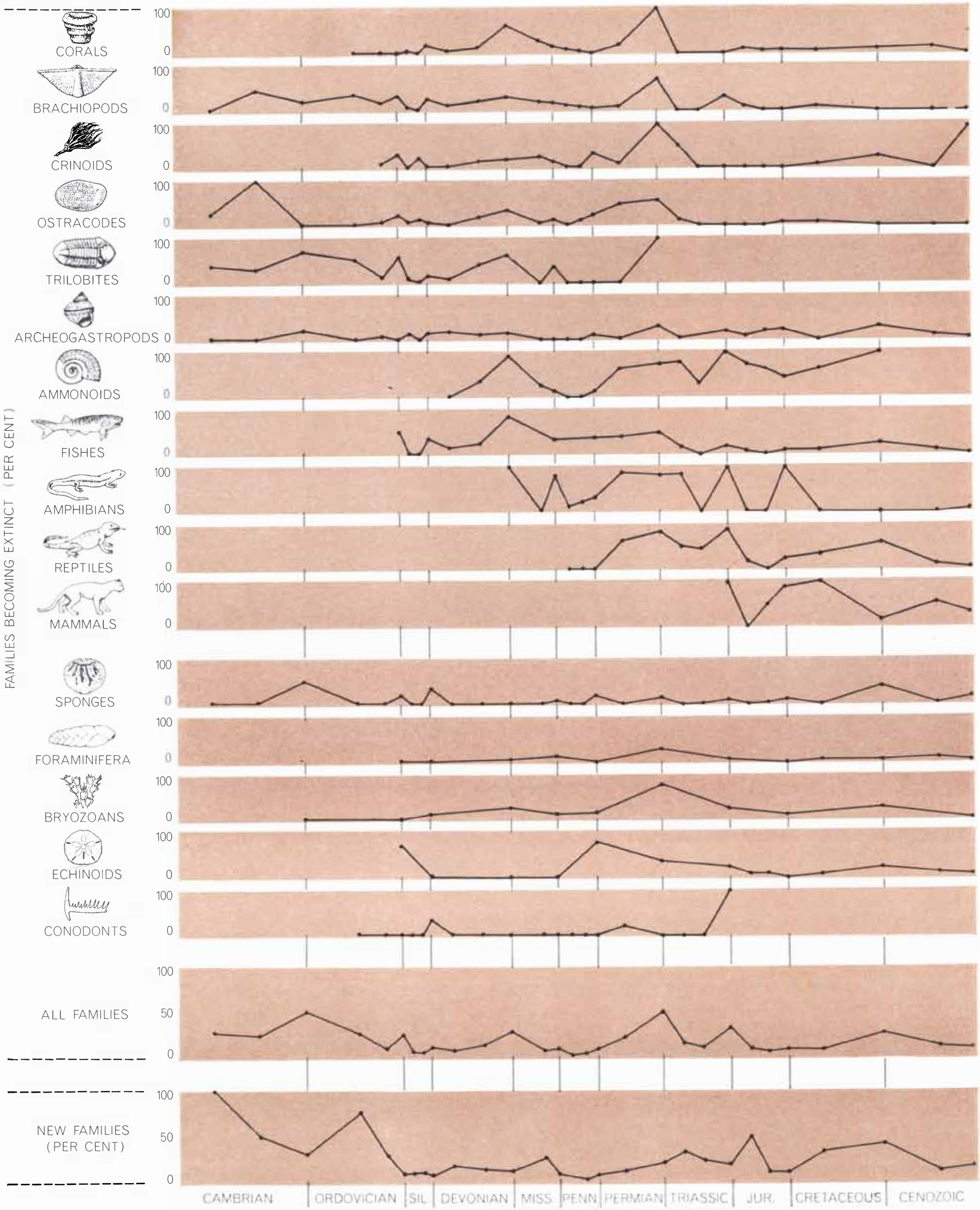
Studies of recent mammal extinctions show that man has been either directly or indirectly responsible for the disappearance, or near disappearance, of more than 450 species of animals. Without man's intervention there would have been few, if any, extinctions of birds or mammals within the past 2,000 years. The heaviest toll has been taken in the West Indies and the islands of the Pacific and Indian oceans, where about 70 species of birds have become extinct in the past few hundred years. On the continents the birds have fared somewhat better. In the same period five species of birds have disappeared from North America, three from Australia and one from Asia. Conservationists fear, however, that more North American birds will become extinct in the next 50 years than have in the past 5,000 years.

The savannas of Africa were remarkable until recently for a wealth of large mammals comparable only to the rich Tertiary and Pleistocene faunas of North America. In South Africa stock farming, road building, the fencing of grazing lands and indiscriminate hunting had wiped out the wild populations of large grazing mammals by the beginning of the 20th century. The depletion of ani-





PALEONTOLOGICAL BOUNDARIES are clearly visible in this photograph of the Grand Canyon. The diagram below identifies the stratigraphic boundary between the Cambrian and Ordovician periods (*solid line*) and the top of the Permian rocks (*broken line*). These are world-wide paleontological division points, easily identified by marine fossils.



RECORD OF ANIMAL EXTINCTIONS makes it quite clear that the history of animals has been punctuated by repeated crises. The top panel of curves plots the ups and downs of 11 groups of animals from Cambrian times to the present. Massive extinctions took place at the close of the Ordovician, Devonian and Permian periods. The second panel shows the history of five other groups for which the evidence is less complete. (Curves are extrapolated between dots.) The next to bottom curve depicts the sum of extinctions for all the fossil groups plotted above (plus bivalves and caenogastropods). The bottom curve shows the per cent of new families in the main fossil groups. It indicates that periods of extinction were usually followed by an upsurge in evolutionary activity.

mals has now spread to Equatorial Africa as a result of poaching in and around the game reserves and the practice of eradicating game as a method of controlling human and animal epidemics. Within the past two decades it has become possible to travel for hundreds of miles across African grasslands without seeing any of the large mammals for which the continent is noted. To make matters worse, the great reserves that were set aside for the preservation of African wildlife are now threatened by political upheavals.

As a factor in extinction, man's predatory habits are supplemented by his destruction of habitats. Deforestation, cultivation, land drainage, water pollution, wholesale use of insecticides, the building of roads and fences—all are causing fragmentation and reduction in range of wild populations with resulting loss of environmental and genetic resources. These changes eventually are fatal to populations just able to maintain themselves under normal conditions. A few species have been able to take advantage of the new environments created by man, but for the most part the changes have been damaging.

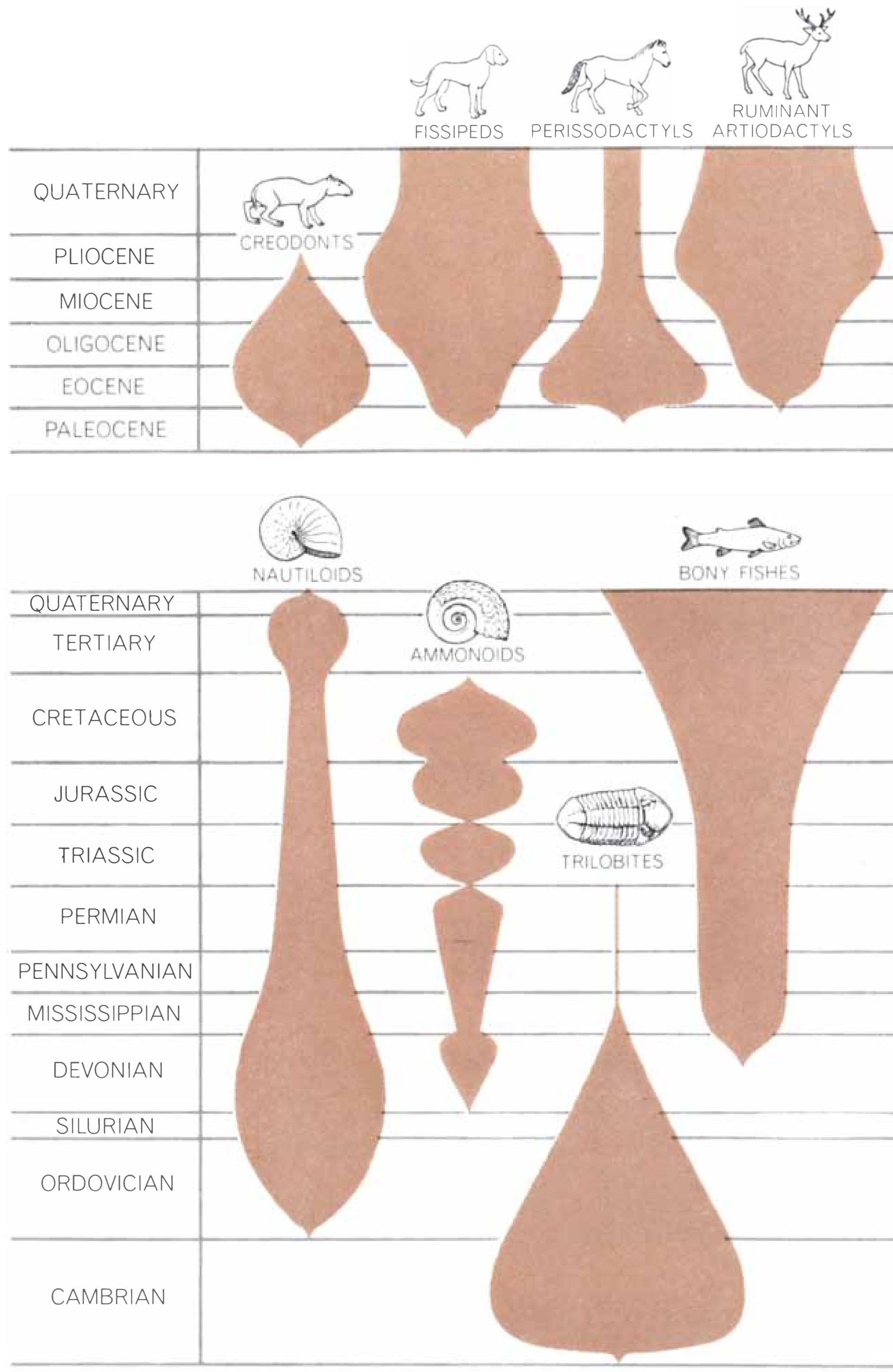
Reduction of geographic range is prejudicial to a species in somewhat the same way as overpopulation. It places an increasing demand on diminishing environmental resources. Furthermore, the gene pool suffers loss of variability by reduction in the number of local breeding groups. These are deleterious changes, which can be disastrous to species that have narrow tolerances for one or more environmental factors. No organism is stronger than the weakest link in its ecological chain.

Man's direct attack on the organic world is reinforced by a host of competing and pathogenic organisms that he intentionally or unwittingly introduces to relatively defenseless native communities. Charles S. Elton of the University of Oxford has documented scores of examples of the catastrophic effects on established communities of man-sponsored invasions by pathogenic and other organisms. The scale of these ecological disturbances is world-wide; indeed, there are few unmodified faunas and floras now surviving.

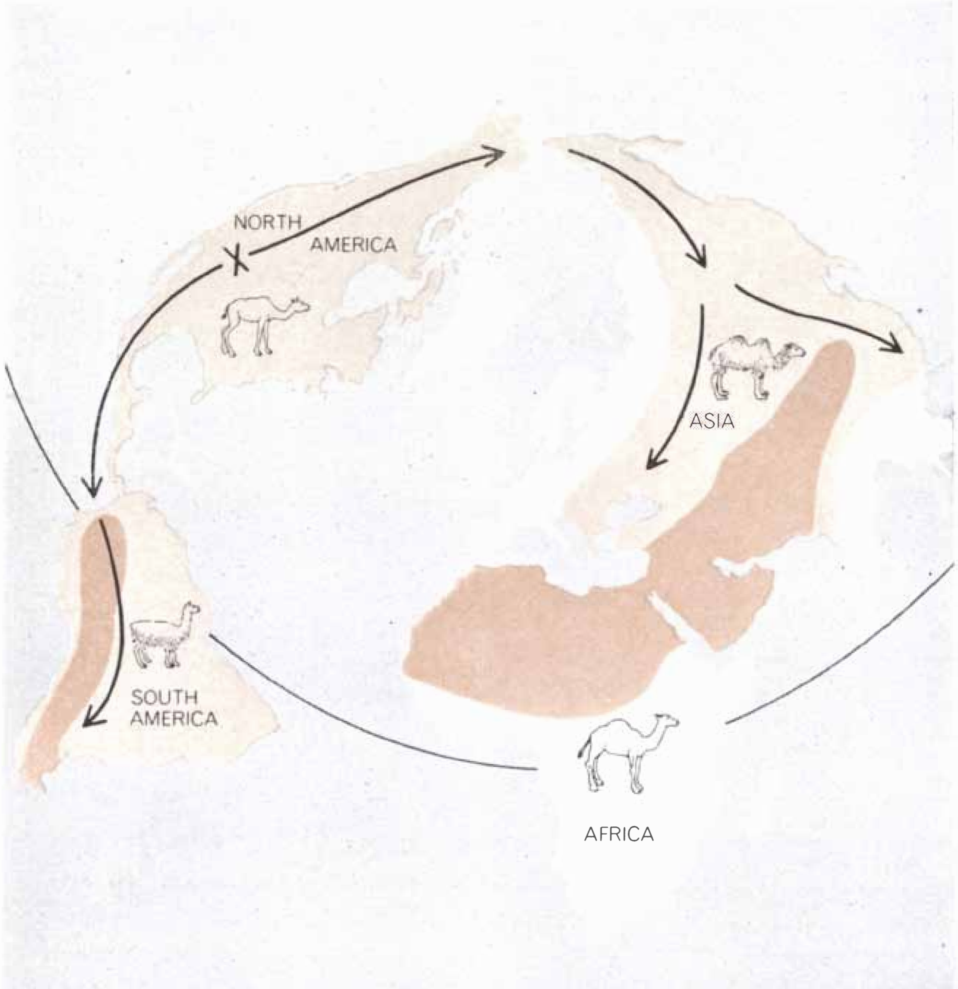
The ill-advised introduction of predators such as foxes, cats, dogs, mongooses and rats into island communities has been particularly disastrous; many extinctions can be traced directly to this cause. Grazing and browsing domestic animals have destroyed or modified vegetation patterns. The introduction of European mammals into Australia has been a primary factor in the rapid decimation of the native marsupials, which cannot compete successfully with placental mammals.

An illustration of invasion by a pathogenic organism is provided by an epidemic that in half a century has nearly wiped out the American sweet chestnut tree. The fungus infection responsible for this tragedy was accidentally introduced from China on nursery plants. The European chestnut, also susceptible to the fungus, is now suffering rapid decline, but the Chinese chestnut, which evolved in association with the blight, is comparatively immune.

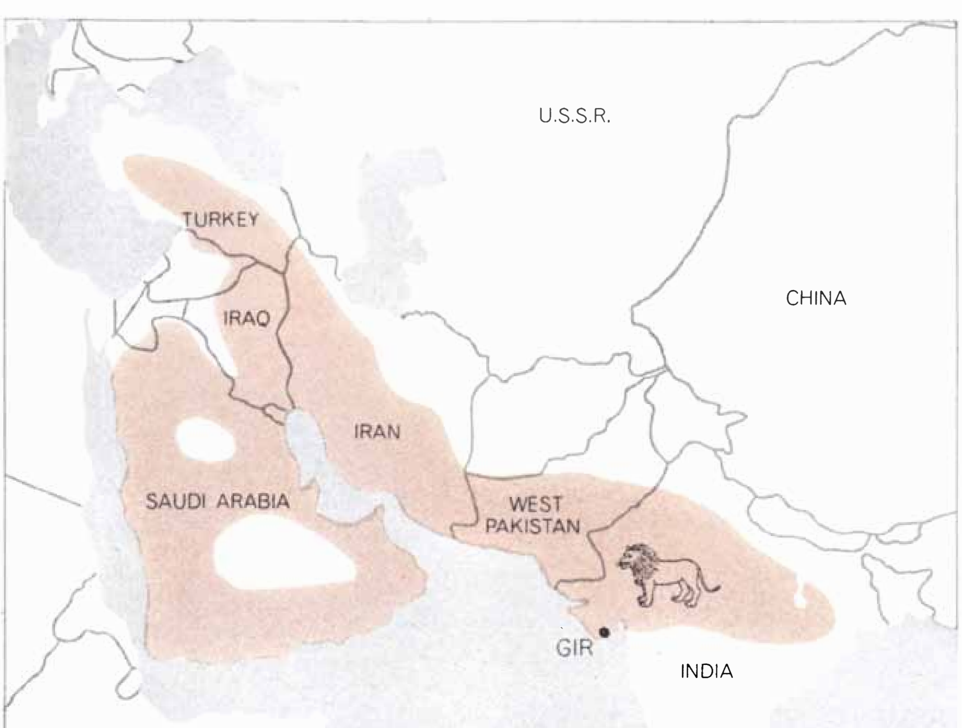
Another example is provided by the marine eelgrass *Zostera*, which gives food and shelter to a host of invertebrates and fishes and forms a protective blanket over muddy bottoms. It is the



ECOLOGICAL REPLACEMENT appears to be a characteristic feature of evolution. The top diagram shows the breadth of family representation among four main groups of mammals over the last 60-odd million years. The bottom diagram shows a similar waxing and waning among four groups of marine swimmers, dating back to the earliest fossil records. The ammonoid group suffered near extinction twice before finally expiring. The diagrams are based on the work of George Gaylord Simpson of Harvard University and the author.



DISPERSAL OF CAMEL FAMILY from its origin (*X*) took place during Pleistocene times. Area in light color shows the maximum distribution of the family; dark color shows present distribution. This map is based on one in *Life: An Introduction to Biology*, by Simpson, C. S. Pittendrigh and L. H. Tiffany, published by Harcourt, Brace and Company.



DISTRIBUTION OF ASIATIC LION has contracted dramatically just since 1800, when it roamed over large areas (*shown in color*) of the Middle East, Pakistan and India. Today the Asiatic lion is found wild only in Gir, a small game preserve in western India.

most characteristic member of a distinctive community that includes many plant and animal species. In the 1930's the eelgrass was attacked by a virus and was almost wiped out along the Atlantic shores of North America and Europe. Many animals and plants not directly attacked nevertheless disappeared for a time and the community was greatly altered. Resistant strains of *Zostera* fortunately escaped destruction and have slowly repopulated much of the former area. Eelgrass is a key member of a complex ecological community, and one can see that if it had not survived, many dependent organisms would have been placed in jeopardy and some might have been destroyed.

This cursory glance at recent extinctions indicates that excessive predation, destruction of habitat and invasion of established communities by man and his domestic animals have been primary causes of extinctions within historical time. The resulting disturbances of community equilibrium and shock waves of readjustment have produced ecological explosions with far-reaching effects.

The Causes of Mass Extinctions

It is now generally understood that organisms must be adapted to their environment in order to survive. As environmental changes gradually pass the limits of tolerance of a species, that species must evolve to cope with the new conditions or it will die. This is established by experiment and observation. Extinction, therefore, is not simply a result of environmental change but is also a consequence of failure of the evolutionary process to keep pace with changing conditions in the physical and biological environment. Extinction is an evolutionary as well as an ecological problem.

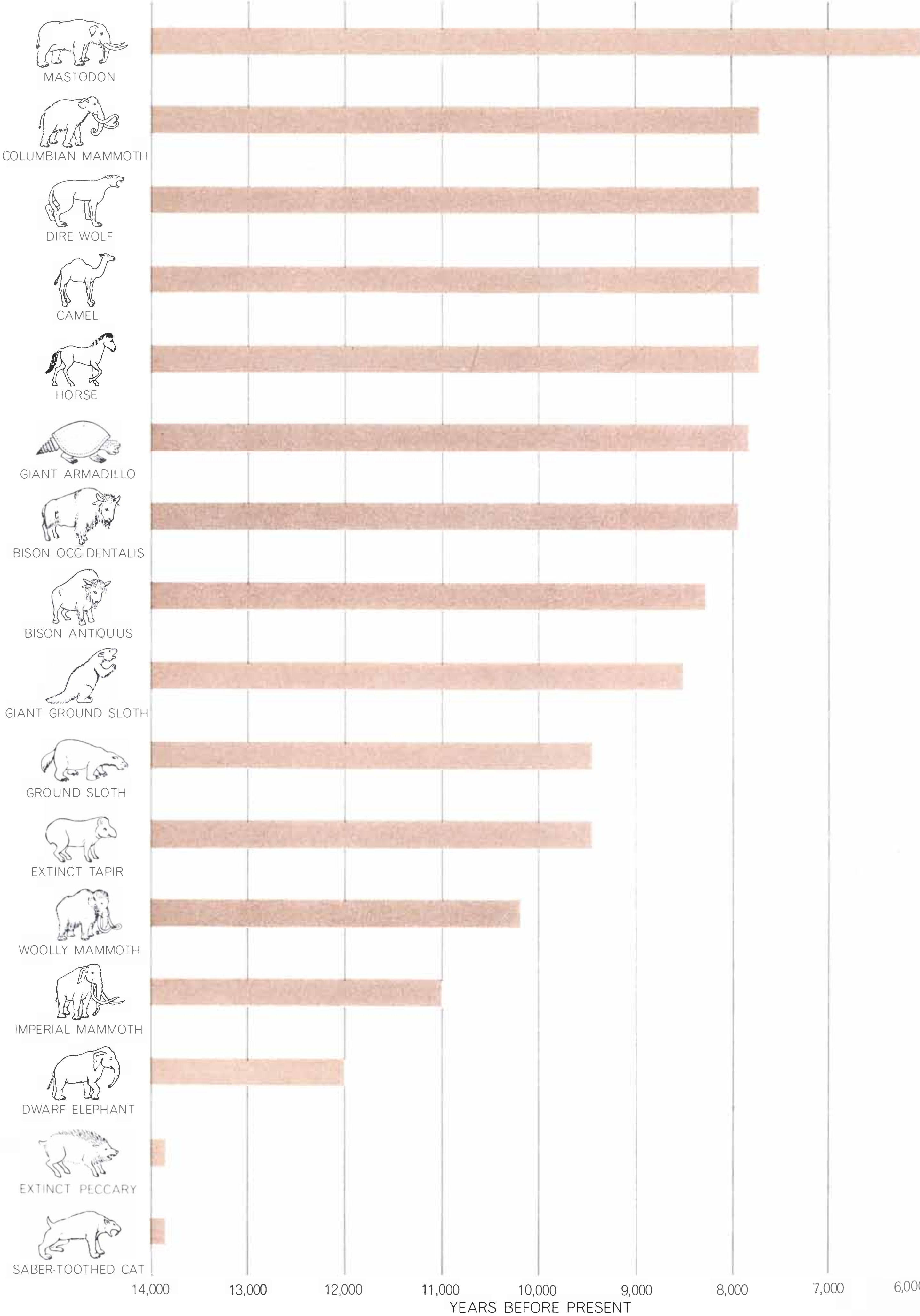
There has been much speculation about the causes of mass extinction; hypotheses have ranged from worldwide cataclysms to some kind of exhaustion of the germ plasm—a sort of evolutionary fatigue. Geology does not provide support for the postulated cataclysms and biology has failed to discover any compelling evidence that evolution is an effect of biological drive, or that extinction is a result of its failure. Hypotheses of extinction based on supposed racial old age or overspecialization, so popular among paleontologists a few generations ago and still echoed occasionally, have been generally abandoned for lack of evidence.

Of the many hypotheses advanced to explain mass extinctions, most are unsatisfactory because they lack testable corollaries and are designed to explain only one episode of extinction. For example, the extinction of the dinosaurs at the end of the Cretaceous period has been attributed to a great increase in atmospheric oxygen and alternatively to the explosive evolution of pathogenic fungi, both thought to be by-products of the dramatic spread of the flowering plants during late Cretaceous time.

The possibility that pathogenic fungi may have helped to destroy the dinosaurs was a recent suggestion of my own. I was aware, of course, that it would not be a very useful suggestion unless a way could be found to test it. I was also aware that disease is one of the most popular hypotheses for explaining mass extinctions. Unfortunately for such hypotheses, pathogenic organisms normally attack only one species or at most a few related species. This has been interpreted as an indication of a long antecedent history of coadaptation during which parasite and host have become mutually adjusted. According to this theory parasites that produce pathological reactions are not well adapted to the host. On first contact the pathogenic organism might destroy large numbers of the host species; it is even possible that extinction of a species might follow a pandemic, but there is no record that this has happened in historical times to any numerous and cosmopolitan group of species.

It is well to keep in mind that living populations studied by biologists generally are large, successful groups in which the normal range of variation provides tolerance for all the usual exigencies, and some unusual ones. It is for this reason that the eelgrass was not extinguished by the epidemic of the 1930's and that the human race was not eliminated by the influenza pandemic following World War I. Although a succession of closely spaced disasters of various kinds might have brought about extinction, the particular virus strains responsible for these diseases did not directly attack associated species.

Another suggestion, more ingenious than most, is that mass extinctions were caused by bursts of high-energy radiation from a nearby supernova. Presumably the radiation could have had a dramatic impact on living organisms without altering the climate in a way that would show up in the geological record. This hypothesis, however, fails to account for the patterns of extinction actually observed. It would appear that radiation would affect terrestrial organ-


MASTODON
COLUMBIAN MAMMOTH
DIRE WOLF
CAMEL
HORSE
GIANT ARMADILLO
BISON OCCIDENTALIS
BISON ANTIQUUS
GIANT GROUND SLOTH
GROUND SLOTH
EXTINCT TAPIR
WOOLLY MAMMOTH
IMPERIAL MAMMOTH
DWARF ELEPHANT
EXTINCT PECCARY
SABER-TOOTHED CAT
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
YEARS BEFORE PRESENT

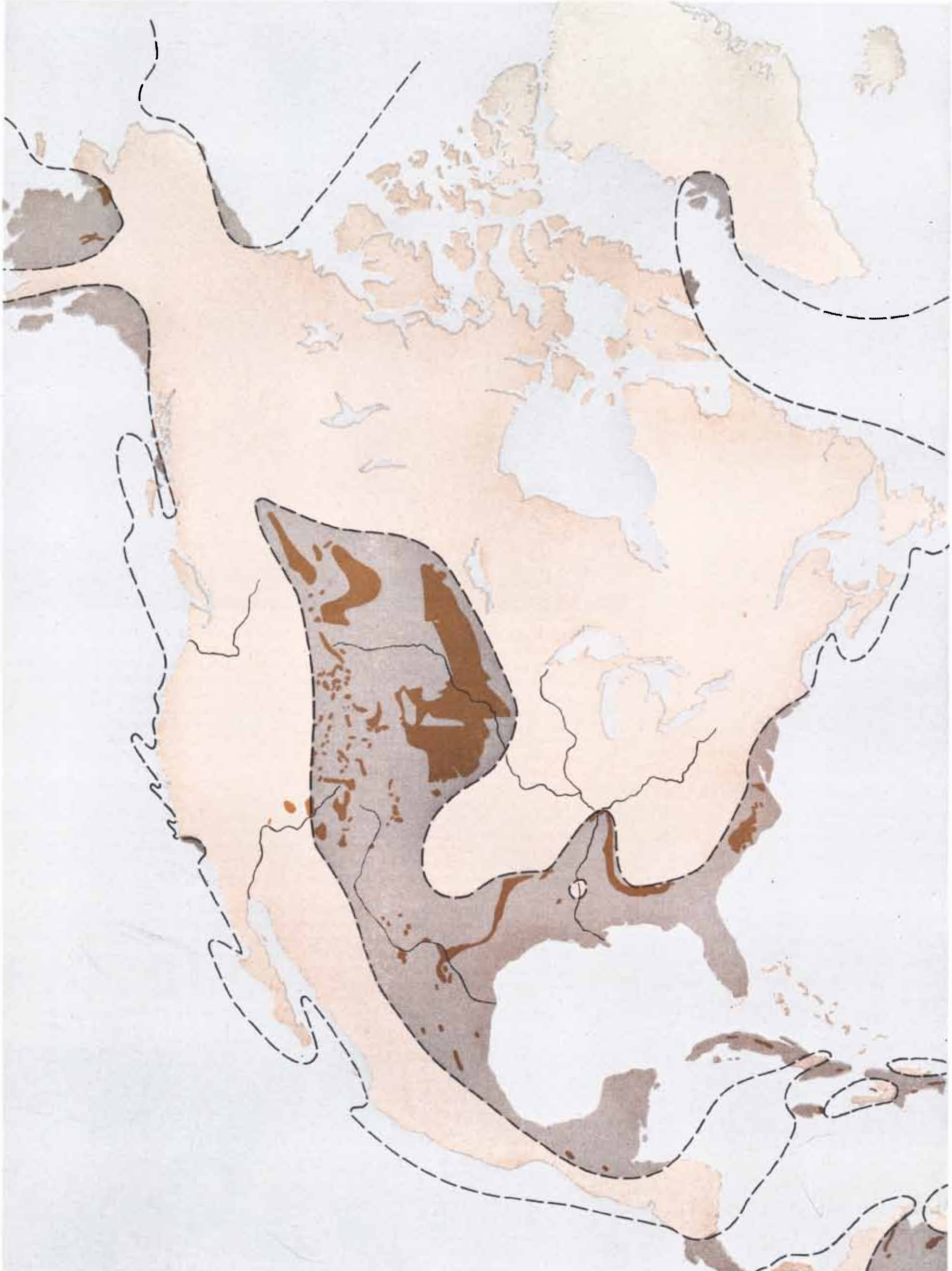
isms more than aquatic organisms, yet there were times when most of the extinctions were in the sea. Land plants, which would be more exposed to the radiation and are more sensitive to it, were little affected by the changes that led to the animal extinctions at the close of the Permian and Cretaceous periods.

Another imaginative suggestion has been made recently by M. J. Salmi of the Geological Survey of Finland and Preston E. Cloud, Jr., of the University of Minnesota. They have pointed out that excessive amounts or deficiencies of certain metallic trace elements, such as copper and cobalt, are deleterious to organisms and may have caused past extinctions. This interesting hypothesis, as applied to marine organisms, depends on the questionable assumption that deficiencies of these substances have occurred in the ocean, or that a lethal concentration of metallic ions might have diffused throughout the oceans of the world more rapidly than the substances could be concentrated and removed from circulation by organisms and various common chemical sequestering agents. To account for the disappearance of land animals it is necessary to postulate further that the harmful elements were broadcast in quantity widely over the earth, perhaps as a result of a great volcanic eruption. This is not inconceivable; there have probably been significant variations of trace elements in time and place. But it seems unlikely that such variations sufficed to produce worldwide biological effects.

Perhaps the most popular of all hypotheses to explain mass extinctions is that they resulted from sharp changes in climate. There is no question that large-scale climatic changes have taken place many times in the past. During much of geologic time shallow seas covered large areas of the continents; climates were consequently milder and less differentiated than they are now. There were also several brief episodes of continental glaciation at low latitudes, but it appears that mass extinctions did not coincide with ice ages.

It is noteworthy that fossil plants,

ICE-AGE MAMMALS provided North America with a fauna of large herbivores comparable to that existing in certain parts of Africa today. Most of them survived a series of glacial periods only to become extinct about 8,000 years ago, when the last glaciers were shrinking. The chart is based on a study by Jim J. Hester of the Museum of New Mexico in Santa Fe.



LATE CRETACEOUS SEA covered large portions of Central and North America (*dark gray*). Fossil-bearing rocks laid down at that time, and now visible at the surface of the earth, are shown in dark color. The approximate outline of North America in the Cretaceous period is represented by the broken line. The map is based on the work of the late Charles Schuchert of Yale University.

which are good indicators of past climatic conditions, do not reveal catastrophic changes in climate at the close of the Permian, Triassic and Cretaceous periods, or at other times coincident with mass extinctions in the animal kingdom. On theoretical grounds it seems improbable that any major climatic zone of the past has disappeared from the earth. For example, climates not unlike those of the Cretaceous period probably have existed continuously at low latitudes until the present time. On the other hand, it is certain that there have been great changes in distribution of climatic zones. Severe shrinkage of a given climatic belt might adversely affect many of the contained species. Climatic changes almost certainly have contributed to animal extinctions by destruction of local habitats and by inducing wholesale migrations, but the times of greatest extinction commonly do not clearly correspond to times of great climatic stress.

Finally, we must consider the evidence that so greatly impressed Cuvier and many geologists. They were struck by the frequent association between the last occurrence of extinct animals and unconformities, or erosional breaks, in the geological record. Cuvier himself believed that the unconformities and the mass extinctions went hand in hand, that both were products of geologic revolutions, such as might be caused by paroxysms of mountain building. The idea still influences some modern thought on the subject.

It is evident that mountains do strongly influence the environment. They can alter the climate, soils, water supply and vegetation over adjacent areas, but it is doubtful that the mountains of past ages played dominant roles in the evolutionary history of marine and lowland organisms, which constitute most of the fossil record. Most damaging to the hypothesis that crustal upheavals played a major role in extinctions is the fact that the great crises in the history of life did not correspond closely in time with the origins of the great mountain systems. Actually the most dramatic episodes of mass extinction took place during times of general crustal quiet in the continental areas. Evidently other factors were involved.

Fluctuations of Sea Level

If mass extinctions were not brought about by changes in atmospheric oxygen, by disease, by cosmic radiation, by trace-element poisoning, by climatic changes or by violent upheavals of the earth's crust, where is one to look for a satisfactory—and testable—hypothesis?

The explanation I have come to favor, and which has found acceptance among many students of the paleontological record, rests on fluctuations of sea level. Evidence has been accumulating to show an intimate relation between many fossil zones and major advances and retreats of the seas across the continents. It is clear that diastrophism, or reshaping, of the ocean basins can produce universal changes in sea level. The evidence of long continued sinking of the sea floor under Pacific atolls and guyots (flat-topped submarine mountains) and the present high stand of the continents indicate that the Pacific basin has been subsiding differentially with respect to the land at least since Cretaceous time.

During much of Paleozoic and Mesozoic time, spanning some 540 million years, the land surfaces were much lower than they are today. An appreciable rise in sea level was sufficient to flood large areas; a drop of a few feet caused equally large areas to emerge, producing major environmental changes. At least 30 major and hundreds of minor oscillations of sea level have occurred in the past 600 million years of geologic time.

Repeated expansion and contraction of many habitats in response to alternate flooding and draining of vast areas of the continents unquestionably created profound ecological disturbances among offshore and lowland communities, and repercussions of these changes probably extended to communities deep inland and far out to sea. Intermittent draining of the continents, such as occurred at the close of many of the geologic epochs and periods, greatly reduced or eliminated the shallow inland seas that provided most of the fossil record of marine life. Many organisms adapted to the special estuarine conditions of these seas evidently could not survive along the more exposed ocean margins during times of emergence and they had disappeared when the seas returned to the continents. There is now considerable evidence that evolutionary diversification was greatest during times of maximum flooding of the continents, when the number of habitats was relatively large. Conversely, extinction and natural selection were most intense during major withdrawals of the sea.

It is well known that the sea-level oscillations of the Pleistocene epoch caused by waxing and waning of the continental glaciers did not produce numerous extinctions among shallow-water marine communities, but the situation was quite unlike that which prevailed during much of geological history. By Pleistocene times the continents stood high above sea level and the warm interior seas had long since disappeared. As a result the Pleistocene oscillations did not produce vast geographic and climatic changes. Furthermore, they were of short duration compared with major sea-level oscillations of earlier times.

Importance of Key Species

It might be argued that nothing less than the complete destruction of a habitat would be required to eliminate a world-wide community of organisms. This, however, may not be necessary. After thousands of years of mutual accommodation, the various organisms of a biological community acquire a high order of compatibility until a nearly steady state is achieved. Each species plays its own role in the life of the community, supplying shelter, food, chemical conditioners or some other resource in kind and amount needed by its neighbors. Consequently any changes involving evolution or extinction of species, or the successful entrance of new elements into the community, will affect the associated organisms in varying degrees and result in a wave of adjustments.

The strength of the bonds of interdependence, of course, varies with species, but the health and welfare of a community commonly depend on a comparatively small number of key species low in the community pyramid; the extinction of any of these is sure to affect adversely many others. Reduction and fragmentation of some major habitats, accompanied by moderate changes in climate and resulting shrinkage of populations, may have resulted in extinction of key species not necessarily represented in the fossil record. Disappearance of any species low in the pyramid of community organization, as, for example, a primary food plant, could lead directly to the extinction of many ecologically dependent species higher in the scale. Because of this interdependence of organisms a wave of extinction originating in a shrinking coastal habitat might extend to more distant habitats of the continental interior and to the waters of the open sea.

This theory, in its essence long favored by geologists but still to be fully developed, provides an explanation of the common, although not invariable, parallelism between times of widespread emergence of the continents from the seas and episodes of mass extinction that closed many of the chapters of geological history.

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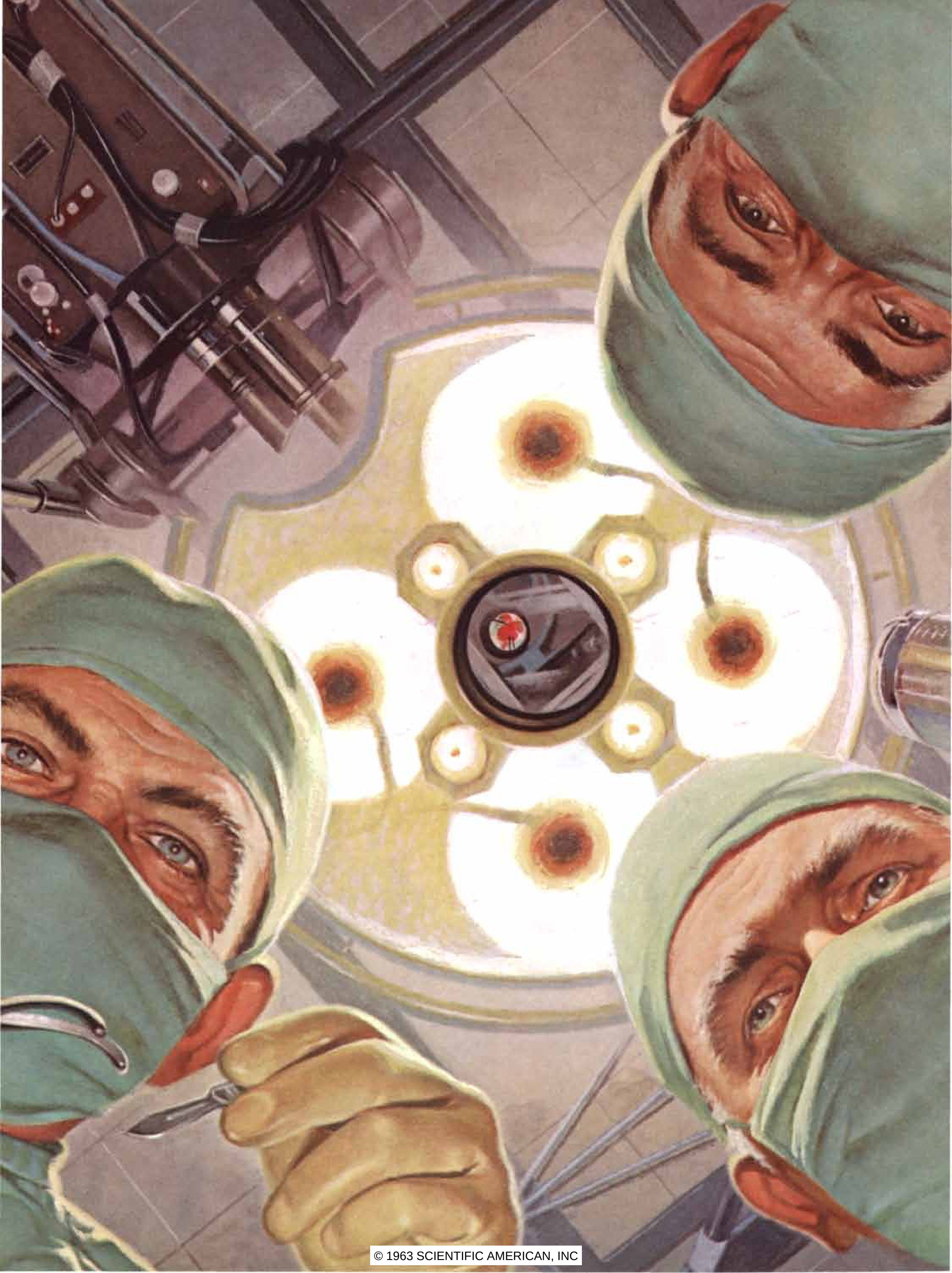

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SUMMIT OF CITY MOUND at Kültepe, which rises more than 60 feet above the level of the surrounding plain, is the open, treeless area in the bottom half of this photograph. The piles of rubble at the perimeter (*left center*) were left by early excavators who mistook the mound for the source of Assyrian cuneiform tablets. A recent excavation can be seen in progress in the foreground.

PRE-HITTITE ARTIFACTS found in the vicinity of Kültepe are characteristic of the indigenous art at the time of the Assyrian colonization of Anatolia. The three gold objects are a bowl, a ceremonial headdress and an ornamental pendant about four inches long. The pitcher (*left*), animal forms (*center*) and fruitstand (*right*) are all made of polished clay. Objects are not in same scale.

An Assyrian Trading Outpost

Clay tablets unearthed at the site of Kanesh in Anatolia describe in detail an Assyrian merchants' colony there, the headquarters of an extensive commercial system that linked two ancient cultures

by Tahsin Özgüç

Students of the ancient world once tended to think of each civilization as an isolated entity, a network of agricultural communities and administrative cities tied together by common cultural and political institutions and perhaps by rudimentary trade or some special common need such as an irrigation system. Sumer, Egypt, Assyria and the rest were conceived of as existing contemporaneously but more or less independently, or as succeeding each other in cycles of conquest or rebellion. In recent years a great deal of archaeological evidence has accumulated to show that this conception was incorrect, that man of the ancient civilizations was to a surprising degree a traveler and trader, and that civilizations influenced one another across deserts, mountains and seas. Most of the evidence has necessarily been indirect. Archaeologists investigating a site have found raw material that must have come from a distant place, an artifact of unmistakably foreign manufacture, a written reference to far-off peoples or a clear case of alien influence in indigenous works of art.

The site in central Turkey that my colleagues and I have been excavating for the past 14 years has provided more explicit and detailed evidence for such an interrelation of two ancient civilizations. What we have been studying is a commercial "colony," a foreign outpost in the central Anatolian city of Kanesh. Here, for 200 years from 1950 B.C. to 1750, two peoples with different languages and cultures lived together in a mutually advantageous commercial symbiosis. The local people were the native Hatti of Anatolia; the foreigners were Assyrian traders and businessmen from the plains of Mesopotamia far to the south. Their homes and artifacts and above all the thousands of clay tablets on which they recorded every detail of their personal and business lives are providing us with a detailed picture of the complex politico-economic ties by which the Assyrians of Kanesh were linked to their homeland and to the local people and rulers.

The Assyrian colony in Kanesh was the culmination of many centuries of trade development. Since the plain of the Tigris and Euphrates is conspicuously deficient in mineral resources, the Mesopotamian cities were dependent from the beginning on imports for their metals. There are indications that as early as 3500 B.C. trade expeditions from the southernmost cities of Sumer were obtaining copper from the mountains of Urartu and central Anatolia, more than 1,000 miles to the north. A half-legendary text dating from a later period recalls a punitive expedition led by King Sargon the Great of Akkad against the Anatolian city of Purushanda, in the area of the "silver mountains," where the natives had been molesting itinerant Akkadian merchants. By the turn of the second millennium B.C. extensive foreign trade had become established as one of the primary features of Mesopotamian culture, and the most enterprising and successful businessmen of this period were the Assyrians.

Instead of relying on occasional expeditions, the Assyrians assured themselves of an adequate and dependable flow of raw materials by setting up permanent trade colonies at key locations throughout the principal ore-producing districts of central and eastern Anatolia. Regularly scheduled donkey caravans traveling over fixed trade routes connected these colonial outposts to the Assyrian capital of Assur [*see map on next two pages*]. Nine such colonies, or *karums,* are known to have existed in major cities of the indigenous Hatti between 1950 B.C. and 1750. Of eight of these colonies only the names remain; their locations have not been discovered. Kanesh, the one colony that has been found, was the largest and was the controlling center of the whole network. The relation between the Assyrians and the Hatti and their rulers was for the most part harmonious. It was the rise to power of a new Indo-European ethnic group, the Hittites, that eventually put an end to the period of Assyrian colonization. But the Assyrians had left their mark. During their stay the indigenous Anatolian culture had become mixed with that of Mesopotamia. The amalgam became the basis of the ascendant Hittite civilization.

It is a curious fact that scholars knew a little about Kanesh and even suspected it was an Assyrian trading center long before Kanesh itself was uncovered. In 1881 clay tablets bearing Assyrian cuneiform inscriptions began to turn up in the shops of antique dealers in the modern Turkish city of Kayseri, 13 miles southwest of the site of Kanesh. They found a ready market among interested philologists and archaeologists, who could learn only that the tablets had been found by natives of the small village of Karahüyük. The village was near an ancient site known simply as Kültepe, or "ash mound": a hill rising more than 60 feet from the surrounding plain and covered by charred remains. When the French explorer Ernest Chantre undertook the first excavations of the mound in 1893, the villagers were unhelpfully reticent, and Chantre could not find the source of the tablets. Neither could a succession of scholars who followed him, until, in 1925, the Czech scholar Bedřich Hrozný had better luck. A friendly cook for his archaeological field party suggested that he look not on the mound but about 100 yards to the northeast. Hrozný dug there and came on the Assyrian merchants' quarter, the *karum* of Kanesh.

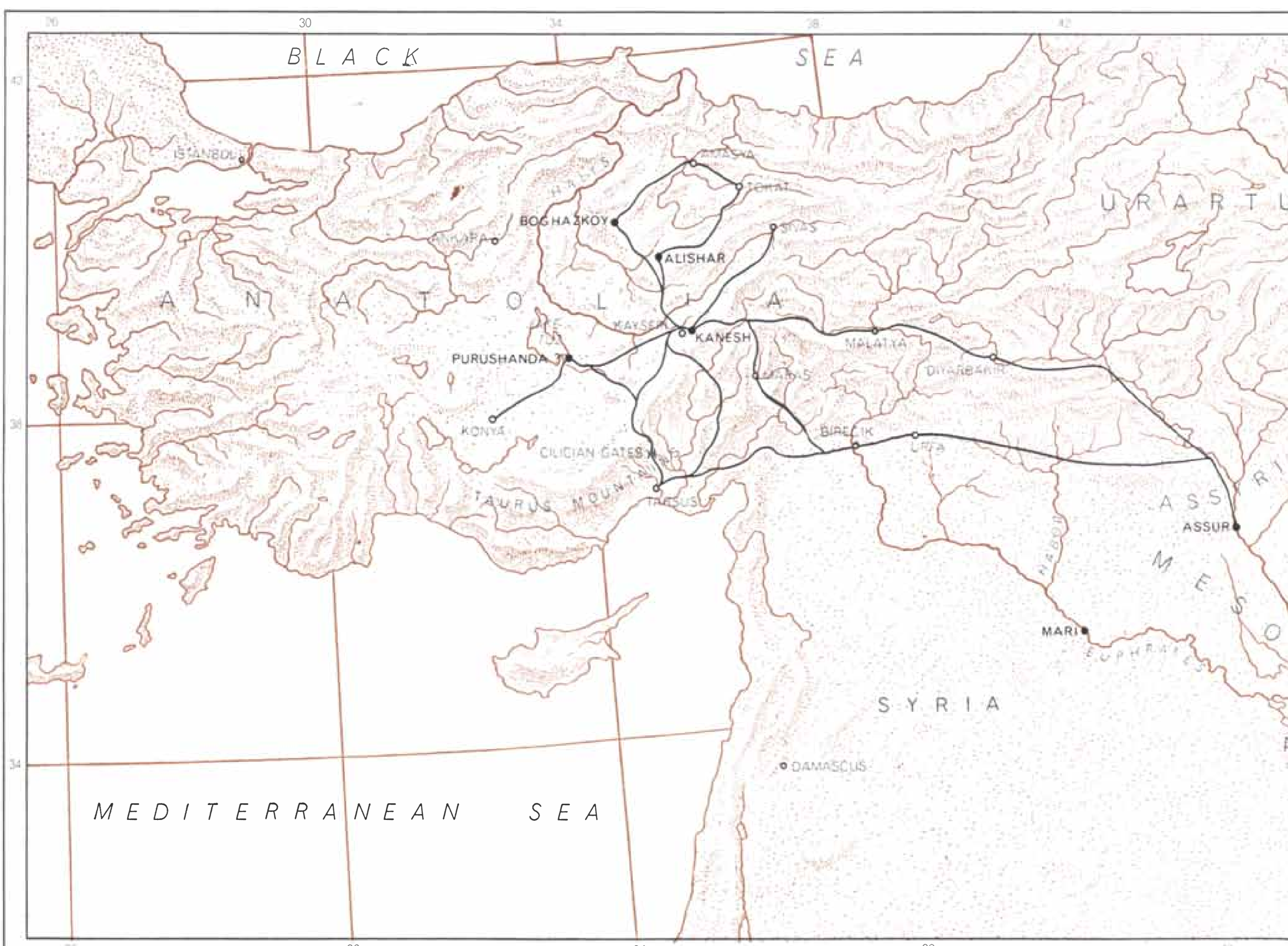
It is in the *karum* that our research under the auspices of the Turkish Historical Society and the Turkish Government's Department of Antiquities has been concentrated since 1948. We have found many thousands of clay tablets, and as we slowly decipher their wedge-shaped cuneiform characters the operations of the Assyrian trading system and the life of Kanesh emerge with increasing clarity.

The principal exports from Anatolia were, of course, metals. Gold, silver and precious stones made up most of the shipments to the markets of Assur. The Assyrians also traded locally in Anatolian copper, which the natives alloyed with tin to make bronze. Large quantities of tin, which was not available anywhere in Anatolia, constituted about 50 per cent of the imports. The Assyrians presumably obtained tin from somewhere in the Zagros Mountains east of Assyria, but their exact source of supply is not known. Textiles and clothing were the other major imports to Anatolia. In addition the Assyrians carried on a brisk local trade in hides, fleece, wool and rugs.

The trade was conducted both by direct barter and by exchange of currency. Gold was the principal capital of the commercial firms at Assur and was sometimes used as money, but silver provided the primary currency for trade with the natives. Both gold and silver were mined extensively in Anatolia, refined at the mines and shipped back to Assur. Within the native economy, on the other hand, copper was the medium of exchange.

The Assyrian merchants applied different terms in their dealings with the local people and among themselves. To their fellow merchants they extended credit more freely and at lower interest rates. In their transactions with the natives they generally preferred cash payment, and when they made loans to Anatolians it was at a higher rate and for a shorter term. Imported manufactures sold in Anatolia at a 100 per cent markup on their price in Assur. The institution of collateral played an important role in trading contracts. A debt might be secured by every item of a man's property—including his wife and children.

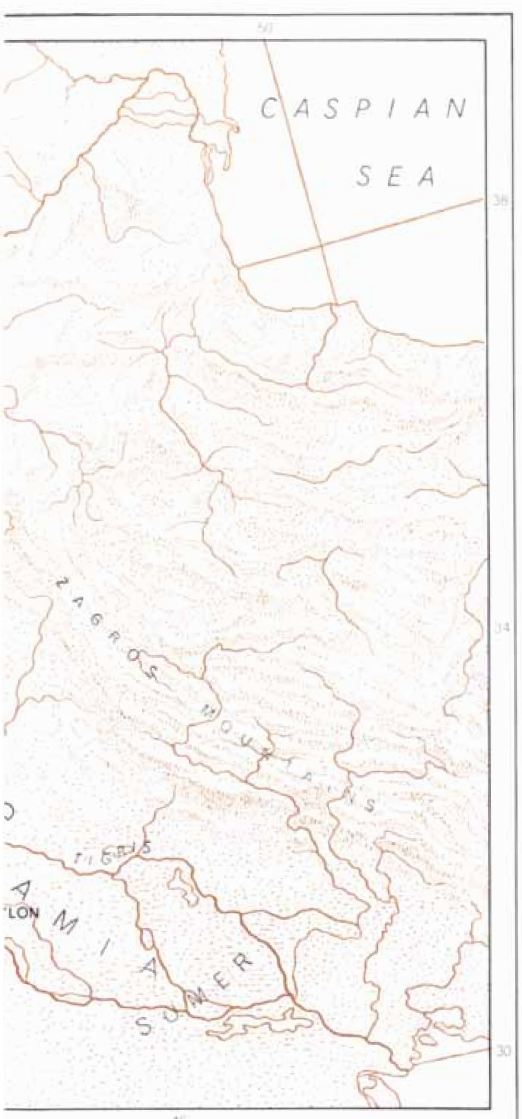
As was their practice throughout Anatolia, the Assyrians did not attempt to interfere in any way with local politics. They managed their commercial activities and settled disputes among themselves through their own Assyrian institutions: local councils made up of officials appointed from Assur and other members elected by resident Assyrian traders for specific terms of office. Where commerce impinged on local politics their councils negotiated treaties or other agreements with the local princes.



PRINCIPAL TRADE ROUTES traversed by the Assyrian merchants originated at Assur in northern Mesopotamia and terminated at the central Anatolian city of Kanesh. The northern route followed the upper Tigris River Valley and entered Kanesh from the east. The southern route skirted the edge of the North Syrian desert and ascended the Anatolian Plateau from three different

The dependence of the councils on the home government at Assur was effected by making them all subject to the *karum* at Kanesh, which was in turn directly connected to Assur, or, as it is usually referred to in the tablets, "the City."

Most of the major Anatolian cities of the period were ruled by local princes and princesses and were entirely autonomous. The Assyrian merchants paid taxes to the local prince on imports, exports and sales. In return the prince guaranteed the trade caravans safe passage through his territory. In the event of any change in local government, such as the accession of a new prince to the throne, an oath of confidence was asked from the council of the *karum*. The prince also acted as an arbitrator in cases of conflict between the Assyrians and his native subjects. For a certain fee the prince would provide storage space for merchandise in the cellar of his palace. We have found such cellar warehouses in both of the two palaces so far exca-



directions. Auxiliary routes connected all the major trade centers of Anatolia to Kanesh. Open circles indicate modern cities.

CLAY TABLETS were often stored in large earthenware jars like this one, photographed as it was uncovered in the house of a merchant in Level II. The foot rule indicates scale.

vated on the Kültepe mound. In addition to his regular fee the prince also had the first option to buy any of the latest imports from Assur.

Most of the documents unearthed from the *karum* at Kanesh are of a purely commercial nature. They include business letters, contracts, bills of lading, memoranda about purchases and sales, and deeds between Assyrian traders. The local princes and even some of the common people learned to use the Assyrian script. We have found letters from one native to another, legal documents, lists of palace staffs and documents bearing on family relations that teach us something about the Hatti administrative system and civilization. In some cases the mention of proper names—local gods, people and places—provides a clue to the unwritten local language of the time.

More than most archaeological finds, some of the tablets give vivid insights into personal lives. One letter from a woman at home in Assur to her trader husband in Kanesh complains about her mother-in-law. Another woman left behind in Assyria writes to bemoan the fact that she does not have enough money to buy a sacrifice to a god. And we have one letter, apparently never dispatched, in which a woman whose mother-in-law is dying asks her sister-in-law to come to Kanesh to help. Encountered among vast stacks of commercial documents, these letters cut sharply through the centuries and remind one of the human beings behind the clay tablets and pottery shards.

The first Assyrian traders settled at Kanesh in about 1950 B.C. They established residence in a section of the city that lay like a crescent around the northeastern rim of the central mound, and it was this area that became the Assyrian *karum*. It is some 1,000 yards long, 700 yards wide and only a couple of yards above the level of the plain. Whereas the central city was populated from the Early Bronze Age until the end of the Roman era in the fourth century A.D., the *karum* was inhabited for but a short period of time. Only four distinct building levels are to be found there, the total thickness of which, from virgin soil to the floor of the latest level, is just under 28 feet. The two lowest levels, designated III and IV, antedate the Assyrian colonization and no written documents have yet been found there. It is Level II that introduces the documented historical era and the Assyrians, and it is here that we have unearthed the majority of the tablets—more than 14,000 of them.

The city of this era was divided into various quarters by squares and streets wide enough to allow the passage of carts. The residences of the Assyrian merchants were concentrated in the center and northern section of the *karum*, with local Anatolians in the southern part. Apparently the Assyrians preferred to stick together, but the boundaries between quarters were not distinct. The shops of craftsmen were grouped at the center of the community. We have found two-room buildings containing large amounts of crockery and kitchen equipment; these may have been restaurants. Other small buildings open to the street and outfitted with stone or wooden shelves seem to have been shops of some kind, but we do not yet know what they

CLAY ENVELOPES in which the tablets were enclosed to be filed or dispatched were sealed with the writer's personal design, applied with a cylinder seal. Such a design is seen at the top of this envelope. The writing below may be an address or a summary of contents.

contained. Most of the residences were two stories high and had three or four rooms on each floor, grouped around a covered courtyard. In many cases small rooms filled with tablets and separated from the living quarters appear to have served as offices.

Unfortunately for the inhabitants but fortunately for the archaeologist, the history of Level II ended with a disastrous fire. The inhabitants departed in a hurry, leaving behind them the contents of their houses and workshops. Whatever resisted the flames remains to this day substantially as it was abandoned. The site was uninhabited for between 30 and 60 years, after which a new city was built on the ruins, apparently by a new generation of Assyrian merchants. The new city is designated I*b* to distinguish it from a slightly later, non-Assyrian level, I*a*. The houses of I*b* were larger and individual rooms were more spacious. Although we have found less evidence of business activity in the form of cuneiform records (only some 80 tablets have been unearthed so far), Level I*b* apparently represents a city at least as prosperous as its predecessor. Whereas the walls of houses in the earlier city had been built of mud brick on wooden frames, stone-wall construction now became more popular. The Assyrian merchants were still influential in the I*b* city, but more of the native merchants in the southern part of the city now lived in houses as large and well designed as those of the colonists.

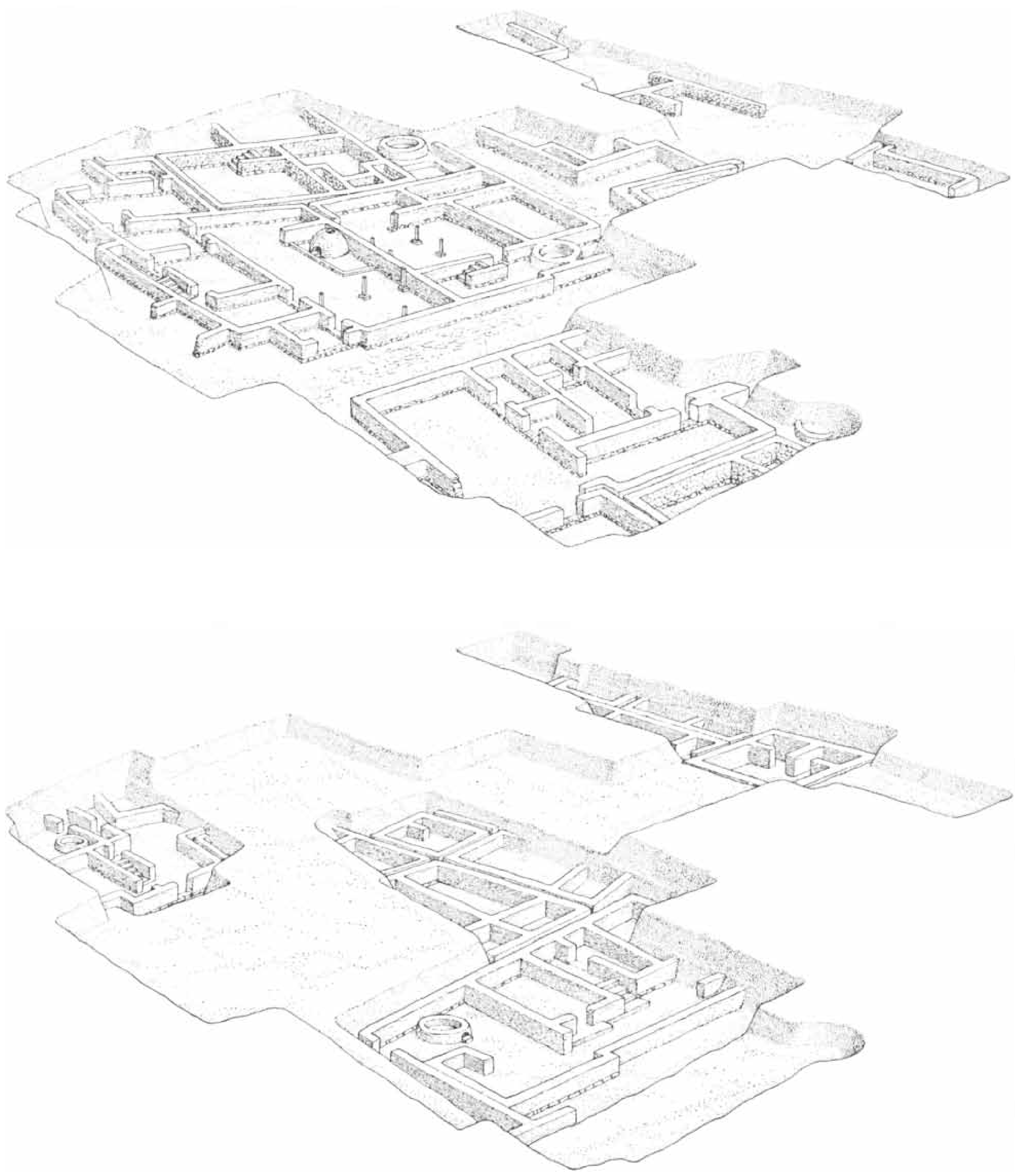
The artifacts found in Levels II and I*b* reflect the remarkable degree to which the Assyrian colonists adopted the culture of their Hatti neighbors. Ex-

MAP OF SITE shows the central mound where the Hatti city of Kanesh was located and the outlying *karum* of the Assyrian merchants. The diagonally hatched areas around the perimeter of the mound were excavated by early archaeologists. The author's excavations on the mound and in the *karum* are outlined in black. Contour intervals are indicated in meters above the level of the plain.

cept for the clay tablets, with their cuneiform script and distinctly Mesopotamian cylinder-seal impressions, all the artifacts of these levels are in the native style. If the tablets and their sealed envelopes had not been found, in fact, we might never have suspected the existence of the merchant colony.

It was during the colonial period that the ceramic art reached its highest development in Anatolia. Some of the pottery was richly decorated, but the finest pieces depended for their beauty on purity of line and burnished monochrome finishes. Human and animal figures, drinking cups and small cosmetic boxes molded in the form of animals rank among the masterpieces of their kind.

The clay envelopes in which cuneiform tablets were enclosed were sealed with elaborate impressions made by carved stone cylinder seals [*see bottom illustration on page 104*]. The natives took over this ancient Mesopotamian de-



KARUM OF KANESH had four distinct building levels, two of which are shown in this schematic drawing of an excavation at the site. The houses of the earlier Level II (*bottom*), the settlement in which most of the clay tablets were found, were largely of mud-brick construction. Those of the later Level I*b* (*top*) were more spacious and closer together, and many of them had stone walls.

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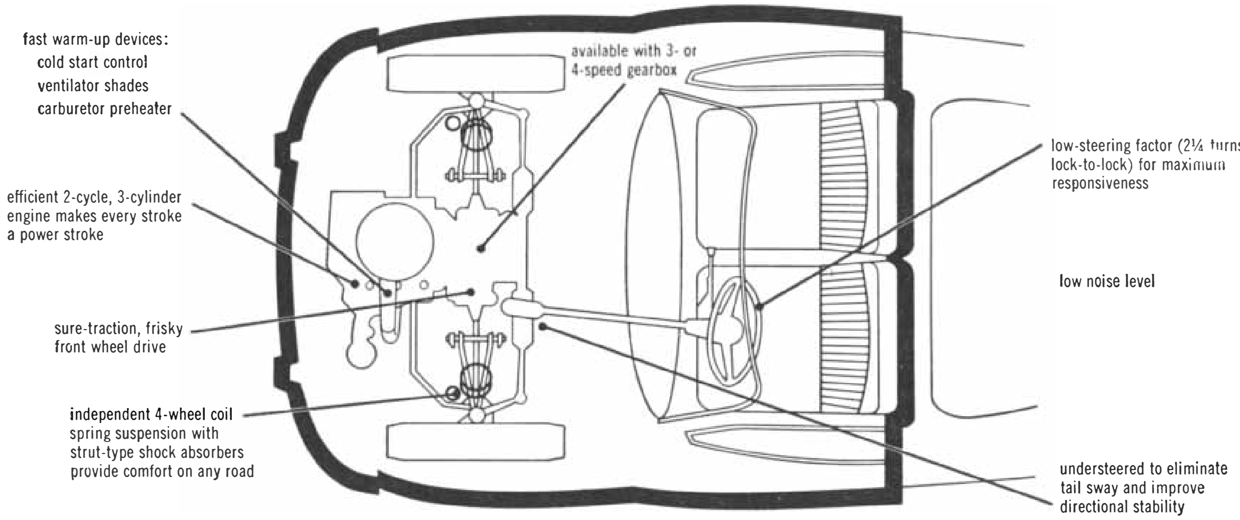

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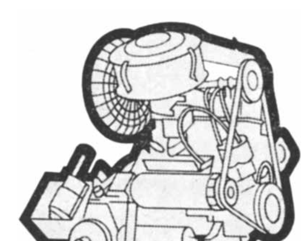

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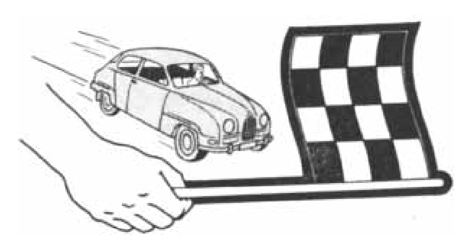

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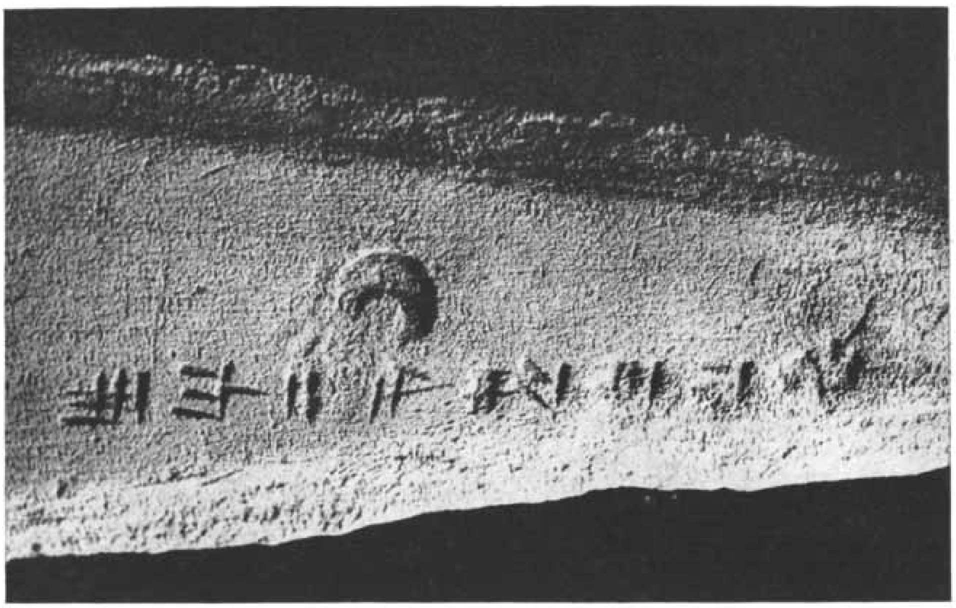

BRONZE DAGGER from the mound of Kanesh bears the Assyrian words "Palace of Anitta, the King." Anitta ruled in the region toward the end of the Assyrian colonial period.

vice and developed it in their own distinctive style. In the locally made seals processions of gods and scenes of the hunt and of battle are prominent; many of these themes were later developed into primary motifs of Hittite art.

Although the resident Assyrians apparently had little effect on Anatolian art forms aside from the cylinder seals, we have found a strong North Syrian influence, particularly in metal objects, pottery and small statues. Evidence of this influence is found in both imports and imitative native products. One of the most interesting imports is a hollow-shafted adz that is distinctly foreign to Anatolia and must have been brought in from the area of the Habor River [*see map on pages 98 and 99*]. This tool and many other metal objects found in specific strata at Kanesh and at Syrian sites are useful for establishing archaeological synchronism. In both levels of the *karum* we have found clothing pins, axes, daggers and spearheads fashioned in bronze, silver or gold. None of these objects has been excavated at levels dating from either before or after the Assyrian colonization. The fact that they are not Assyrian but North Syrian indicates that the Kanesh *karum* maintained close relations not only with Assur but also with other neighboring lands. Some of them may not have been important items of trade but merely the personal effects of itinerant merchants passing through Kanesh.

Among the figurines of gods and goddesses, we have found two that are in a style alien to Anatolia. One is made of a glazed pottery and the other of ivory. Both materials are native to North Syria. The ivory statuette is remarkably similar to the figures of naked goddesses discovered at Mari in North Syria and must have been an import from that area. Both of these figurines were found in the grave of a foreign merchant. They are in sharp contrast to the majority of the religious figures uncovered in Level I*b*, which are in the native style. Most of these are lead plaques showing the principal Anatolian goddess, with or without her family, in low relief. We have also found the stone molds from which the plaques were cast.

During the time when Level I*b* was occupied, major changes were taking place in Anatolia. Regional kings arose and began to extend their control over the feudal domains of the local princes. One of the rulers was Anitta, whose name appears on a bronze dagger unearthed in the remains of a palace on the mound of Kanesh. Anitta was king of the city of Kussara and apparently held dominion over Kanesh. Shortly after the reign of Anitta, during the first half of the 18th century B.C., invaders from the north—presumably Hittites—attacked and burned both the central city and the Level I*b* *karum*. Although a small city was built on the ruins and left its remains as level I*a* in the *karum* area, the fire marked the end of the Assyrian colony. With the consolidation of political power in the Hittite Old Kingdom, the immediate Assyrian influence in Anatolia was at an end.

The influence of Assyria in Anatolia nonetheless persisted. For more than a century the Anatolians had been in direct contact with the advanced culture of Mesopotamia, with a written lan-

CYLINDER SEAL is shown at the right. At the left is its impress, made by rolling it over wet clay. Cylinder seals were characteristic Mesopotamian devices and were introduced into Anatolia by the Assyrians. This particular seal probably came from North Syria.


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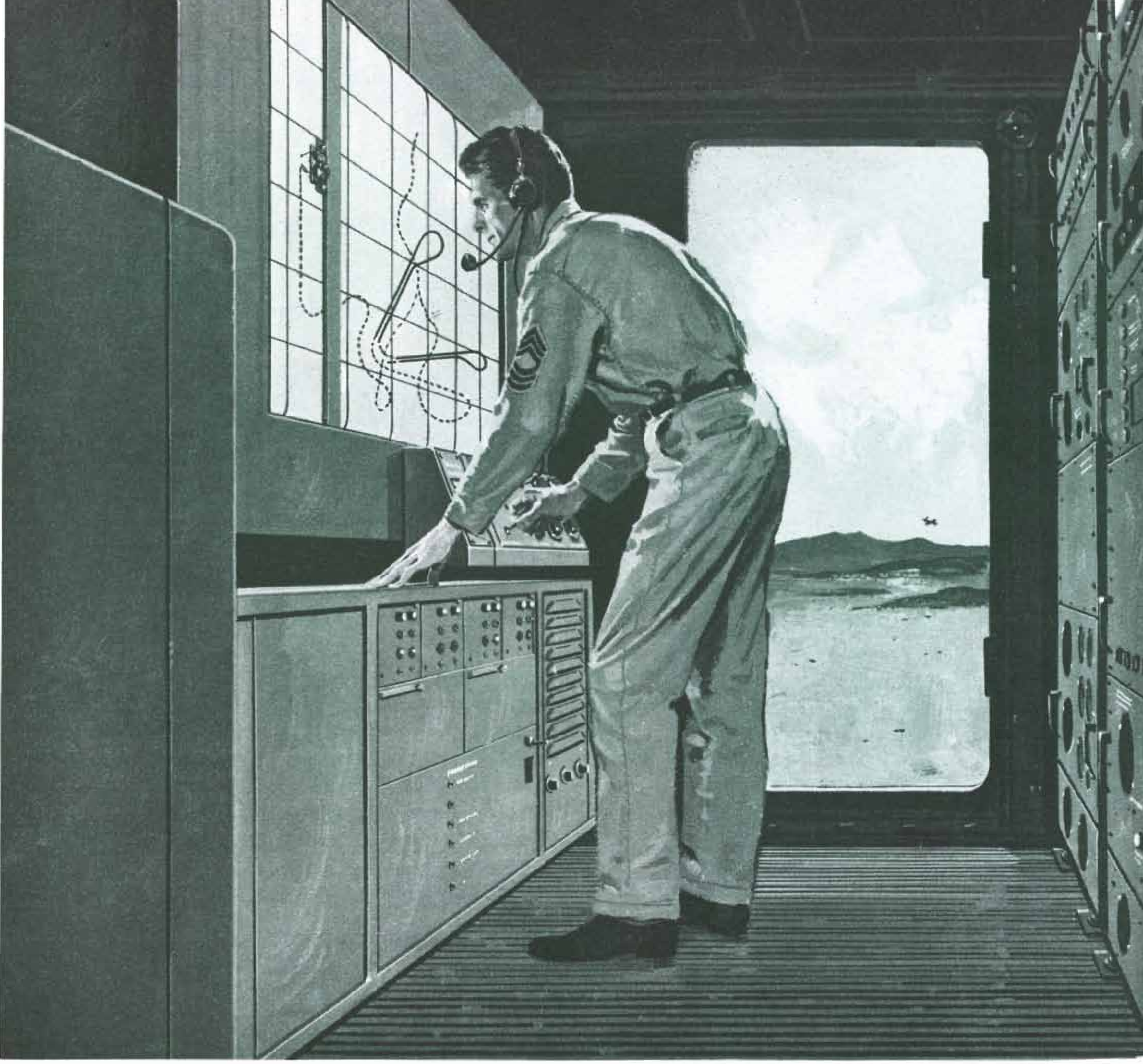
guage and with a highly organized commercial system. Assyrian scribes served in the palaces of the Anatolian kings, and some of the local people learned enough of the written language to use it for commercial, legal and administrative purposes. The upper classes in particular came under the broadening influence of the Assyrians. They acquired a taste for the fashions and luxuries of Babylon and picked up administrative techniques and business acumen. Perhaps most important of all, this provincial people acquired from the Assyrians a sense of empire that later expressed itself in the powerful Hittite civilization, which dominated Asia Minor in the centuries that followed.

FIGURINE of the mother goddess carved in ivory was found in a Level *Ib* grave. It was probably imported from a North Syrian city.



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Shock Waves and High Temperatures

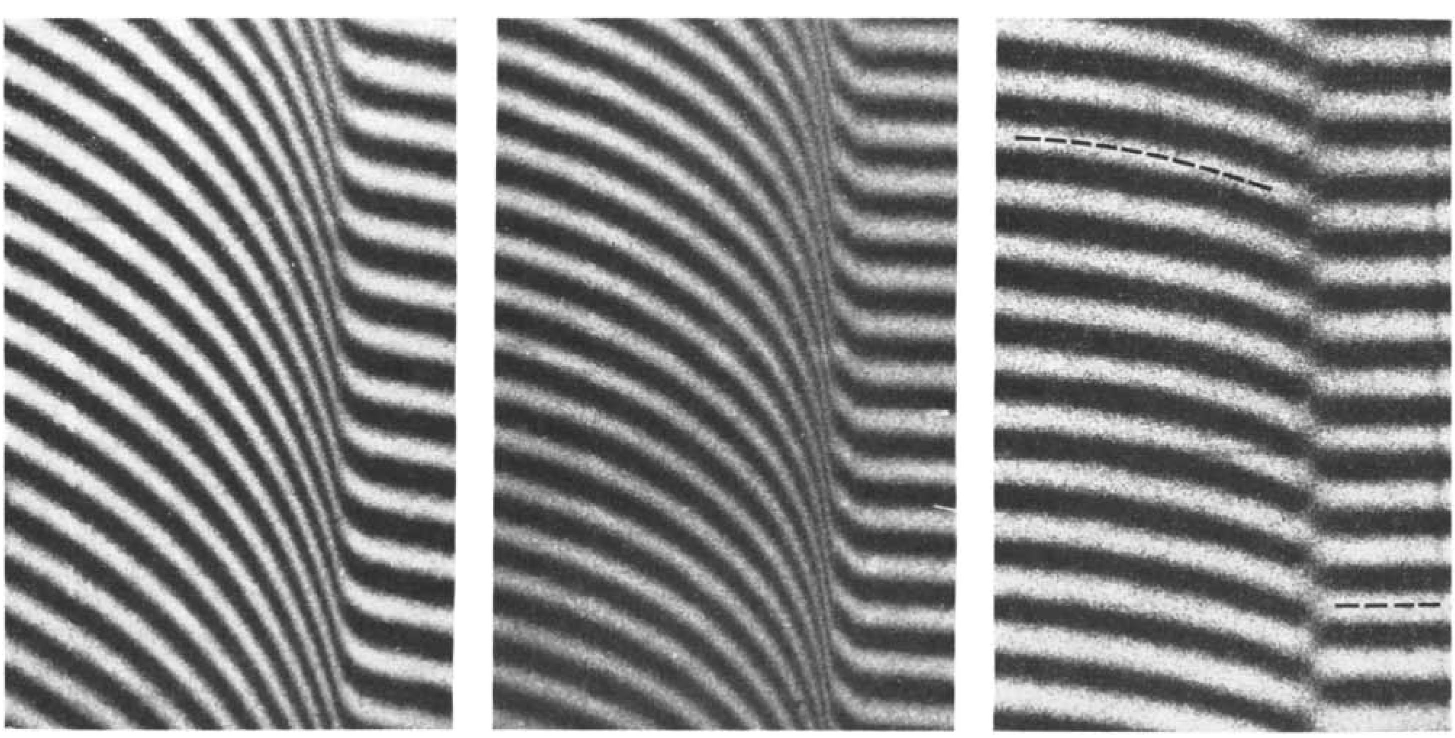
New versions of the shock tube, the device that is used to produce shock waves under controlled conditions in the laboratory, can heat a gas to temperatures approaching those of thermonuclear reactions

by Malcolm McChesney

A handclap and a thunderclap, the sonic boom from a supersonic aircraft that can break windows and the blast wave from an explosion that can flatten a building—these are examples of shock waves: pressure disturbances of finite amplitude that in a gas move at a speed in excess of the speed of sound. By the time the handclap or the thunderclap reaches the ear, the energy that initiated the disturbance has almost been dissipated and the shock wave has decayed into a train of sound waves: pressure disturbances of minute amplitude that travel at the speed of sound. In the case of the sonic boom and the blast wave, the breaking of the window and the collapse of the building give evidence that the shock wave has arrived intact bearing a large quotient of the energy that initiated it.

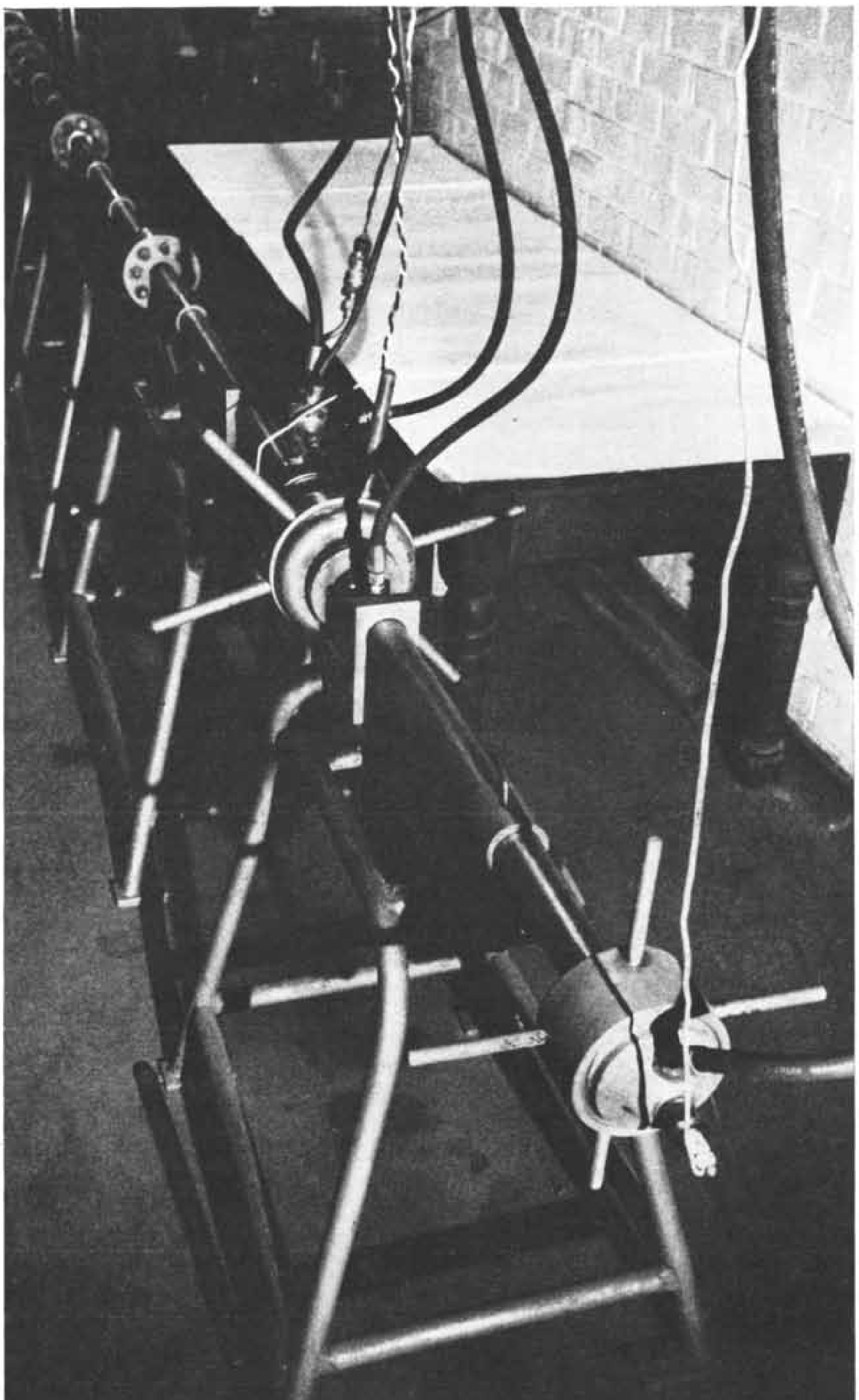
Concern with the destructive effect of shock waves brought the invention some years ago of the shock tube. This instrument for the study of shock waves on a small scale has now become a fairly common piece of laboratory equipment. Interest in the subject has taken a new turn because the shock wave has proved to be the medium for the attainment of some of the highest temperatures on earth outside of a nuclear explosion. An understanding of the condition and behavior of atoms and molecules in such extreme states of excitation is crucial for work along many lines, from fundamental questions in thermodynamics to engineering problems in rocketry. Presently the temperatures in laboratory shock waves are approaching the thermonuclear range, above a million degrees Kelvin (degrees centigrade above absolute zero). Here investigators have encountered a new kind of shock wave for which there is no adequate theoretical model. When this situation is better understood, the latter-day descendants of the shock tube that generate such shock waves may turn out to be the prototypes of the reactor that will harness thermonuclear reactions for the production of useful power.

The generation and movement of a shock wave are best illustrated in the operation of what can now be described as the classical shock tube. This consists of a long pipe a few inches in cross section,



FORMATION OF SHOCK WAVE is shown at three stages in these photographs by Walker Bleakney of Princeton University. The wave is moving from left to right and the displacement of an interference fringe from the normal horizontal position is a measure of the gas density. The broken lines at right mark the same fringe on both sides of the shock front; the displacement is about seven fringes.

either round or square and sealed at both ends. At some point between the two ends a breakable diaphragm divides the pipe into two sections. One section—the "driver," or high-pressure, section—is filled with a light gas at high pressure; for example, hydrogen or helium or a mixture of combustible gases such as oxygen greatly diluted with hydrogen. The other section—the "expansion," or low-pressure, section—is filled with some test gas in which it is proposed to study the behavior of the shock wave; the pressure of the test gas is usually set at considerably less than the pressure of the atmosphere. The diaphragm is a sheet of plastic or metal, and it is designed to be ruptured "naturally" by the building up of gas pressure in the driver section or "artificially" by any one of several methods such as pricking it with a steel needle or melting it with a hot wire. In the ideal case the ruptured diaphragm is assumed to open up instantaneously to the full cross section of the shock tube, bringing the high-pressure gas in the driver section into contact with the low-pressure gas in the expansion section and creating an abrupt discontinuity of pressure in the tube.



SHOCK TUBE used by the author at the University of Liverpool is approximately 18 feet long. The shorter "driver" section, about three feet long, contains a gas under high pressure.

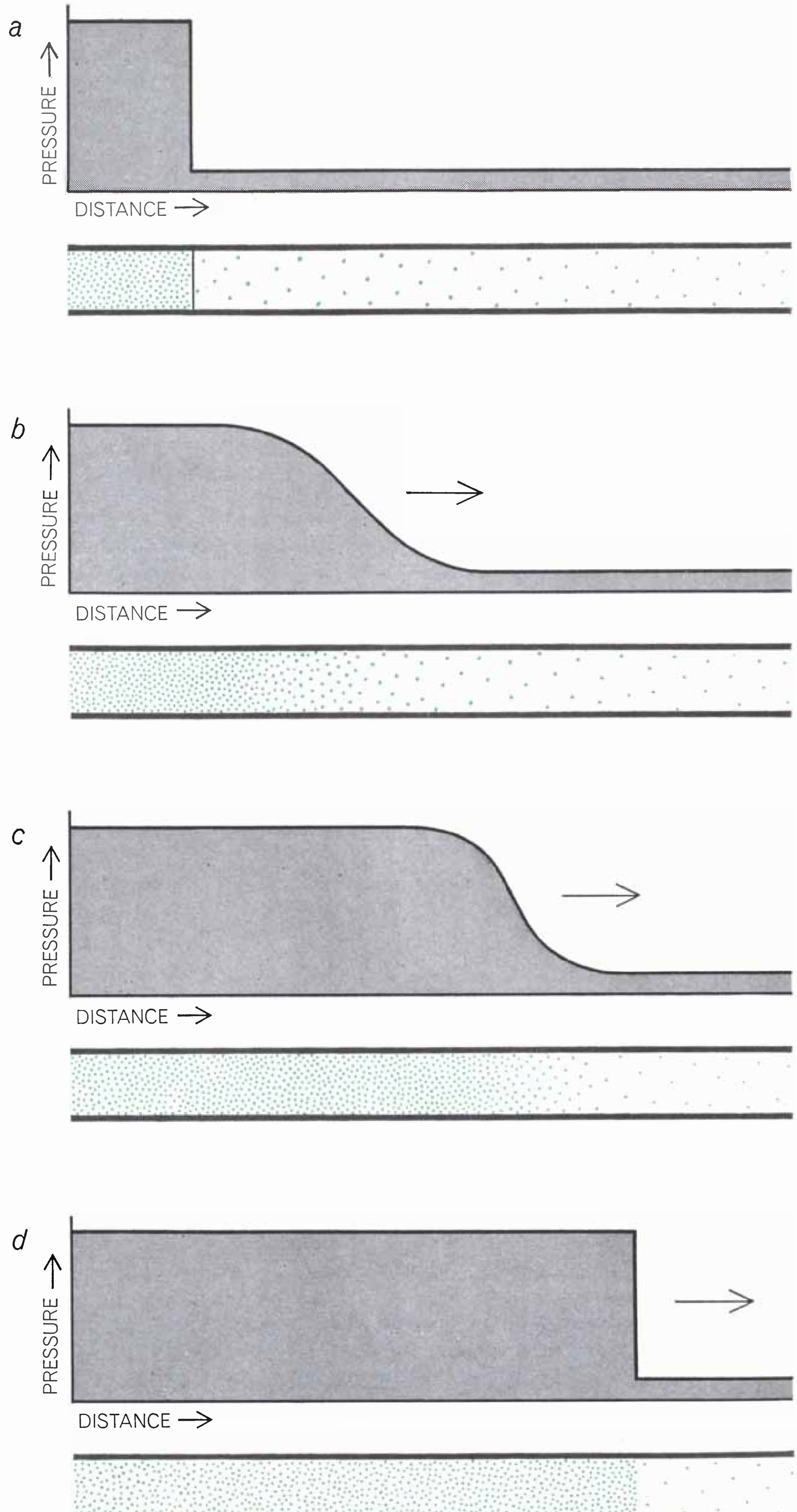
What happens now can be visualized by imagining the high-pressure gas to be a solid piston that is suddenly allowed to move in the pipe. The little slab of low-pressure gas immediately ahead of the piston will be compressed, heated and set in motion, much as happens in a bicycle-tire pump. This slab of compressed, hot gas pushes against the next slab of cold gas down the pipe and similarly compresses, heats and sets it in motion. Hence a minute pressure wave proceeds through the test gas, and the gas through which it passes is compressed, heated and set in motion. As the piston moves forward it starts a new wave at each point, and in this way generates a train of pressure pulses that moves through the gas. The compression of a gas by such pressure waves was predicted by Isaac Newton and correctly analyzed by the 18th- and 19th-century French mathematician and astronomer Pierre Simon de Laplace, who called the waves "sound waves." Laplace also showed that the speed of a sound wave depends on the temperature of the medium through which it is traveling. Thus in the shock tube as each little pulse starts out from the piston and heats the gas through which it passes, the succeeding pulse in the train moves into gas already heated and travels faster. In the train of pressure pulses generated by the forward movement of the piston the later pulses catch up with the earlier ones until they all coalesce at some point in the pipe to form a large pressure pulse.

The movement of large pressure pulses of this kind was subjected to analysis about a century ago by the German mathematician Georg F. B. Riemann. He found that the velocity of any portion of the pulse depended on the ratio of the pressure at that portion of the pulse to the pressure of the undisturbed gas ahead of the pulse. This means that the portion of the pulse at higher pressure will travel faster and that the peak of the pulse, where the pressure is highest, will travel fastest of all, possibly several times the speed of sound; whereas the forward base of the pulse, where the pressure is not much higher than it is in the undisturbed gas ahead, will travel at the speed of sound. It is clear that as the pulse moves down the pipe it will change its pressure profile: the peak that travels fastest will tend to overtake the base, steepening the differential in pressure as it moves on, until the profile has attained a theoretically infinite steepness. The pressure pulse now moves as a pressure discontinuity in the gas, just like the piston that generated it but at a faster speed. The train of minute pressure waves, or sound waves, has built into a large pressure pulse that has grown into a shock wave moving faster than sound.

Riemann's predictions were verified in their essentials by the French engineer Paul M. E. Vieille, who devised the first shock tube for this purpose in 1899. Later British investigators, working on problems of safety in coal mines, used the shock tube to study explosions in mine gases. The biggest boost to shock tube technology came during World War II, when U.S. investigators undertook systematic study of the military aspects of blast waves: how these waves damage buildings and how, in particular, the blast wave of a nuclear explosion is amplified by the Mach effect, which results when the reflected blast wave from the ground, traveling through air already compressed and heated, overtakes and merges with the initial blast wave. In connection with this work, investigators at Princeton University made the discovery that not only could the shock tube be employed to study the pressures due to shock waves but also, and more important, that these waves generate high temperatures in the gases through which they pass.

Pressure-driven, or hydrodynamic, shock tubes are now used to study shock waves in many laboratories around the world. Ranging from simple pipes to big-gun barrel installations, they operate over a considerable range of pressure and temperature. Work with the shock tube speedily came up against a temperature ceiling not predicted in Riemann's theoretical scheme. Observation and theory now show that, regardless of the ratio of the pressures in the high- and low-pressure sections of the shock tube, the pressure and temperature of the gas behind the shock wave is limited and, in fact, depends on the ratio of the speed of sound in the driver gas and in the driven gas. Put another way, the speed of the piston that drives the shock wave is limited to a few times the speed of sound in the high-pressure gas.

Riemann's mathematical analysis is subject to still another correction that explains more vividly the limitations on

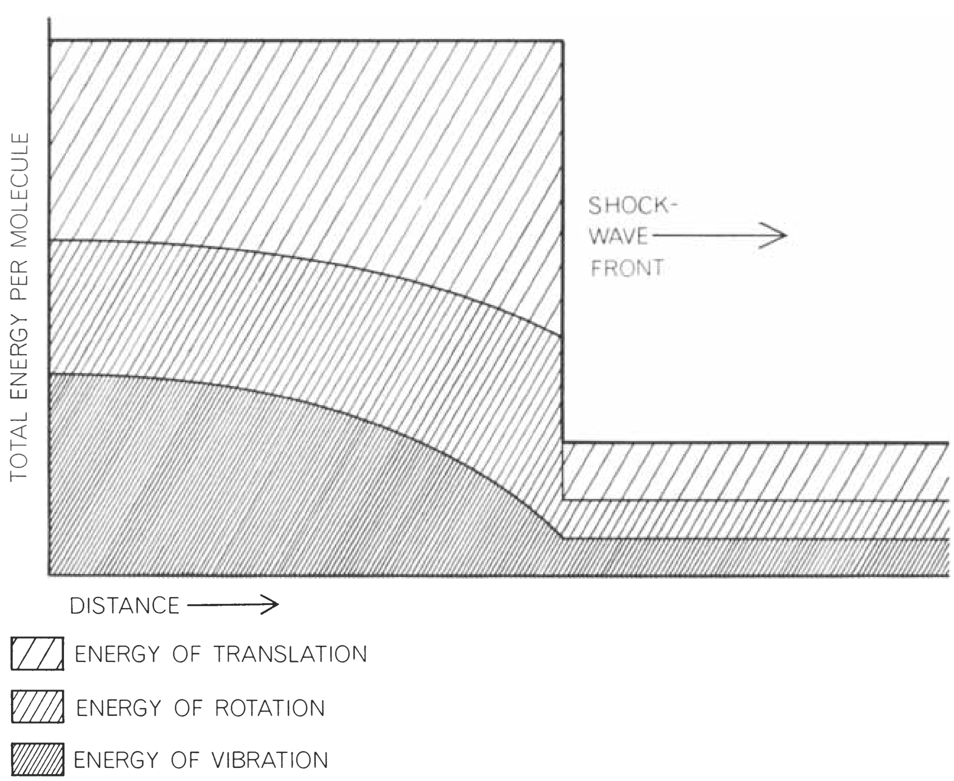


DEVELOPMENT OF SHOCK WAVE in a shock tube is depicted graphically and schematically. A diaphragm (*lower diagram in* a) separates one gas at high pressure from another at much lower pressure. The plot of pressure against distance shows this division. When the diaphragm is ruptured (*b*), the driver gas generates a continuous pressure gradient (or profile) ahead of it as it moves down the tube. This pressure gradient becomes increasingly steep as it propagates (*c*), until it becomes a near discontinuity, that is, a shock wave (*d*).

the temperature attainable in the hydrodynamic shock tube. The correction also serves to clarify the physical mechanism by which the energy stored in the high-pressure driver gas is transformed into heat and other forms of energy in the gas traversed by the shock wave. Riemann assumed the gas to be a structureless fluid, or, as it is called, a continuum. A gas, however, is composed of atoms or molecules and a great deal of empty space—it is a medium far from continuous in texture. In any given volume of gas the molecules tirelessly rush about, colliding with one another or the walls of their container, then travel freely and collide again. Such terms as density, temperature, heat and pressure each describe certain aspects of this situation. Density, of course, refers to the average number of molecules per unit volume; this has the important effect of determining the average distance (termed the mean free path) that any one molecule can travel before it collides with another. Temperature is a measure of the average energy of the molecules as they move about in arbitrary directions; as such it is an index of the heat content of the gas. Not to be confused with temperature, the heat content is the total energy of this random motion of the molecules in the gas; it is therefore a function of density as well as of temperature. The pressure is the force exerted on the walls of the container as a result of the density of the gas and the heat energy it contains.

The build-up of a shock wave can now be described in terms of the "molecularity" of the gas. At the instant the diaphragm in the shock tube is ruptured, the molecules of gas in the low-pressure section are moving about over relatively long mean free paths, owing to the low density of the gas, and at the rather leisurely average speed of about 1,000 feet per second, the speed of sound in light gases at ordinary temperatures. Compression of the gas in the first little slab ahead of the outrushing piston of high-pressure gas shortens the mean free path of the molecules and steps up the rate of collision among them, increasing the velocity of the molecules and consequently the temperature of the gas. The first minute disturbance passes forward at the speed of sound into the next slab, compressing and preheating it for the arrival of the next wave. As the waves overtake one another, building up into a large pressure pulse, and as the pressure pulse grows into a shock wave, the mean free path of the molecules in the wave grows still shorter and the temperature rises.

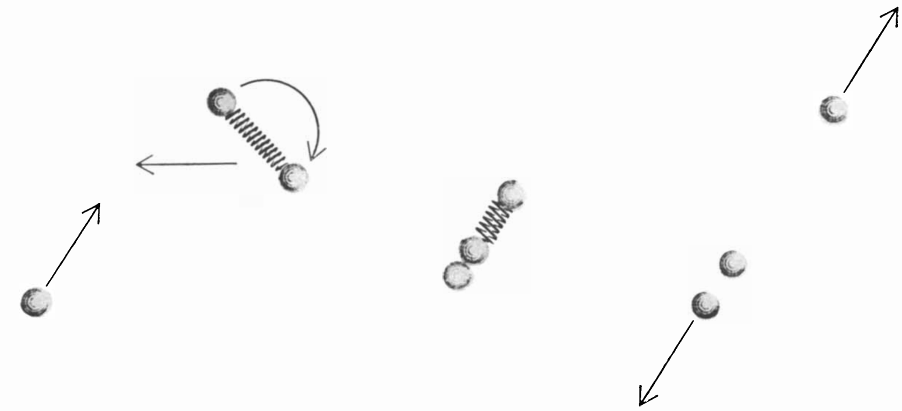
The shock wave cannot, however, attain the infinite discontinuity of the Riemann equations, and the zero thickness this implies, precisely because it is made up of molecules. The shock wave must always be spread out over some finite distance in the gas, measurable in terms of the length of the mean free path. Across this distance the gas density, temperature, pressure and velocity all change. As the shock wave forms and these gradients grow steeper, energy in the form of heat and also momentum flows more swiftly from regions of high temperature and velocity to those regions in the wake of the wave where these quantities are low. Ultimately these opposing mechanisms of steepening and spreading balance and the shock wave profile becomes stable.



KINETIC ENERGY OF SHOCK WAVE is transformed into three energy modes among the gas molecules swept up by the wave. The distribution of energy among these modes before the shock wave front arrives is represented by the relative heights of the hatched areas to the right of the front. ("Energy of translation," the energy of random translational motion of the molecules, manifests itself as temperature. "Energy of rotation" is that with which a molecule as a unit rotates. "Energy of vibration" is that with which the interatomic bonds of a molecule vibrate.) The impact of the shock wave produces a sudden increase in translational energy (i.e., an increase in temperature). Some of this energy is transformed almost instantaneously into rotational energy (in a few millionths of a second, or within the width of the shock wave front). As the molecules continue to translate and rotate (farther and farther behind the front) there is a further decrease in both modes and a corresponding increase in vibrational energy, until the equilibrium distribution of energy is established.

The heating of the gas by the advancing shock wave illustrates the essential nature of heat: it is the energy of the random motion of the molecules in the gas. By way of emphasizing this point, in considering the heating process on the molecular scale it can be supposed for a moment that the shock wave is at rest and that the gas is flowing into it. This hypothetical reversal of the actual situation calls for no corresponding change in the observed temperature of the gas because the bulk motion of the molecules is directed in a straight line; that is, they are invested with the kinetic energy of the now stationary shock front, and this kind of energy does not register on a thermometer moving with the streaming gas. As they stream into the shock front, however, the molecules encounter a sharp increase in density and proceed to make numerous scattering collisions with the shock-front molecules and with one another. Their directed motion is thereupon exchanged for random motion, which manifests itself in an increase in the temperature of the gas.

At this point the investigator whose objective is high temperatures must contend with another set of natural obstacles. By no means all of the kinetic energy of the shock wave is transformed into heat as it sweeps up the molecules



THERMAL DISSOCIATION of molecules is caused by more intense shock waves, because of the greater frequency and violence of intermolecular collisions. Such a collision (*left and middle*) increases the vibrational energy of the interatomic bonds and they break (*right*).

THREE-BODY RECOMBINATION is the reverse of the dissociation process shown in the illustration above. Two particles form an interatomic bond in a collision with a third particle. The third particle leaves the collision with more energy than it had originally.

in its path. In fact, with each increase in temperature an increasing percentage of the energy is transformed into energy modes other than the random translational motion of the molecules.

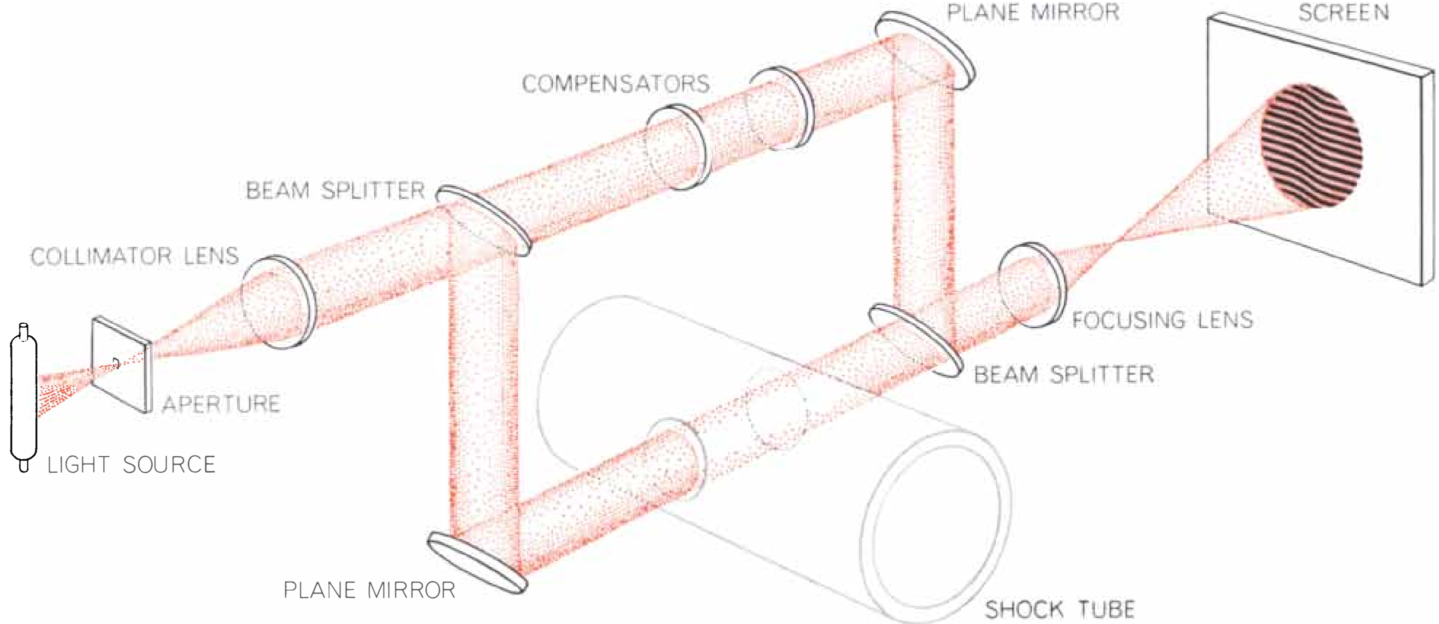
In the zone of highest temperature just behind the shock front, the molecule-molecule collisions cause the molecules to spin as well as to rebound elastically from one another; some of the energy of heat is thereby transformed into the energy of rotation of the molecules. Back a little farther the violence of intermolecular collisions makes the interatomic bonds of the molecules vibrate. These transformations are predicted in the powerful generalizations of quantum theory that show that a molecule can possess only certain discrete (as opposed to continuous) amounts of energy of each kind and that a particular minimum energy is required to set each energy mode into action. The energy minimum is negligibly small for the translational motion of the molecule as a whole; it is reasonably small for the rotation of simple diatomic molecules, such as those of oxygen or carbon monoxide; and it is quite large for vibration of the diatomic bond of these molecules. In the shock wave, as these minimum thresholds are crossed, some of the translational energy of the molecule passes into stepping up the rotational energy and then to starting the vibrational energy mode of the molecule.

This transformation of energy from translation to rotation to vibration is known as energy relaxation, and it has been beautifully demonstrated by shock tube experiments in diatomic and polyatomic gases. As the translational energy (and along with it the temperature) drops from its highest value immediately behind the shock wave front to a lower value some distance behind it, the gas density behind the shock front changes accordingly. The events that transpire here show up in photographs made with the Mach-Zehnder interferometer, an optical instrument that reveals small changes in gas density by passing one beam of light through the relaxing gas and a second beam of light through an undisturbed constant-density gas and superimposing the two images in register on the film. Mach-Zehnder photographs made with a sufficiently short exposure effectively "freeze" the shock wave in the field of view and show plainly the zones of density change associated with molecular rotation and vibration [*see top illustration on next page*].

Such pictures have more than artistic value; they can be used to calculate the time required to transform energy from one mode to the next. These measured relaxation times are an indication of the number of molecule-molecule collisions necessary to produce the energy transfer. The efficiency of the energy exchange—or, to put it more formally, the collision cross section for energy exchange—between two molecules can thereby be computed. Such cross sections are also calculable from quantum theory, so that the shock tube provides a splendid means for confronting theory with experiment in connection with the important process of intermolecular energy exchange. Pioneer studies of rotational and vibrational relaxation were conducted in the shock tube laboratories at Brown University and Princeton University respectively. Experiment and theory show that for all but the weakest shock waves the translational and rotational energies are quickly activated, usually within a few mean free paths, whereas the vibrational mode lags considerably in activation.

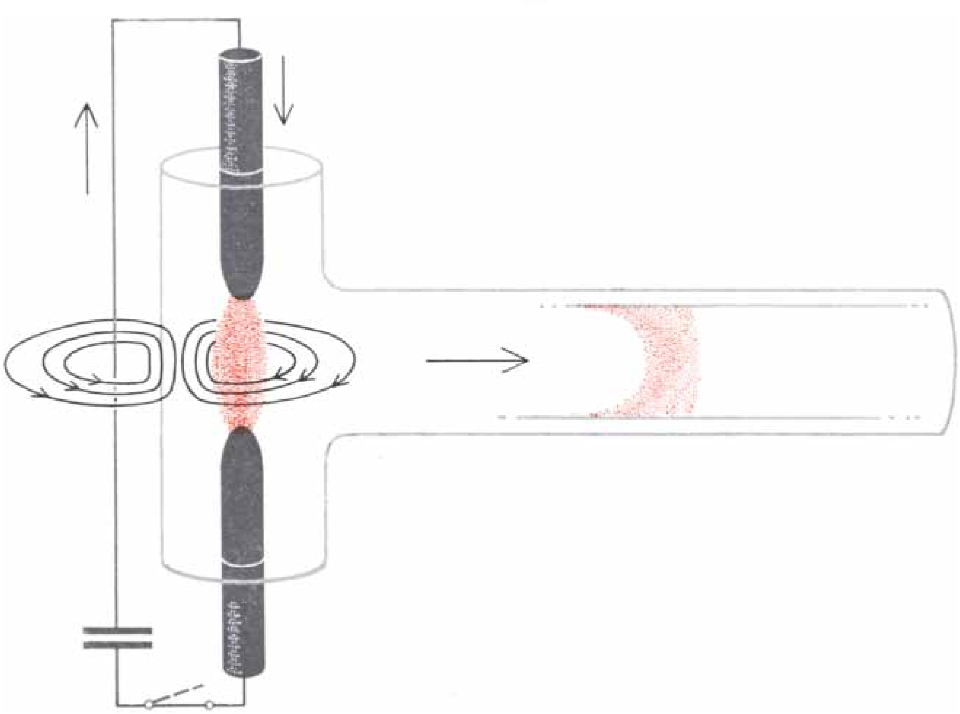
In a more intense shock wave, with a still higher temperature and thus greater frequency and violence of intermolecular collision, the molecular vibrations become sufficiently energetic to break the molecular bond, causing the atoms to fly apart. Now, the process of thermal dissociation, like most atomic or molecular processes, is reversible. The collision in which particle *A* (an atom or a molecule) strikes the molecule *BC* with sufficient energy to break the bond is an "inelastic" collision: some of the energy of motion goes to break the bond and the three independent particles—*A*, *B* and *C*—leave the scene of their encounter with reduced velocity. In the reverse process, known as three-body atomic recombination, two free atoms, *B* and *C*, combine in the presence of a third body, *A*; the energy liberated by their reaction is transferred to *A*. From this "superelastic" collision particle *A* flies off with more energy of motion than it came in with.

Molecular dissociation and the study of it in shock tubes held the center of the stage during the early phases of the recent spectacular advances in rocketry. One of the major obstacles to be surmounted was the heating of the nose cone or the space vehicle on re-entry into the earth's atmosphere. With the vehicle traveling at four or more times the speed of sound, a shock wave of high intensity builds up just in front of its forward face.



MACH-ZEHNDER INTERFEROMETER is used to study changes in gas density that are caused by the passage of a shock wave. Light from a single source is split and one beam is passed through the shock tube. In practice the beam paths are equivalent except for the effects of the shock wave. Changes in gas density are manifested as changes in the fringe pattern formed by the recombined beams.

In the zone of high temperature behind the shock wave all the processes of molecular rotation, vibration, dissociation and recombination are set going. Now, it is bad enough to have hot air flowing over the surface of the vehicle, but in addition the heating of the vehicle can be dangerously aggravated by three-body atomic recombination. In a high percentage of these events the vehicle itself acts as the third body! The energy released is given up in the form of heat directly to the surface of the vehicle. In the design of nose cones and heat shields for space vehicles the shock tube made it possible to simulate some of the conditions of the re-entry process. Specifically, these experiments led to the development of materials that inhibit molecular recombination; such materials are said to have noncatalytic surfaces. The shock tube has of course played other roles in rocket engineering, since shock waves attend many aspects of the violent energy-transformation processes involved in this art.



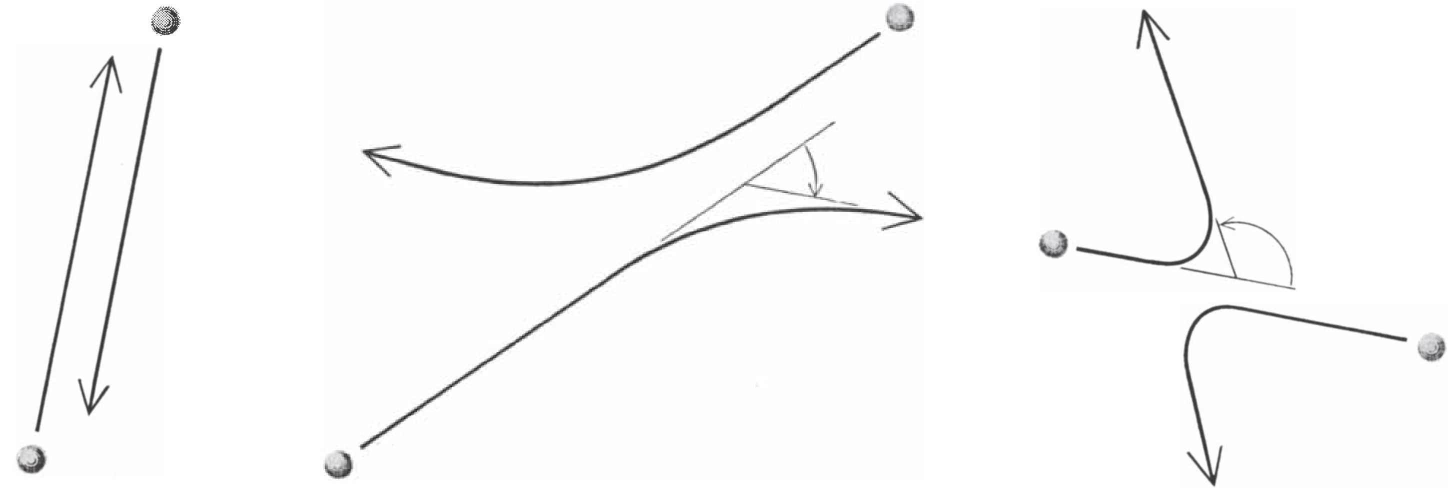
ELECTROMAGNETICALLY DRIVEN SHOCK WAVE is produced in an experimental apparatus essentially like that illustrated here. When the circuit is closed, the capacitor bank discharges its current through the electrode gap, producing an arc plasma (*cigar-shaped colored area*). The circuit is so arranged that the associated magnetic fields (*flattened oval curves*) are in opposition. Electromagnetic forces of repulsion that result drive the plasma down the tube (*colored area at right*), generating a shock wave in the gas of the tube.

It was not long after the shock tube had arrived in the laboratory that investigators were impressed to observe that the hot gases in a shock tube give off light. When a gas heated by a shock wave has attained a sufficiently high temperature, in fact, this becomes one of the principal modes by which energy is bled off from the gas. The light emitted by a hot gas—in a flame or a carbon arc as well as in a shock wave—is generated by the same process. The main actor is the planetary electron, revolving on its orbit around the nucleus of the atom and jumping or being pushed from orbit to orbit. According to strict quantum rules, the orbits, or energy states, occupied by each electron in each atom in the gas depend on the temperature, and for any temperature there is a specific distribution of electrons throughout all the atoms in the gas. Although the distribution is strict, it is dynamic. Inelastic collisions are constantly boosting the electrons to the higher energy states appropriate to the temperature. The electrons thus excited tend constantly to fall back to allowed orbits where their potential energy is at a minimum compatible with certain quantum restrictions on the number of electrons that may occupy an orbit. They make their return either by spontaneous quantum jumps or as the result of superelastic collision; in the former case they emit the difference in energy between the upper and lower energy states as a photon, or quantum of light. The higher the temperature, the greater the number of inelastic collisions causing excitation and consequently the greater the number of photons emitted. Generally speaking, therefore, the hotter the gas, the more light it gives out.

The shock tube has made it possible to bring this cardinal process of nature under systematic study. One of the objects of this work is to determine how long an electron occupies an excited energy state before spontaneously jumping to a lower level—provided that a superelastic collision does not remove it beforehand. The mean lifetime of the excited state is in principle calculable from theory; for all but the simplest atoms and molecules, however, such calculations are prohibitively difficult. Experimental results obtained by heating gases with arc and spark discharges are blurred by the introduction of impurities from the electrodes into the gases. The shock tube provides impurity-free hot gases at temperatures and densities that can be precisely controlled by adjustment of the pressures in the two sections of the tube. On a small scale in the laboratory an astrophysicist can reproduce conditions observed at the surface and in the atmosphere of a star and study the microscopic processes that go on there.

It is not at the surface but in the interior of a star that the temperatures necessary to ignite the thermonuclear reactions are attained. In the temperature range above a million degrees Kelvin the translational energy of particles becomes great enough to overcome the huge forces of repulsion between naked atomic nuclei and bring about their fusion. From this ultimate inelastic collision there emerges a single new nucleus —a helium, say, from the fusion of two nuclei of the heavy isotopes of hydrogen —of slightly less mass than its parents, plus a quantity of energy representing the vanished mass.

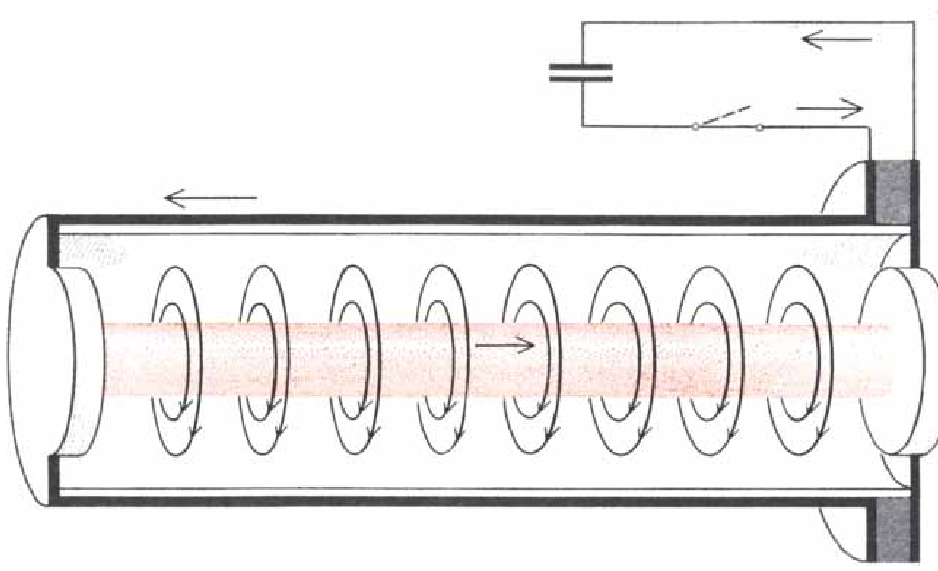
One significant development in the push to this temperature range is the electromagnetically driven shock tube, first demonstrated at the University of Oklahoma and now under extensive study at the Naval Research Laboratory in Washington and elsewhere. The mechanism is relatively simple. The driver gas in the high-pressure section is replaced by two electrodes that are connected to a bank of electrical condensers charged to a high voltage. The electrical circuit is so arranged that the wires from the two electrodes run from the condenser bank parallel and in close proximity to the electrode gap. When the switch is closed, the condensers discharge their electrical energy into the gap and pro-



TWO TYPES OF COLLISION discussed in the text are compared. Uncharged particles that pass close together affect one another very little (*left*). The force fields of like-charged particles, however, frequently result in what is known as a distant-encounter collision (*middle*); that is, they are turned from their original paths even though they do not collide directly. Such encounters usually involve a turn of much less than 90 degrees. Only in a close encounter (*right*) is the amount of turning more than 90 degrees.

duce an arc plasma; that is, the gas in the gap is ionized by the stripping of one or more electrons from some of or all the atoms. During the instant of discharge the current in the plasma flows parallel to that in the wires but in the opposite direction. An elementary law of electricity, demonstrated by Michael Faraday more than a century ago, shows that strong electromagnetic forces of repulsion are set up by currents flowing in this manner. In accordance with the "left-hand" rule, the repulsive force is exerted in the third dimension of space around the electrical conductor, at a right angle to the current and its associated magnetic field. In the electromagnetic shock tube this force violently accelerates the plasma away from the electrodes. The projected plasma acts to all intents and purposes like the piston in the hydrodynamic shock tube. The resulting shock wave has been clocked at Mach 200–200 times the speed of sound, or 40 miles per second! With temperatures in the range of 500,000 degrees K., these shock waves fall short of the thermonuclear standard, but they open up a new realm of high temperatures to investigation.

The first efforts to produce controlled thermonuclear reactions relied on the "pinch effect," which is achieved by a mechanism precisely the opposite of the electromagnetic repulsion that drives the electromagnetic shock tube. A bank of electrical condensers is discharged abruptly through electrodes to a plasma, with the result that the current flows as a sheet at the boundary between the gas and its container. This hollow cylinder of current can be thought of as an infinite number of filamentary currents all flowing in the same direction. In accordance with Faraday's left-hand rule, the currents attract one another. The cylindrical sheet of current collapses inward by a radial implosion, subjecting the gases within to a sudden "pinch."



Z PINCH involves a powerful electrical discharge (*horizontal black arrow at center*) along the axis of a cylinder containing highly ionized gas. The resulting plasma (*color*) is compressed ("pinched") by the magnetic field (*circular arrows*) generated by the discharge. The compressing force of the field generates a radially imploding shock wave in the plasma.

There are two types of pinch discharge. In what is called the Z pinch the current flows along the axis of the electrode gap and produces a magnetic field circumferentially around the cylinder; in the theta pinch the current flows circumferentially around the cylinder and the magnetic field lies along the cylinder axis. In either case the left-hand rule predicts a force acting inward in the radical direction on the current sheet, causing it to collapse. The gas enclosed by the current is swept up in the implosion and compressed at the axis of the container. Given a sufficiently rapid discharge of the condenser bank, the speed of collapse can be made to exceed the speed of sound in the gas. The current sheet then acts like a piston on the gas, producing a shock wave ahead of itself. Generally speaking, the faster the current is deposited in the gas, the stronger the shock wave and the higher the temperature of the gas that lies between it and the collapsing sheet of current. It is desirable that the gas be at least partially ionized before the current is discharged into it, so that none of the electrical energy need be expended to excite molecular rotation, vibration, dissociation and subsequent ionization. This preionization is a problem that so far has been only partially solved.

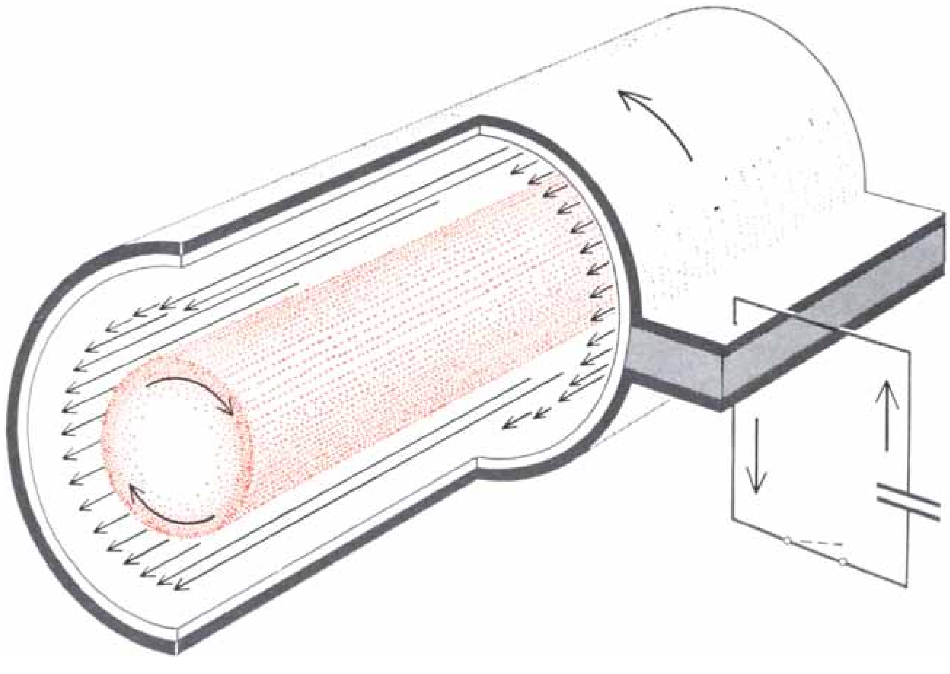
A mathematical analysis of the collapse of the current sheet made at the Los Alamos Scientific Laboratory in

1954 showed that the speed of the radially imploding shock wave, and as a result the temperature, is directly proportional to the plasma voltage and inversely proportional to the square root of the density of the gas ahead of the shock wave. It would appear, therefore, that one could make the pinch effect generate as high temperatures as one could wish simply by increasing the plasma voltage and decreasing the density of the gas. As might be expected, however, nature does not yield so easily.

In the first place, even with the best electrical condensers available today 100,000 volts is about the maximum that can be handled, particularly in view of the enormous currents that are required in these experiments—hundreds of thousands if not millions of amperes. The switching of voltages and currents of this magnitude is a major headache in electrical technology. In the second place, there is a limit to which one can reduce the density of the gas that is to be shocked by the shock wave; this is set by considerations of mean free path.

When it comes to determining the mean free path, the plasma of charged particles raises something of a paradox. The mean free path in an un-ionized gas can be defined unambiguously, since electrically neutral atoms and molecules do not interact over distances much greater than a few atomic or molecular diameters. Disregarding the effects of gravity, the particles in such a gas can be regarded as moving most of the time in force-free space. The fully ionized gas presents quite a different picture, because each particle, whether it is an ion or an electron, is surrounded by a force field that extends theoretically to infinity. If this were exactly true, the particles would always be interacting no matter how distantly they were separated. The collision mean free path would therefore be zero, or, to put it more correctly, the concept would be inapplicable to the plasma.

All is not lost, however, because the distance at which the particles interact effectively is a finite one. What is more, they enter into only a few heat-dissipating inelastic collisions and tend to make many elastic collisions in which they exchange only small amounts of energy. Mathematical analysis shows that these collisions usually occur at large separations between the particles; from these "distant encounter" collisions the collision partners go off on paths not greatly different from those on which they collided. The mean free path in a plasma



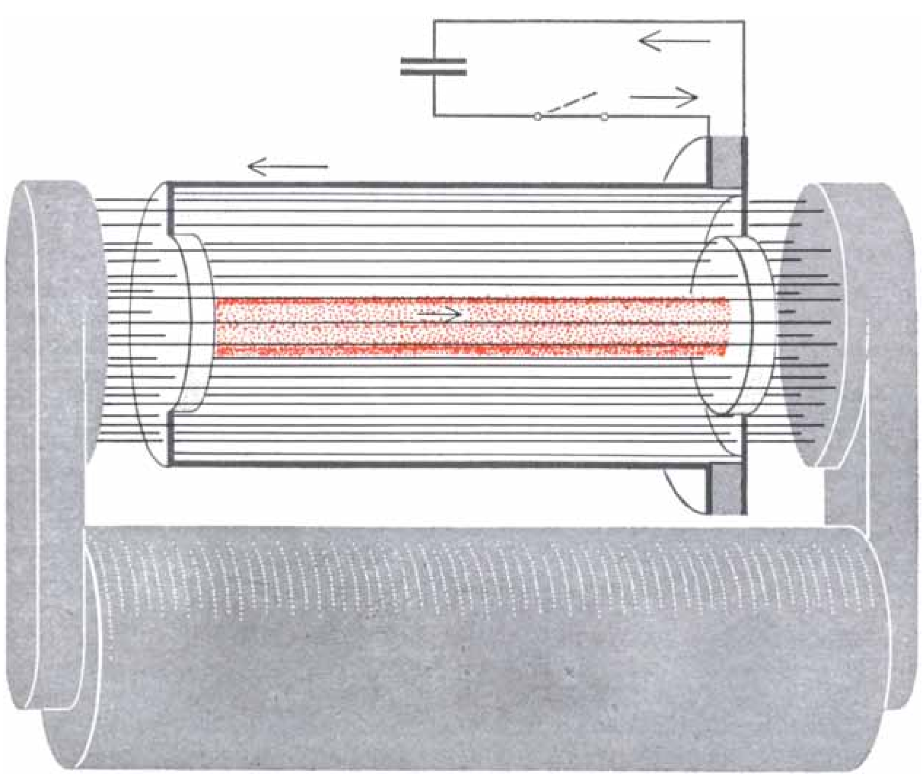
THETA PINCH is generated by an electric current flowing circumferentially (*curved arrow at right*). This generates a longitudinal magnetic field (*long arrows*) and flows circumferentially (*two curved arrows*) through the plasma (*color*). The interaction of the magnetic field and the plasma current in turn generates a radially imploding shock wave.

therefore requires a special and somewhat arbitrary definition: it is the distance a particle must travel, on the average, before a series of distant-encounter collisions turns its course through a right angle from its initial direction. Statistical analysis shows that the mean free path in a plasma is proportional to the square of the temperature and inversely proportional to the density.

By analogy from the un-ionized gas, it can be argued that the thickness of the imploding shock wave generated by the pinch effect is related to the length of the mean free path thus defined. If anything, this is an understatement; the thickness of the wave appears to be large. Because the vessel containing the plasma must be considerably greater in size than the thickness of the shock wave, if a shock wave is to be produced in it, the density of the gas cannot be reduced below a certain practical limit. Considerations of this kind underlie the only partly jocose estimate that the reaction chamber of the thermonuclear reactor is likely to be the size of the *Queen Mary*. For the present the experimental chambers must be of convenient laboratory size and practicable from the engineering standpoint; for example, they must be capable of containing a plasma with the density of a pretty good vacuum. The temperature attainable by shock-wave heating is therefore limited by the requirements of mean free path as well as by the ceiling on the voltages that can be built up in a modern condenser. Detailed calculations show that this maximum temperature is about two million degrees K., which is not yet high enough to initiate significant thermonuclear reactions.

There is still another chapter to the story, however, and this brings forward a different kind of plasma shock wave, only recently recognized as such. Experiments with the pinch effect were plagued from the outset by unstable magnetic forces that distorted the plasma column, eventually causing it to break up. To counteract these forces and stabilize the plasma, it was found necessary to create a magnetic field inside and along the axis of the column. This "backbone" field is in place when the condenser bank is discharged and the shock wave implodes radially into the preionized gas. The magnetic field and the inward-moving charged particles of the plasma now set up an electromagnetic interaction that changes the whole nature of the shock wave: it ceases to be a hydrodynamic shock wave and becomes what is called a hydromagnetic shock wave.

As a result of their interaction with the magnetic field the particles in the shock wave proceed to move in tight spirals around and along the magnetic lines of force. Associated with this corkscrew movement are two important quantities: the number of revolutions per second (gyro-frequency) and the radius of the spiral (gyro-radius). If the plasma density is so high that the number of distant-encounter collisions per second greatly exceeds the gyro-frequency, the



HYDROMAGNETIC SHOCK WAVE may be produced when a Z-pinch discharge occurs in an already existing longitudinal magnetic field (*straight black lines*). Although the discharge flow is indicated (*black arrows*), the conditions illustrated are those before discharge. Too little is known about this wave to make possible any representation of the interaction of the discharge field (*see bottom illustration on page 116*) and the longitudinal field.

corkscrew motion is thwarted. If the plasma is tenuous and hot, as a thermonuclear plasma must be, the particles make many spirals before suffering collisions. Such a plasma shows different properties in different directions; in particular the magnetic field constrains the particles to move along the lines of force rather than in directions that allow the dissipation of energy and momentum by the process of thermal conduction and viscosity. In the hydrodynamic shock wave thermal conduction and viscosity effects limit the steepening of the shock wave and ultimately the temperature attainable. The hydromagnetic shock wave is sufficiently tenuous to preclude these effects. What, then, limits its steepening? At present there is no satisfactory answer to the question. Clearly whatever the answer turns out to be, the collision mean free path will not be a useful quantity to describe it. The situation is bizarre, to say the least. In the hydrodynamic shock wave such high temperatures as can be attained are generated by numerous collisions in the gas, the number rising in inverse ratio to the length of the mean free path. The hydromagnetic shock wave now confronts investigators with the task of explaining the generation of high temperatures by some process involving practically no collisions at all; in other words, to the exclusion of everything learned about heat from the kinetic theory of gases!

The uncertain explanations of the "collision-free hydromagnetic shock wave" advanced so far do not merit examination here. One aspect of this theorizing deserves mention, however, on practical grounds. The shock wave thickness—whether it is ascribed to the gyro-radius of the ions, the much smaller gyro-radius of the electrons or yet other smaller characteristic lengths—is always considerably less than the collision mean free path of a plasma of the same density. It would therefore appear that hydromagnetic shock wave heating of a plasma can be managed under conditions where the collision mean free path is comparable in size to or greater than the container—provided that the characteristic thickness of the zone of high temperature in the wave, whatever it may be, is less than the dimensions of the vessel. The unsolved problems—and the promise—of this strange type of shock wave have inspired extensive theoretical and experimental studies, although these waves are extremely difficult to produce in the laboratory. When they are better understood, man will no doubt find ways to use them.

Why so many?

We admit it.

Amphenol, more than any other connector manufacturer, accepts responsibility for confronting you with a seemingly endless selection of rack and panel connectors.

There's a good reason.

For some uses, a ten-contact connector the size of an Idaho potato will do just fine. In others, ten connections must be squeezed into a space no bigger than a jelly bean. Still other applications have unique requirements that relate to environment or mating force—even the technical skill of the operator.

WHY WE DO IT

We make a lot of different rack and panel connectors because it takes a lot to satisfy the wide range of applications.

For example: the Amphenol Blue Ribbon® rack and panel connector is widely used in "blind" mating applications. Part of Blue Ribbons' popularity is due to the fact that they mate with a smooth and gradual wedge-like force. Because they mate so smoothly, the "feeling" of correct alignment is unmistakable.

Another advantage of the Blue Ribbon design is the wiping action that occurs as connectors mate. Each time Blue Ribbons are mated, contact surfaces are wiped clean. Combine wiping action with high mated contact pressure, and the result is an extremely low-resistance connection.

THINKING SMALL?

As fine a connector as we know the Blue Ribbon is—it's just not right for the real tiny stuff. Thus, as miniaturized electronic equipment became popular, Amphenol engineers developed the Micro Ribbon®—a rack and panel connector utilizing the ribbon contact principle, but in as little as one-half the space. Further development produced a circular Blue Ribbon connector which crammed 50 contacts into a diameter just under 3 inches.

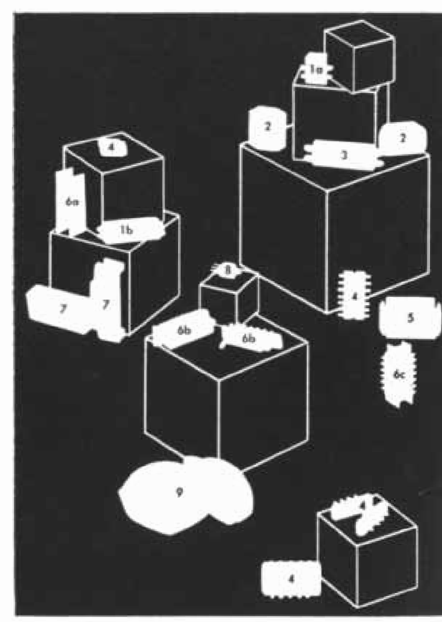
Also, there's the question of terminating rack and panel connectors. Often, confined quarters or complex wired harnesses can tax the dexterity of even the most skilled worker.

To solve this problem, Amphenol engineers developed rack and panel connectors with Poke-Home® contacts. Poke-Home contacts make it possible to terminate conductors independent of the connector. Contacts are crimped, soldered, or even welded to conductors, then inserted into the connector. Besides simplifying assembly, Poke-Home contacts can be easily removed *after* assembly should circuit changes or repairs later become necessary. Needless to say, Amphenol rack and panel connectors with Poke-Home contacts (Min-Rac 17®, 93 and 94 Series, for example) are popular items with engineers who are forced to think small, spacewise.

BEATING THE ELEMENTS

There's a need for environmentally resistant rack and panel connectors, too. High performance aircraft, missiles and space craft led to the development of Amphenol 126 and 217 Series environmentally sealed rack and panel connectors. (The 217 offers the added feature of Poke-Home contacts.) Other Amphenol rack and panel connectors can accommodate coaxial connectors; many can be supplied with hermetically sealed contacts. There are rack-to-cable connectors available in every series. There are super-economy types and super-reliable types.

So, when you have a rack and panel connector problem, contact an Amphenol Sales Engineer (or an authorized Amphenol Industrial Distributor). With the broadest line of rack and panels in the industry—if he can't solve it, no one can. If you prefer, write directly to Dick Hall, Vice President, Marketing, Amphenol Connector Division, 1830 South 54th Avenue, Chicago 50, Illinois.



Amphenol connectors shown on the opposite page are: **1**—Min-Rac 17 with (a) crimp-type contacts and (b) solder-type contacts **2**—94 Series **3**—Micro-Ribbon **4**—126 Series Rectangular **5**—93 Series **6**—Blue Ribbon with (a) barrier polarization, (b) pin polarization and (c) keyed shell and barrier polarization **7**—126 Series "CNI" **8**—126 Series Hexagonal **9**—Circular Blue Ribbon

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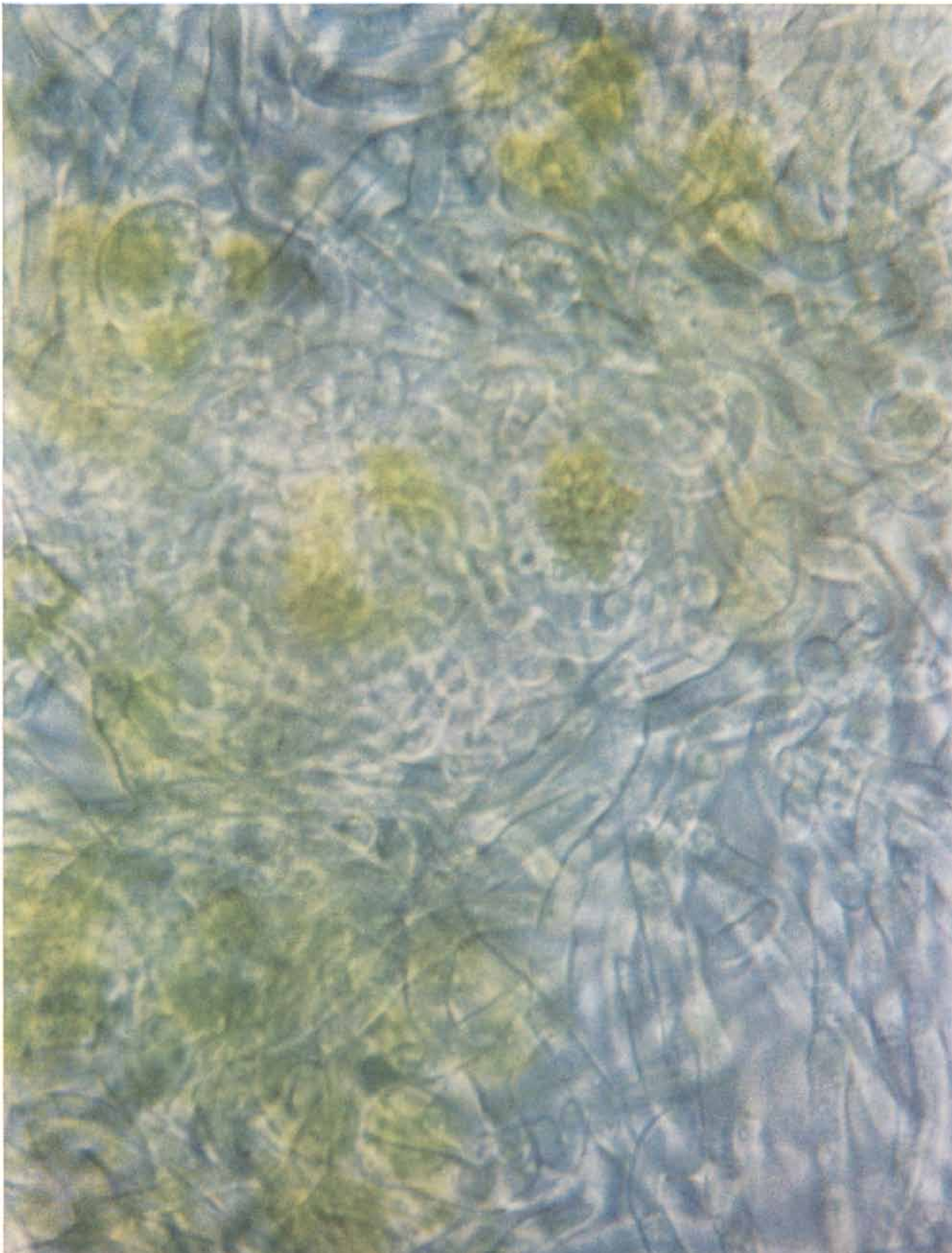


LICHEN TISSUE, synthesized in the author's laboratory, is composed of clumps of green algae enveloped by cells formed from fungal threads. The algae and fungus are those of the lichen *Acarospora fuscata*. They were isolated from the lichen, cultured separately and then mixed together. Lacking other nutrients, the fungus was forced into association with the algae as in a natural lichen. The photomicrograph was made by the author five weeks after the combined culture was started. Magnification is 4,300 diameters.

THE FUNGI OF LICHENS

Lichens are composite plants, associations of fungi and algae. The problem is to separate the two partners and study the fungi in isolation, and then to try to put the lichen together again

by Vernon Ahmadjian

One of the main goals of the work in our laboratory is to synthesize an organism. Lest this seem too large an ambition—at a time when the successful synthesis of a molecular constituent of a living cell is still an occasion for celebration—I should add at once that the organism we are seeking to synthesize is a natural synthetic: the lichen. A lichen is a plant that is composed of two plants. One is an alga, an organism that manufactures its own food by photosynthesis; the other is a fungus, an organism that must depend on other organisms, living or dead, for its food supply. The two together form a third entity quite different in appearance and life history from either of its components and adapted to environments in which neither could thrive alone [see "Lichens," by I. Mackenzie Lamb; Scientific American, October, 1959].

The success of the union is indicated not only by the abundance and wide distribution of lichens but also by the fact that fungi and algae must have come together more than once in the course of evolution to produce some 15,000 species of lichens. A number of different species of algae and an even greater diversity of fungi have entered these partnerships. The algae appear to be the least affected by the association; their behavior in cultures suggests that all of them can, and probably do, exist alone in nature. On the other hand, there is little evidence to suggest that the lichenized fungi exist in the free-living form. In the lichen it is the fungus that forms the thallus—the principal structural tissue—and determines the nature and shape of the composite plant. As the dominant partner the fungus also produces the fruiting bodies. Although the fruiting body does not furnish the exclusive or even the principal mode of reproduction in all species, it does serve to identify the fungal class from which the lichenized fungus came, and it is the structure on which most lichen names are based.

The synthesis of a lichen in the laboratory obviously requires the prior cultivation of its fungus in independence of the alga that sustains the existence of the composite plant in nature. This task in itself presents a host of problems with which a good part of the effort in our laboratory at Clark University has been preoccupied. Actually it is a fairly simple matter to make the fungus grow in a culture medium. The growth is amorphous, however, and bears little resemblance to the organized structure that characterizes the fungal tissue of the lichen. Nor do these cultures show any but the most remote signs of giving rise to fruiting bodies. Because so little study has been done along these lines—other investigators have been discouraged, no doubt, by the slow pace of lichen growth—our work is largely exploratory.

We have cultured the fungi of hundreds of species of lichens. Among these we have found some that show promising resemblance in the culture dish to certain free-living fungi and a few that are more responsive to our efforts to stimulate their growth through their full life cycle. We have begun to identify certain of the more critical elements in the nutrition of the fungi that are supplied by the associated algae and, on the output side, have found that the laboratory cultures secrete chemical compounds similar to those produced by intact lichens. The latter finding may even have practical significance. Lichens are well known to certain folk cultures, particularly in Scandinavia, as a source of dyes and medicinals; modern research has shown that specific lichen acids are inhibitory to particular kinds of bacteria, viruses and free-living molds. Our isolated fungi grow faster and apparently produce these substances at a greater rate than they do in the lichenized state. Finally, we have induced one fungus to enter into a federation with algal cells, forming a union from which both members gain some benefit and that is in fact the preliminary phase of the natural association.

Although the great 18th-century Swedish botanist Carl von Linné (Linnaeus) called lichens the poor trash of the plant kingdom, these plants won their share of attention during the classical period of biology, when questions of taxonomy were foremost. Lichens were being named even before the discovery (in 1867) of their dual nature. Representatives of three major classes of fungi enter into the formation of lichens. The majority of forms are derived from the Ascomycetes, or sac fungi; their name comes from the word "ascus," designating the sac that contains the spores produced by sexual union. The Deuteromycetes, or "imperfect" fungi, which form asexual spores, or conidia, rather than sexually generated spores, are represented in a dozen or more genera of lichens. From the Basidiomycetes, a group that includes the mushrooms, come three genera of lichens found solely in tropical regions. A fourth class of fungi, the Phycomycetes, which includes the common bread mold, is said to be represented in one genus of lichen, but there is doubt as to this finding.

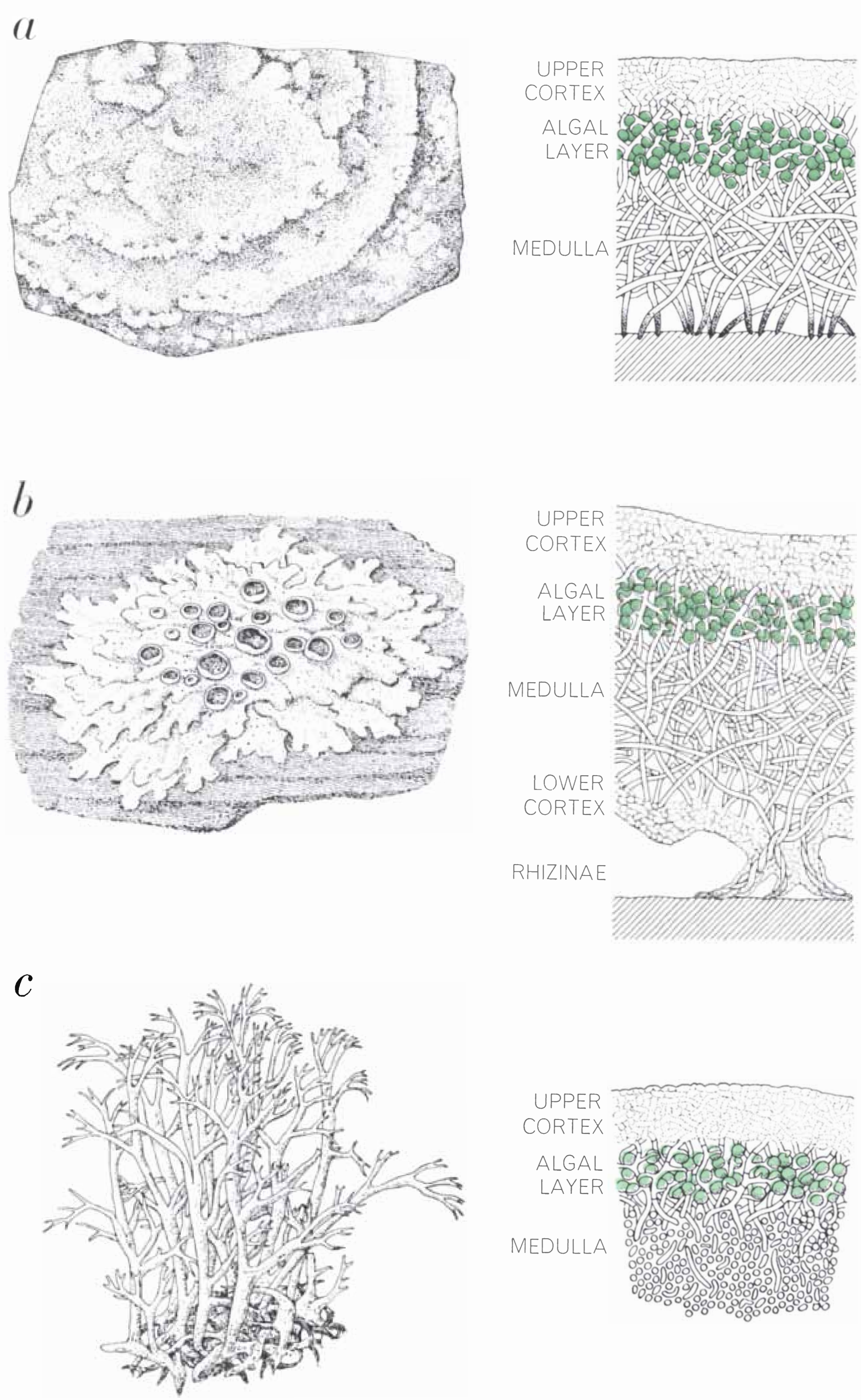
Many of the more familiar lichens have apparently come to occupy their vast ranges of distribution largely by vegetative reproduction, that is, by the scattering of fragments of thallus containing algal cells. In a few lichens, cells of the algal partner are borne within the fruiting tissue as well as in the thallus. These algal cells, which are much smaller than those in the thallus, are carried along by the discharged spores and are therefore on hand to initiate the growth of the composite plant when the environment provides the right conditions. A major mystery of nature is presented, however, by the reproduction of lichens from sexual spores and asexual conidia generated and liberated by the fungal tissue alone. Somehow these spores must find and join with a suitable free-living algal form in order to grow into a lichen. The formation of this union—an event that must take place rather commonly on a microscopic scale—has not been observed in a satisfactory manner under normal conditions.

In the laboratory the discharged spores offer the surest and simplest means of initiating the culture of a lichen fungus. We soak a lichen specimen in water and remove from it one or more fruiting bodies, which we affix with a dab of petroleum jelly to the inside of a culture-dish cover. On the bottom of the dish we spread a sterile layer of agar, which is sometimes fortified with soil nutrients. In time the spore sacs of the fruiting bodies rupture either because of an increase in internal pressure due to the wetting or—more frequently—because the sacs shrink as they dry. The bursting sacs eject the spores forcibly and usually in great abundance onto the agar layer below them.

The rate of spore discharge and of the subsequent germination varies widely. Some species liberate spores within minutes after their washed fruiting bodies are affixed to the cover, and other species take from two to 24 hours. Germination takes another two hours in the genus *Cladonia*—which is among the common fruticose, or stalk-forming, lichens—and as much as 24 hours in other genera. One general observation we have made is that spores from the crustose, or flat, lichens germinate more readily and have a more rapid initial growth rate than spores of the foliose, or leafy, species. One might expect this because the crustose lichens adhere so closely to their substratum that the chances of vegetative propagation by fragmentation are less than in the loosely attached leafy forms.

The progress of germination can be observed without opening the culture dish by inverting the dish on a microscope stage and examining the spores through the agar under low magnification. One can transfer germinating spores to a culture tube either by cutting out a block of agar with spores on it or by flooding the dish with sterile water and picking out suspended spores with a capillary or micropipette.

The discharged spores of about 50 per cent of the species subsequently fail to germinate. Our attempts to induce germination in dormant spores by altering the medium or changing the acidity or temperature have not been successful. Among the species whose spores germinate, the rate of germination ranges from more than 90 per cent to less than 1 per



LICHENS are of three major types. Crustose lichens (*a*) grow as flat patches adhering closely to rock or bark. The foliose type (*b*) is branched and leafy in form and is attached to its substrata more loosely, by rootlike growths. Fruticose lichens are either pendulous strands or, as in the drawing at *c*, hollow upright stalks. The diagrams at the right show vertical sections of crustose and foliose lichen tissue and a horizontal section of a fruticose stalk. The tissue is composed of algae (*color*) and branched fungal threads, or hyphae.

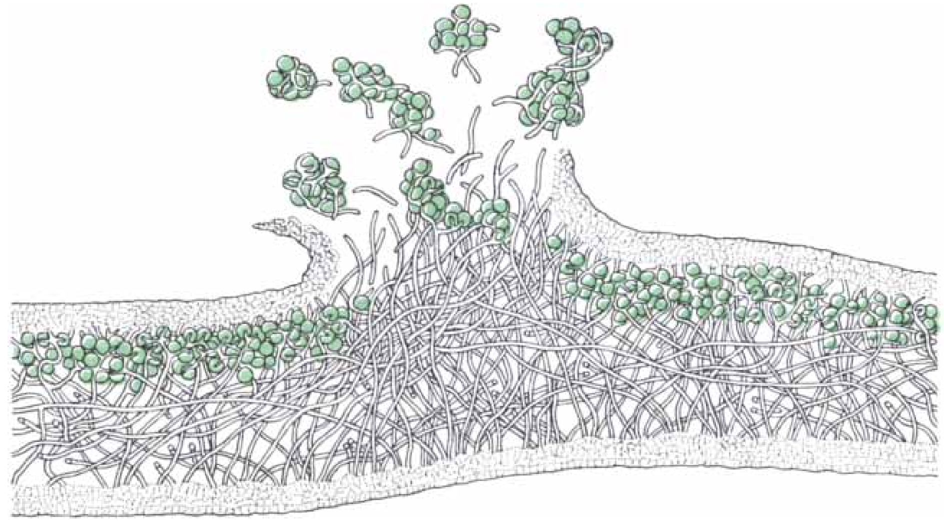
cent. Temperate Zone lichens, we have found, discharge their spores more readily in the early spring and fall, and their spores in turn germinate at a higher rate in these seasons. A significant exception to this rule is the North American lichen *Hydrothyria venosa,* which grows on rocks that are submerged most of the year in fresh-water streams but are exposed during the summer months. This lichen discharges its spores, even in the laboratory, only in July.

In the case of lichens that have not yielded germinating spores or that have no fruiting bodies at all, we have been able to isolate the fungi by dissecting out bits of purely fungal tissue from the thallus. Even though the algal component can be excluded, contamination presents a serious problem when this method is employed. One cannot be sure that the culture represents the true fungal component of a lichen and not a contaminating fungus that has lodged in the thallus.

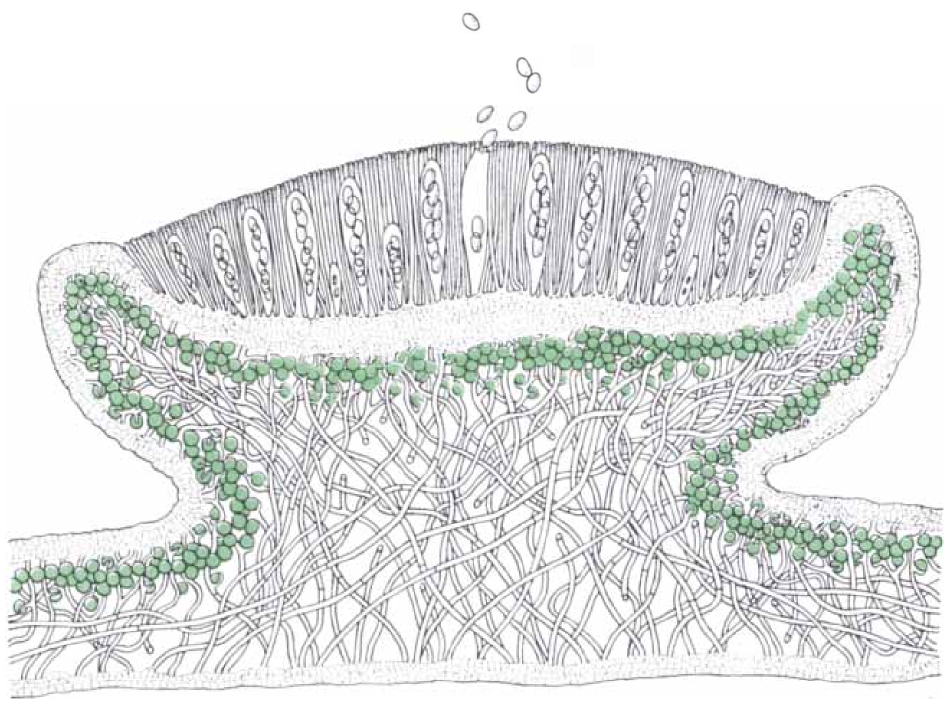
The growth and development of the isolated lichen fungi vary from species to species but, like their parent lichens, most of the fungi grow very slowly. In some instances it takes a year or more for a colony to attain a diameter of one millimeter. Fortunately many of the fungi grow more rapidly, producing colonies several millimeters in diameter, with a dry weight of some 15 to 20 milligrams, within two weeks or a month.

The most striking thing about these cultures is that the isolated fungus usually looks not at all like the lichen from which it came; it forms only an amorphous clump of tangled hyphae, or fungal filaments [*see bottom illustration on next page*]. A few cultures do have a sheetlike or partially upright form suggestive of the original lichen, but even these show no hint of the spongy texture of lichen tissue. The colonies are compact and so hard that it is sometimes difficult to cut them. They vary in size, shape and color. In many tropical and some Temperate Zone species the hyphae bear a thick gelatinous sheath, which in the intact plant must help to resist drought by absorbing and retaining water.

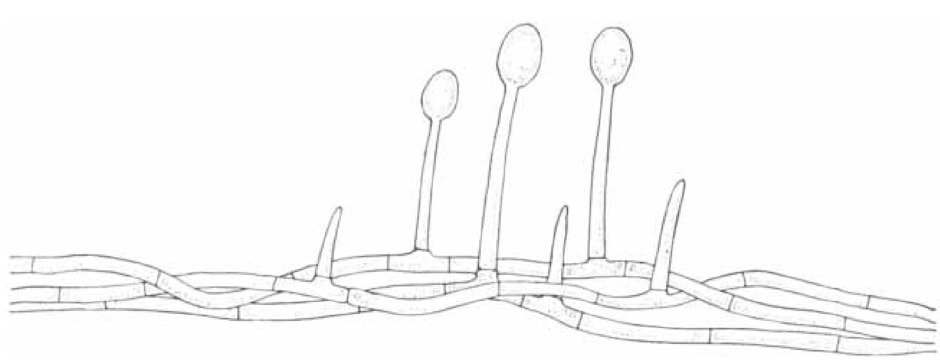
The absence of characteristic fungal spores in most of our cultures makes it difficult to relate the lichen fungi to any free-living forms. Some few cultures, however, have produced asexual conidia, suggesting an affinity to the Deuteromycetes. This is intriguing because in the past careful study has often revealed a previously unrecognized sexual stage in the life cycle of a supposedly imperfect fungus, and the species has thereupon



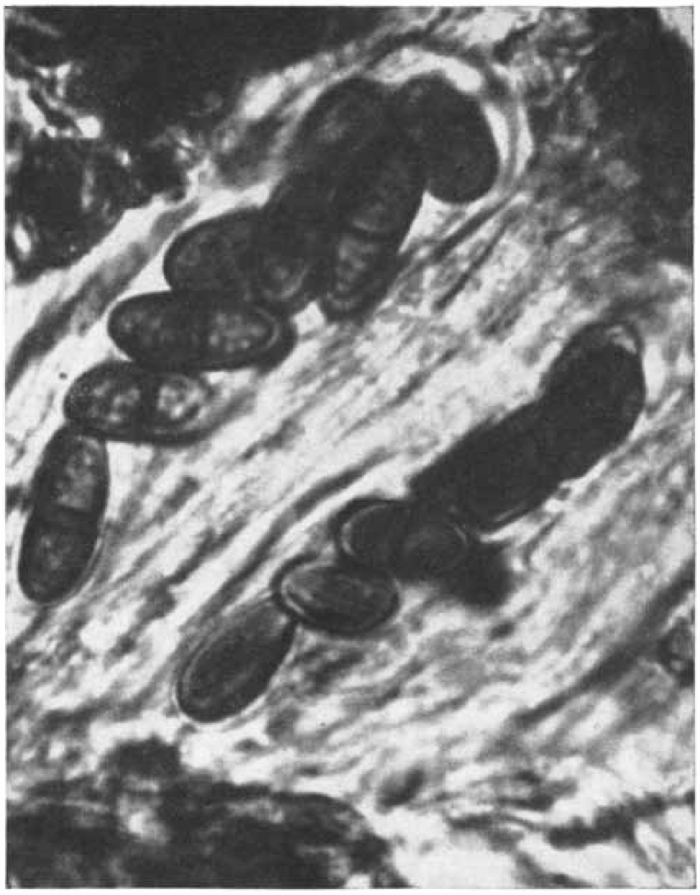
VEGETATIVE PROPAGATION is the surest means by which lichens multiply. One such method is by the breaking off of particles, or soredia, composed of fungal threads and algae.



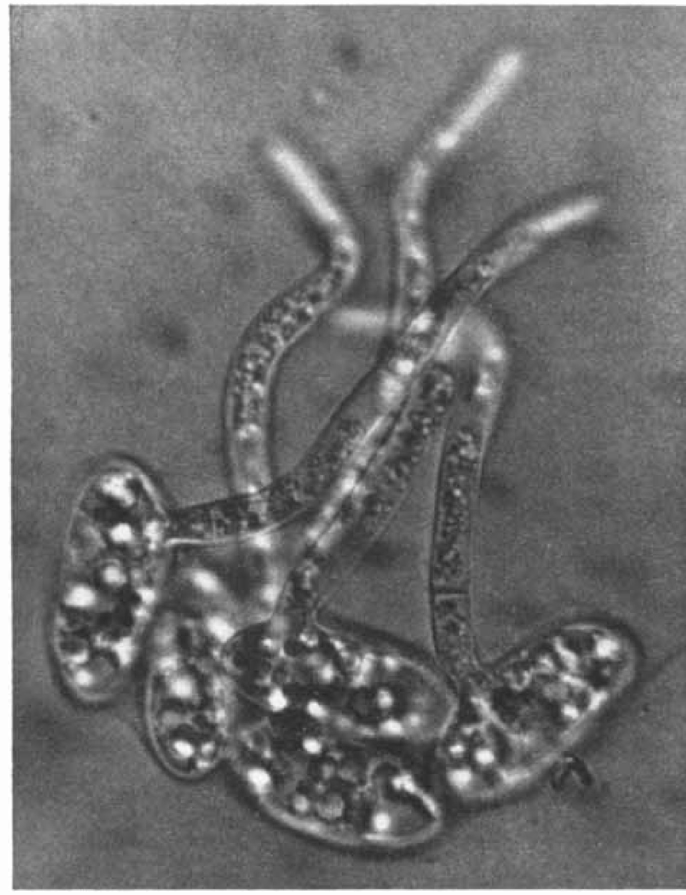
FRUITING BODIES, the typical structures of sexual reproduction in fungi, are found in most lichens but not, as yet, in isolated lichen fungi. Within each fruiting body there are a large number of bulbous sacs containing the reproductive cells, or spores. Even when the fruiting body has algal cells in its rim, as in this case, the spores are purely fungal.



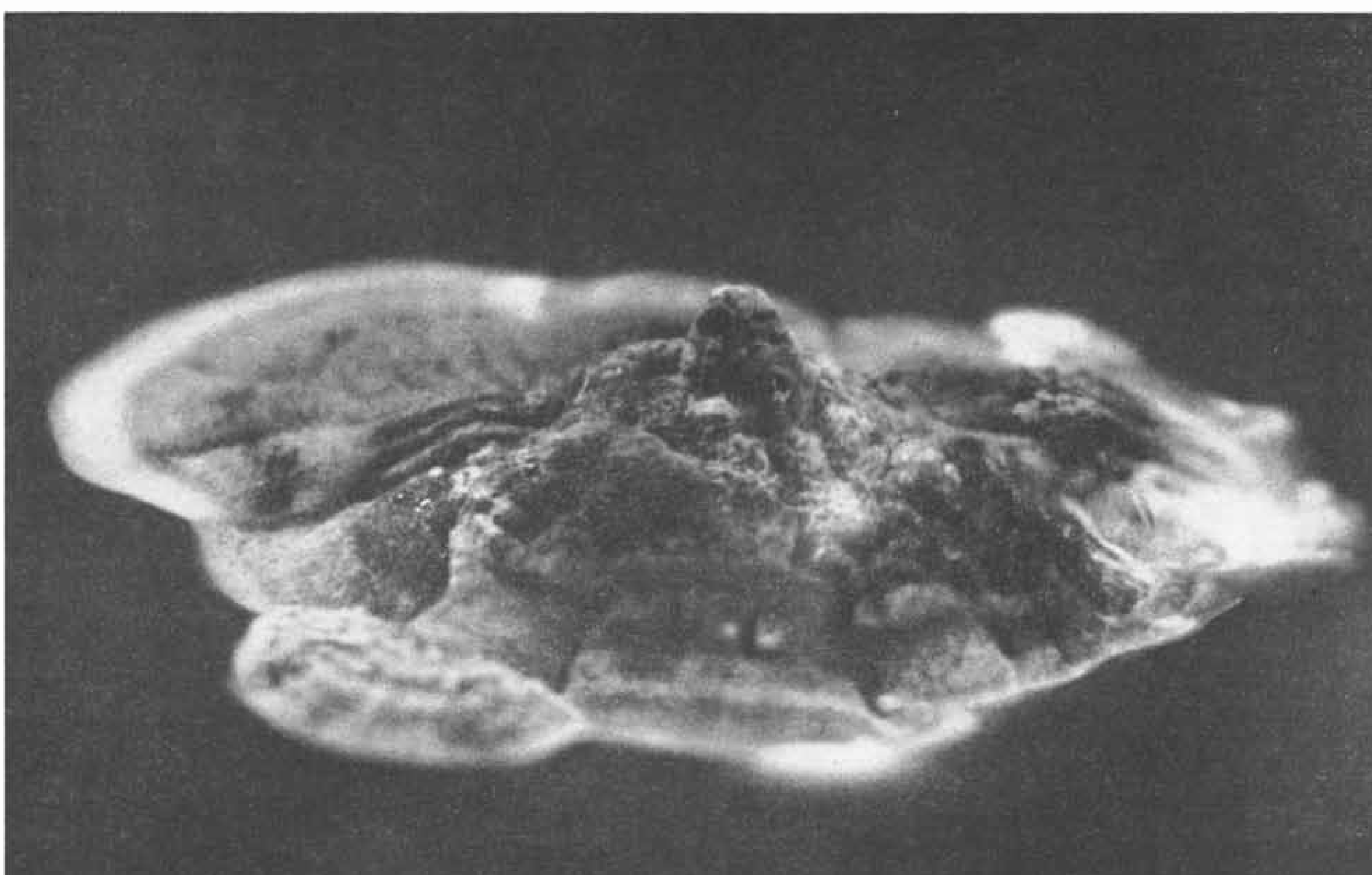
ASEXUAL SPORES, or conidia, form along fungal hyphae or at their tips, and break off to start new colonies. Conidia have been found in many fungi but in only one lichen.



FUNGAL SPORES are shown in a section, magnified 2,500 diameters, of a fruiting body of the lichen *Buellia stillingiana*. The spores are ready for discharge from the two spore sacs, or asci.



GERMINATING SPORES (genus *Lecanora*) are shown a day or two after discharge, magnified 2,000 diameters. Food droplets nourish the germ tubes until they reach a new source of nourishment.



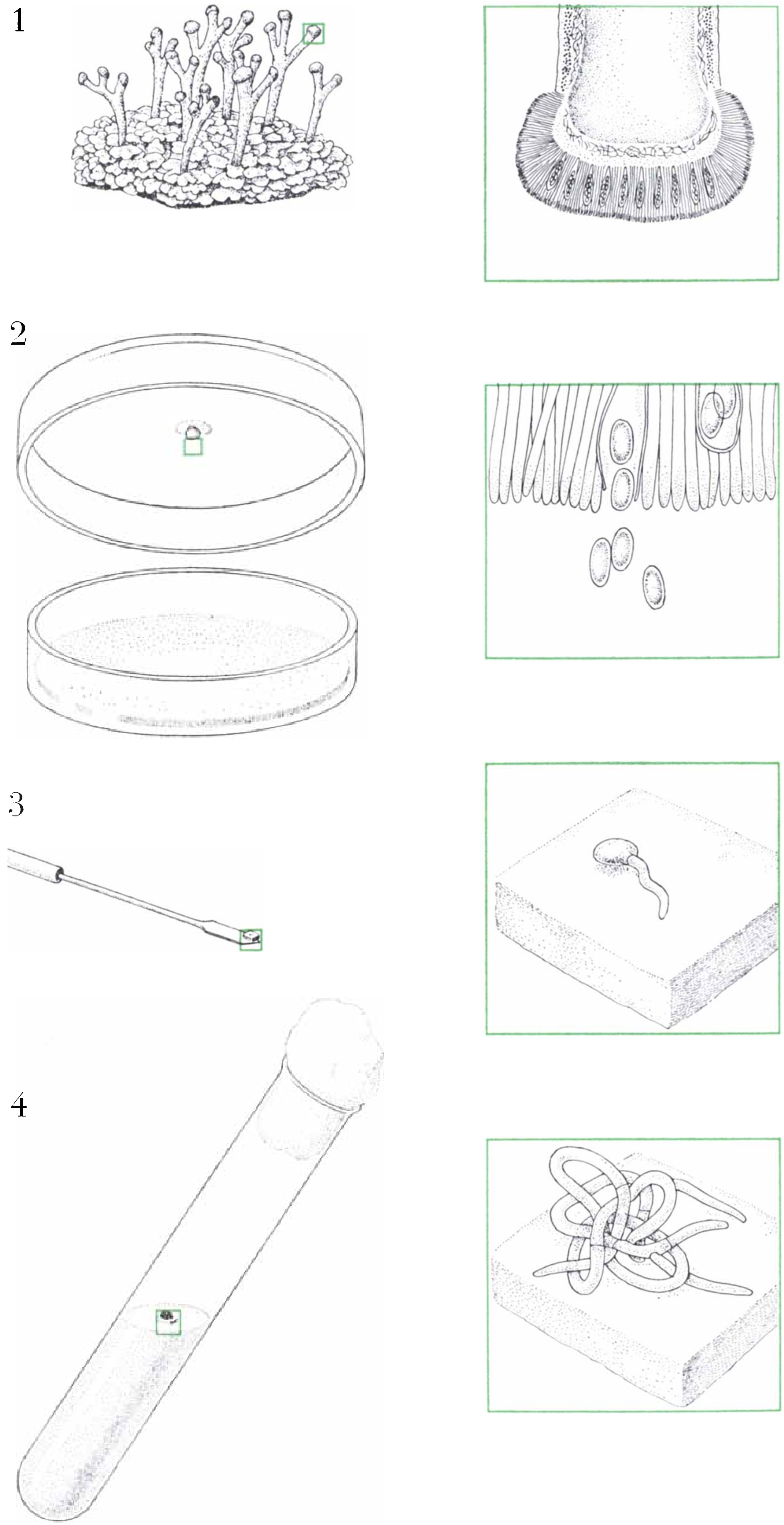
CULTURED MYCOBIONT, or isolated fungus, of *Cladonia cristatella* has grown for six months on an agar medium. The colony measures about 1½ inches in diameter and 1/2 inch in height. It is a mass of hyphae, typically amorphous in shape and structure.

been reclassified as a "perfect," or fruiting, type. This suggests the possibility that some lichen fungi are really free-living imperfect fungi, for the most part undetected as such in nature, that attain a fruiting stage only by entering into the lichenized state with algae. Separation of the lichen fungus from its alga would cause it to revert to the imperfect phase of its life cycle; this would explain the absence of fruiting bodies in the cultures and also account for the appearance of conidia in a few cases.

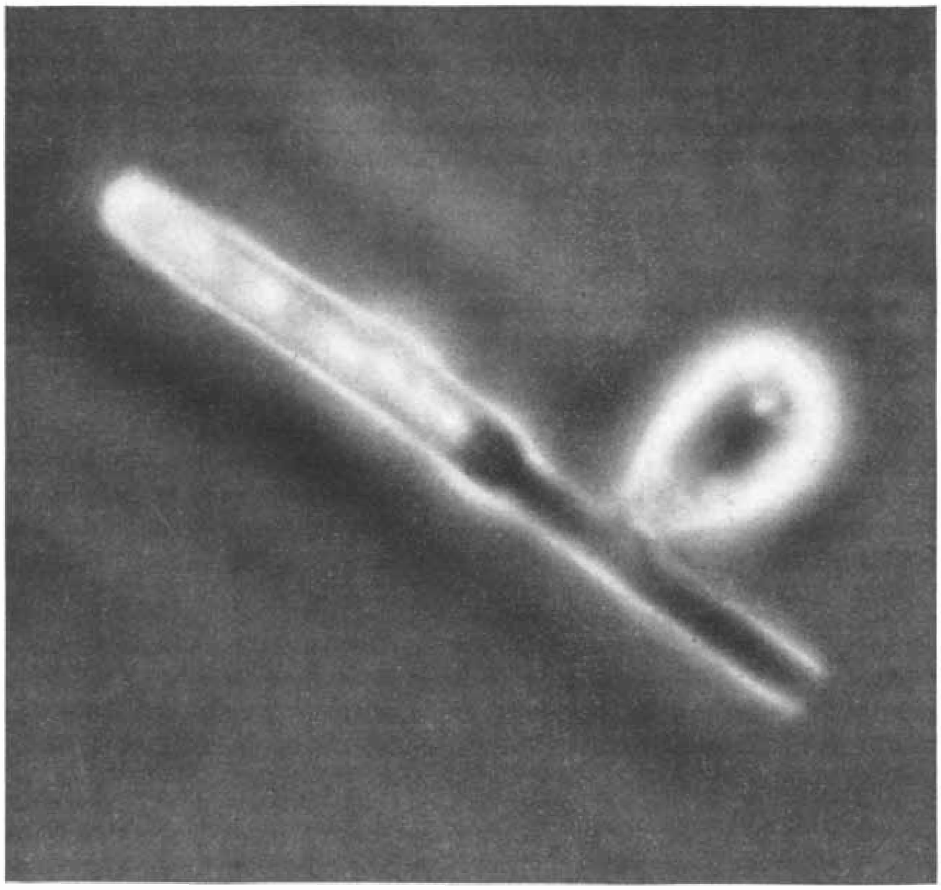
We have found conidia in the cultures of two lichen fungi out of 500 cultured in our laboratory. Mason E. Hale, Jr., of the Smithsonian Institution has reported one other such case. The most consistent producer of conidia is the fungus isolated from *Lecidea sylvicola,* a lichen commonly found on exposed rocks in the northeastern U.S. In cultures of this fungus we regularly find small, colorless single-celled conidia that have budded off from hyphae in groups that form gelatinous masses on the surface of the colony. This is just the way the free-living imperfect fungus *Aureobasidium* (or *Pullularia*) *pullulans* produces its conidia. An extremely common fungus, notable for its appearance in a variety of forms and in different habitats, *Aureobasidium* has been observed to enter into a loose temporary association with algae on tree bark. It would not be surprising, therefore, to find such a variable and adaptable fungus forming a lichen association.

Proceeding on the hypothesis that association with the alga in the lichenized state causes these fungi to attain the perfect stage and produce fruiting bodies, we have tried adding in one instance the proper alga or an extract of the alga to the culture medium on which its fungal partner was growing. One extract, obtained by centrifuging disrupted algal cells at 8,000 times the force of gravity, caused small rounded structures to erupt on the surface of the fungus. The structures resembled lichen fruiting bodies in shape and color. Still in progress, this experiment is promising but not yet conclusive.

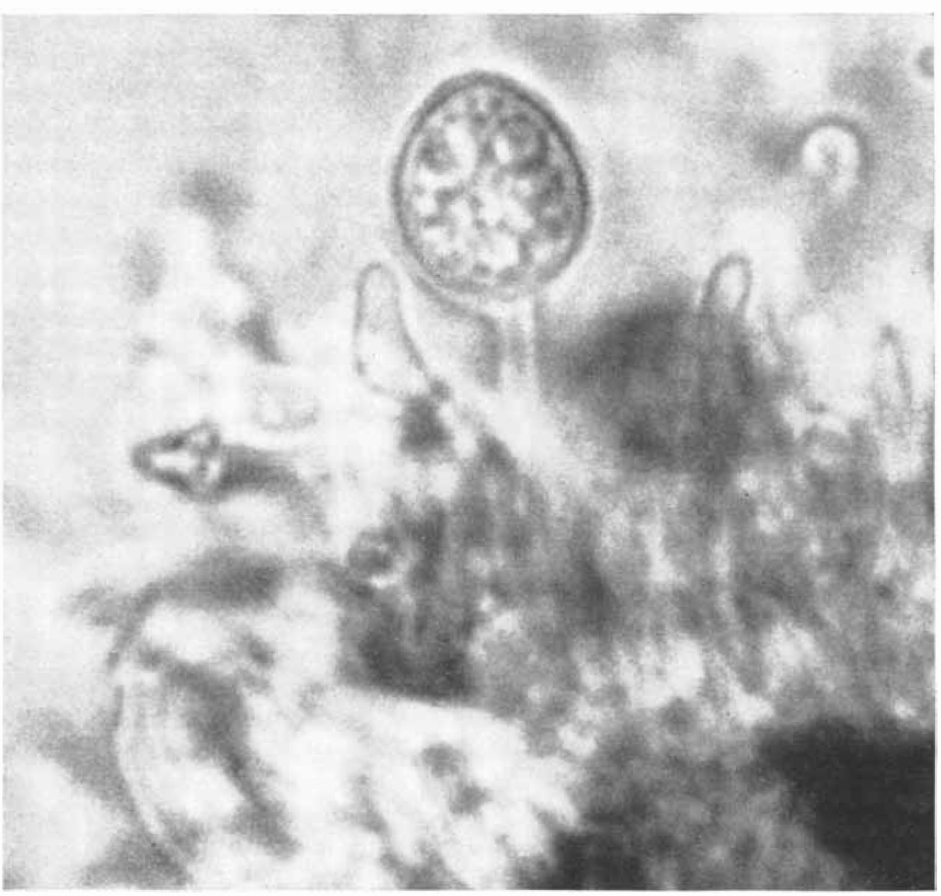
In our culture collection some 15 isolated fungi have been observed to produce chemical compounds identical with or closely related to those produced by the same fungi in intact lichens. These metabolic products usually appear as conglomerations of amorphous or crystalline particles that form saucer-shaped structures on the colony or on the surface of the agar near the fungus; those pro-



LICHEN FUNGUS is cultured by allowing its spores to germinate. A lichen (*1*) is soaked in water and a fruiting body (*right*) is removed and affixed to the top of a culture dish (*2*). The spore sacs rupture (*right*), spewing spores onto the agar layer in the bottom of the dish. After some spores have germinated, a block of agar with spores on it is excised (*3*). Transferred to a culture tube (*4*), the spores grow into a mass of fungal threads (*right*).



CONIDIUM that has budded on a hyphal fragment of the isolated lichen fungus *Lecidea sylvicola* is magnified 4,000 diameters in this dark-field photomicrograph. Conidia formed by this mycobiont are similar to those of the imperfect fungus *Aureobasidium pullulans.*



CONIDIA have been found in only a few other cultures. This one, magnified 3,500 diameters, is at the tip of a fungal thread in a culture of *Phaeographina fulgurata,* a Hawaiian species. The photomicrograph, like the others in this article, was made by the author.

duced by one species take the form of needle-like crystals several millimeters in length that radiate from the colony. The fungus of *Acarospora smaragdula* excretes a compound that is identical in many respects with usnic acid, a material with potentially significant antibiotic properties. The fungus of *Candelariella vitellina* produces a pulvic acid derivative—pulvic anhydride—that is also found in the natural lichen. Hempstead Castle and Flora Kubsch of Yale University have extracted rhodocladonic, usnic and didymic acids, which occur in the lichen *Cladonia cristatella,* from a pure culture of its isolated fungus.

Many of our cultures also produce a variety of pigments, most commonly red, yellow, brown or purple, some of which pass out of the filaments and color the surrounding medium. Such readily detectable substances, in the present exploratory phase of our work, serve as indices for study of the role of vitamins and other nutritional intermediates, and the effect of variation in temperature, in acidity and in carbon and nitrogen supply on the metabolism of the isolated fungi. Colorless and noncrystalline compounds may also be present but would be revealed only by a systematic search, which we have not yet undertaken. By accident we found recently that several Temperate Zone lichen fungi produce visible compounds after being stored for three months at 41 degrees Fahrenheit; this suggests that the low temperatures of winter play a role in the formation of lichen acids.

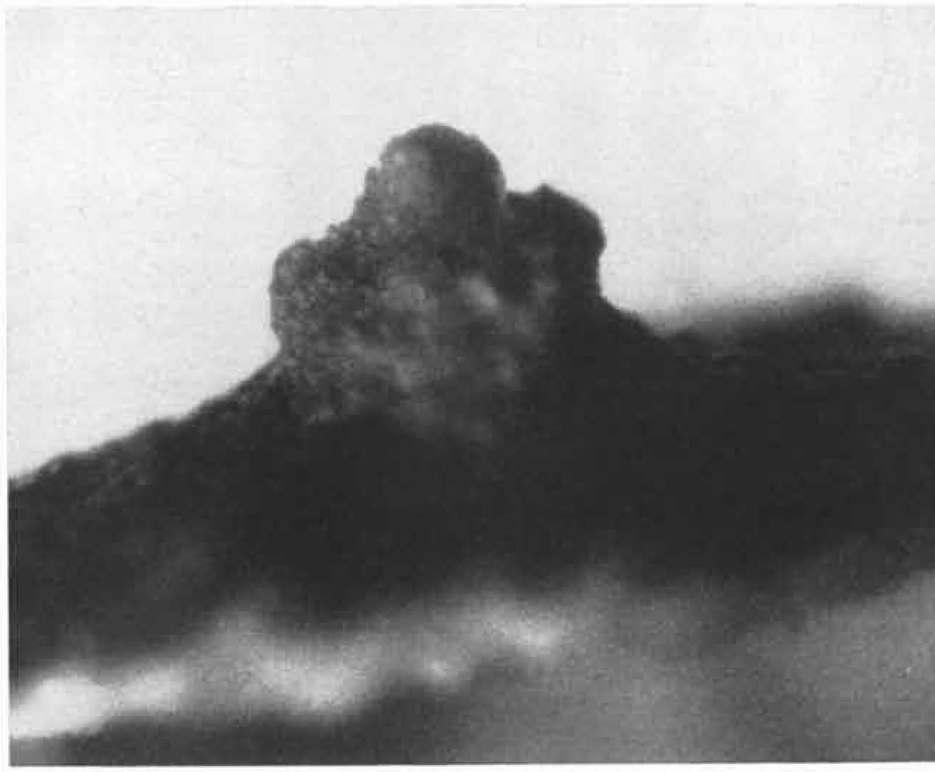
Looking to our ultimate objective of the formation of a fully developed lichen, we have undertaken to culture the intact organism under close observation in the laboratory. We cut small disks from a *Cladonia* thallus and place them on filter paper wetted in a mineral solution. A few of the disks (12 out of 300 in one trial) have produced the stalks, called podetia, that bear the fruiting bodies of this genus [*see upper illustration on page 130*]. Some species of *Cladonia* have generated distinct juvenile fruiting bodies on the tips of these stalks. If we can determine what specific factors—including seasonal variations of temperature and light as well as nutritional elements—influence the formation of podetia and fruiting bodies, it may then be possible to stimulate the formation of similar structures in the isolated fungi. We have already been encouraged by the appearance of rudimentary but distinct podetia-like outgrowths in cultures of two *Cladonia* fungi; they bore no fruiting bodies, but they were the nearest thing to differentiated structures attained in such cultures [*see lower illustration on next page*]. The stalks appeared, however, only in initial cultures from the lichens; when small fragments of the colonies were recultured, the stalks failed to appear.

Our direct attempts at synthesis have shown, as did earlier investigations by the Swiss botanist E. A. Thomas, that a lichen association is formed only as a matter of necessity, when the alga and fungus need each other. Even an established lichen tends to dissociate under favorable conditions of moisture and nutrition. When there is an excess of moisture, the algae simply grow out of and away from the fungus, and an overabundant food supply makes the fungal tissue outstrip the algae. Steady lichen development involves continuous balanced growth of the two partners, a fact that explains the slow growth of the lichen.

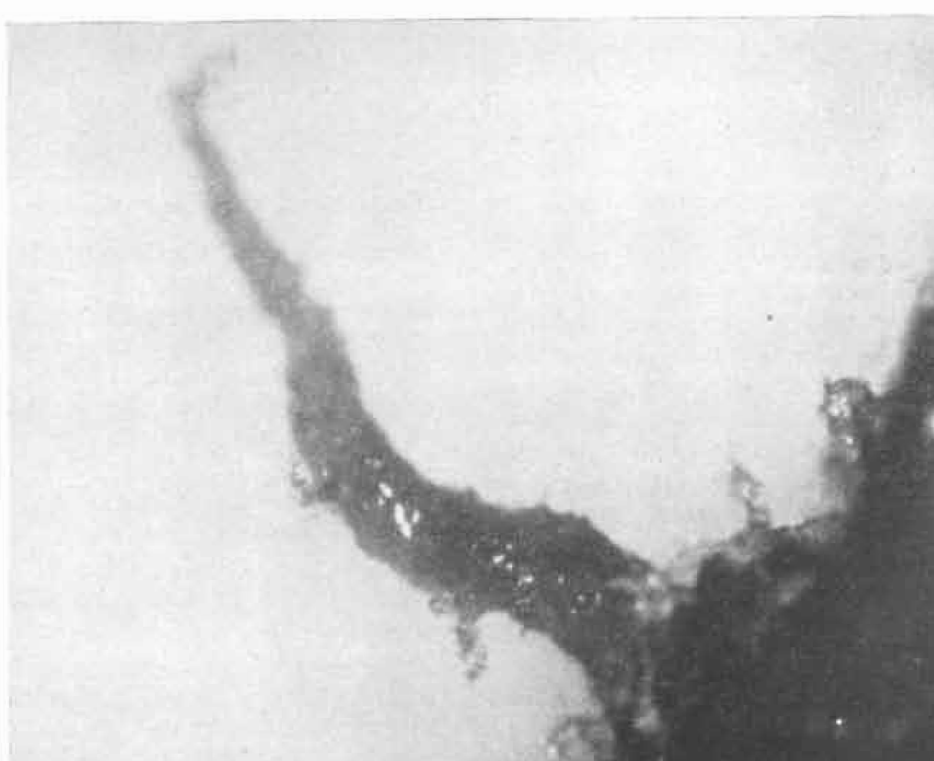
Accordingly, when we bring the fungus and the alga of a lichen together in a culture in the hope that they will form an association, we deliberately starve them. Our procedure is to mix the two components by means of a blender and then introduce the resulting mixture into a culture medium of purified and therefore quite unnutritious agar. The flask is illuminated so that the algae can photosynthesize, but the situation is nevertheless one in which neither component can survive alone for any length of time. For a time the fungal hyphae and the algae live on stored nutrients and the extruded contents of cells that have been disrupted by the shearing action of the blender. Then the elongating hyphae begin to make contact with the algal cells and gradually encircle them. This in itself is not conclusive because the initial outgrowths, or germ tubes, from the spores of lichen fungi will encircle any small, rounded objects in their path, including grains of sand and tiny glass beads. In contact with compatible algal cells, however, the filaments continue to grow and form dense networks that begin to approximate the structure of lichen tissue. The network of fungal threads even differentiates somewhat into more or less dense layers, and the algal cells become localized as they do in an actual lichen thallus.

So far we have not produced a well-developed lichen with fruiting bodies. Nonetheless, the successful cultivation of lichen tissue has given us a means of studying the interrelation of the fungus and the alga. We find that both partners benefit from their association in the culture. The fungus gets food and vitamins from the alga in return for minerals and protection from high light intensity. We are now developing techniques to trace the transfer of metabolites from one to the other with the aid of radioactive isotopes.

The difficulties involved in attaining a complete synthesis raise a nagging question: Just how frequently does a fungal-algal synthesis occur in nature? Some investigators have suggested that



PODETIUM, a fungal stalk, emerges from a disk cut from a lichen (*Cladonia coniocraea*). The dark area is the algal layer and the light area at the bottom is the medulla, the purely fungal region in which the podetium originated. The specimen is enlarged 90 diameters.



RUDIMENTARY PODETIUM produced by the mycobiont *Cladonia piedmontensis* represents the most differentiation yet attained by an isolated lichen fungus; the next stage, the formation of fruiting bodies, has not been reached. The magnification is 90 diameters.

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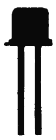

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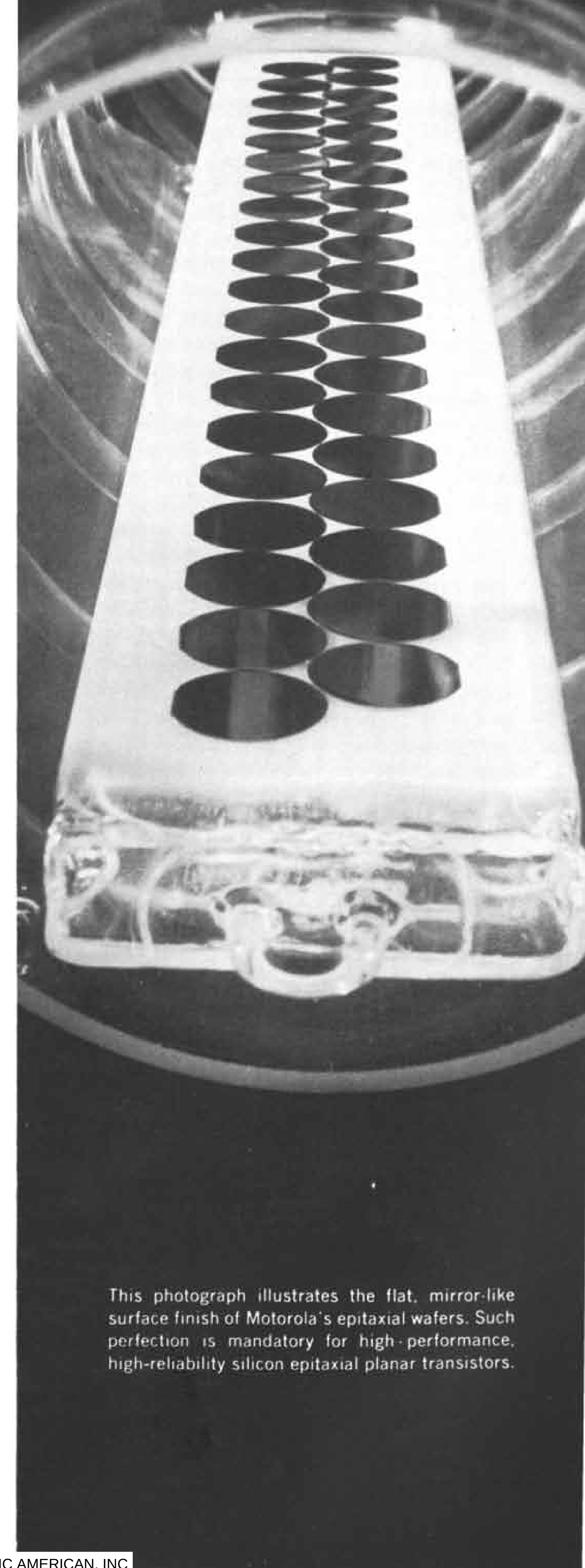
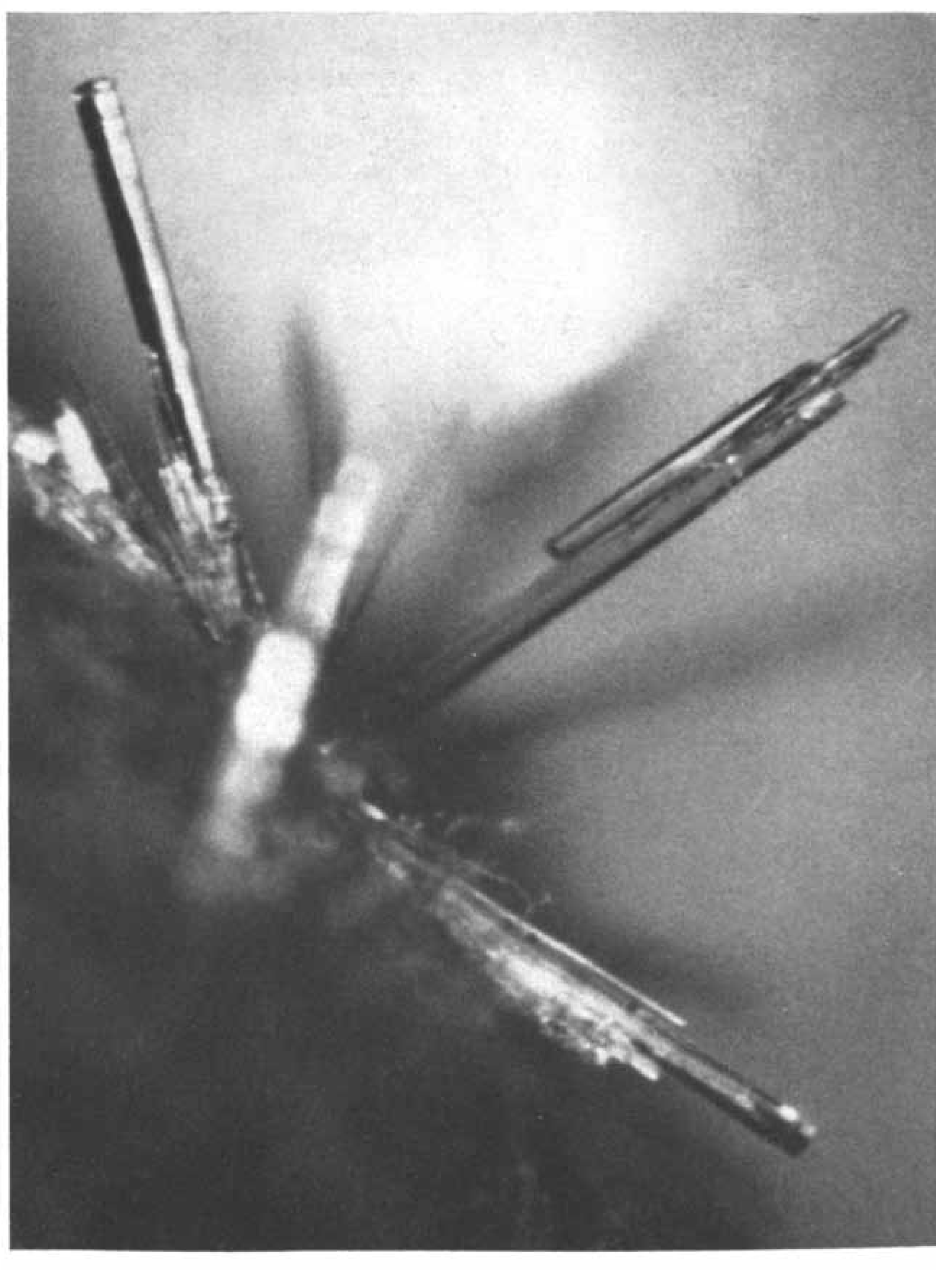


This photograph illustrates the flat, mirror-like surface finish of Motorola's epitaxial wafers. Such perfection is mandatory for high-performance, high-reliability silicon epitaxial planar transistors.

lichens may not multiply by spore germination and reassociation with the appropriate algae but only by vegetative propagation. The view is supported by the fact that algae of the kinds found in lichens are not abundant in the free-living state, and the chance that a germinating spore will happen to meet one does not seem great. Certainly vegetative processes are more dependable. My impression, however, is that the fruiting bodies and their spores also play a part in lichen multiplication.

The spores, after all, do germinate, form hyphal threads and survive. Our experiments have shown that a lichen fungus can persist in isolation for a long period of time and still retain the ability to enter into a union with algae. There is evidence from the field that certain types of fungi live in loose association with colonies of algae. These may be the fungi of lichens living, as it were, in "trial marriages" with various types of algal cells before linking up with their proper algal mate and forming a lichen. As for the lichen algae, although they are not found in large colonies in nature, they do turn up in small, isolated groups among other algae. Perhaps by their very nature they are unsuccessful in the free-living state but highly adapted to the lichen association. The problem of reproduction is only one of the many open questions in the biology of lichens that we hope to answer by studying the fungi that dominate these unique plants.



CRYSTALS of a compound excreted by the mycobiont *Lecidea atrocinera* are enlarged 100 diameters. They appeared on the surface of the colony during three months' storage at 41 degrees Fahrenheit. The composition of this metabolic product is still undetermined.

FROM ASTROLABE TO APOLLO

Astrolabe (1st Century B.C.)—A Greek invention long used by Arabs and Europeans to provide astronomical sightings. The Astrolabe is a predecessor to today's sextant. (Cranbrook Institute of Science)

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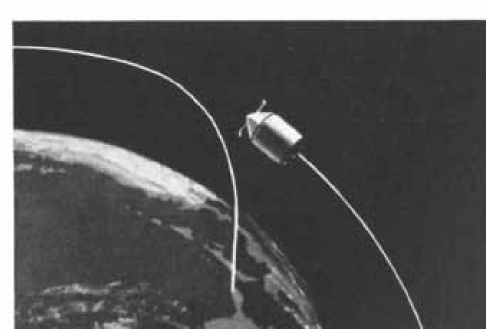

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THE CLOCK PARADOX

This celebrated consequence of the special theory of relativity is that two clocks that are moving with respect to each other run at different speeds. The effect rests on nothing other than the Pythagorean theorem

by J. Bronowski

The paper in which the young Albert Einstein in 1905 set out the special theory of relativity confronted common sense with several new and disquieting ideas. It abolished the ether, and it showed that matter and energy are equivalent. The new ideas derive from the central conception of relativity: that time does not run at the same pace for every observer. This bold conception now lies at the heart of modern physics, all the way from the atomic to the cosmic scale. Yet it is still hard to grasp, and the paradoxes it poses continue to puzzle and to stimulate each generation of physicists. The most searching is the paradox of two identical clocks that separate on different journeys. How do the times on the two clocks compare on their journeys? And if the clocks meet again, can they show different times? This is the famous clock paradox, which I shall analyze.

Einstein's remarkable paper begins with two axioms. One is the axiom that two observers, each of whom appears to the other to be moving with a constant speed in a straight line, cannot tell which of them is moving. The second axiom is that when both observers measure the speed of light, they will get the same answer.

Neither of these axioms was new in itself. The first, the axiom that (to put it roughly) all uniform motion is relative, had long been implicit in the accepted laws of mechanics. The second, the axiom that (again to put it roughly) the speed of light comes out the same in every experiment, was beginning to be accepted as the natural interpretation of the finding by A. A. Michelson and E. W. Morley in 1887 that the speed of light (roughly 186,000 miles, or 3×10^5 kilometers, per second) is not changed by the movement of the earth—by the movement, that is, of the laboratory in which it is measured.

What was new, then, in Einstein's analysis was not one axiom or the other but the confrontation of the two. They form the two principles of relativity not singly but together. This is how Einstein presents them jointly at the beginning of his paper.

It follows at once from the two axioms combined that we have to revise the traditional idea of time. By tradition we took it for granted that time is the same everywhere and for everyone. Why not? What reason had we even to speculate that time might run differently for me writing at my desk and for you reading this on the train? It had seemed natural to assume that time is a universal "now" for every traveler anywhere in the universe.

But time cannot run at the same pace for two observers, one of whom is moving relative to the other, if they are to get the same speed when they time a beam of light that is moving with one of them. The path of the beam of light does not look the same to the two observers. Since the beam is moving with one observer, it seems to the other to be taking a longer path; and if the speed of light is to remain the same, the longer path must seem to take a longer time. To the observer to whom the path of the beam looks longer, the time the beam takes on its path must also seem longer: time must pass faster for him.

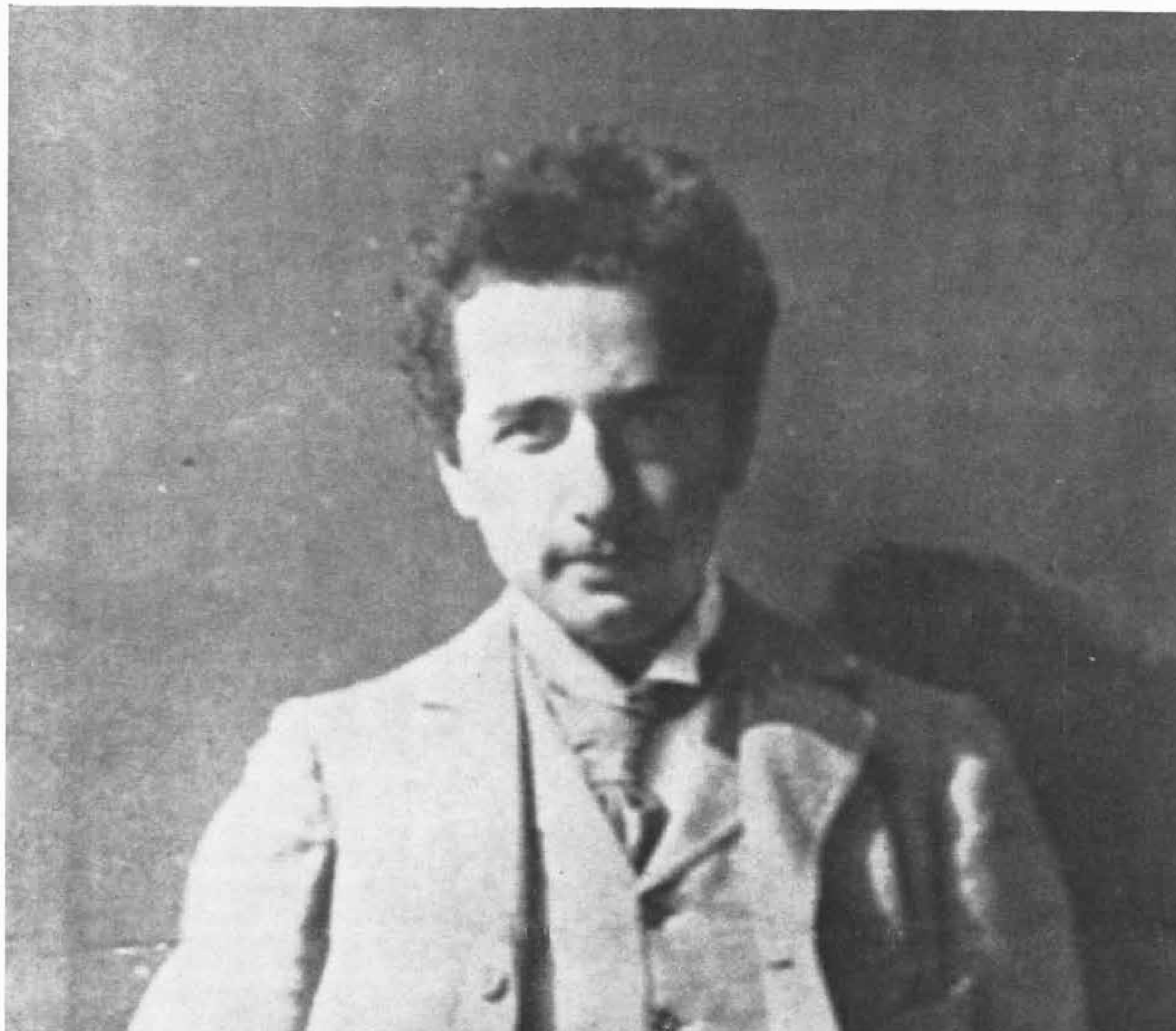
Let me put this in concrete terms. Think of a moving laboratory as simple as possible: a railroad car. Put yourself on one side of the car and look at a match struck on the other side. To you the light from the match seems to have come straight across the car. But a man who is watching the train go by sees the light from the match take a longer path before it reaches you. He sees you moving along the track, and the light crossing diagonally from the point where the match was struck to the point you have reached when the light arrives. The two paths—the path you see and the path the bystander sees—can be described by names that come quite early in the school geometry books. You see the path of the light from the match to you as the altitude of a triangle, and the bystander sees it as the hypotenuse of the same triangle, whose base is the distance your train travels while the light crosses to you. Since the speed of light is to be the same for both of you, it follows that the light must seem to take longer for the bystander than it does for you. Time passes faster for the bystander than for the traveler.

Moreover, we can work out the rate at which time passes for the two with nothing more sophisticated than the school geometry book to help us. Since the traveler and the bystander find the same speed of light, time passes slower for the traveler than for the bystander exactly in the ratio of the distances they see the light travel: in the ratio, that is, of the altitude to the hypotenuse. This is the classical formula of relativity: time passes slower for the traveler in the ratio

$$\sqrt{c^2 - v^2} : c .$$

In this formula c is the hypotenuse of the triangle, v is the base and the radical is the altitude, calculated by the theorem of Pythagoras. As the formula is written, c also stands for the speed of light and v for the speed of the train [*see illustration on page 140*].

There is no good reason for having the formula here, for we are concerned only with the fact that time passes slower



THE YOUNG EINSTEIN posed for this photograph while he was a student at the Federal Institute of Technology in Zurich. Einstein was graduated in 1900 and five years later he published his special theory of relativity, which gave rise to the clock paradox.

for the traveler, not with how much slower. But I cannot resist deriving the formula, because the thought is so simple: it rests on nothing but the dimensions of a right-angled triangle, as Pythagoras calculated them. The fundamental formula of relativity comes from none other than Pythagoras.

It is appropriate that Einstein records in his autobiography the excitement he felt, the sense of the power of mathematics, when an uncle told him the theorem of Pythagoras when he was 10 or 11 and he proved it for himself. As for Pythagoras, he had offered up 100 oxen to the Muses when he discovered the theorem.

Time passes slower for the traveler than for the bystander: that is a necessary consequence of the two axioms of relativity being taken together. I must emphasize that here time is concrete, a succession of physical events as visible as the sweep of the hands of a clock. We are not discussing some intangible feeling, the impatience of a traveler who wants to get on and to whom everything seems to be moving too slow. The passage of time in relativity is measured by physical processes: the rotation of clock wheels, the movement of atoms, the decay of unstable particles. For example, we know by observation how long a meson of one kind survives from the instant of its creation to its disintegration if it remains at rest. We also know by observation how long the same kind of meson survives when it is traveling at high speed. The traveling meson lives longer, in our time, than the meson at rest. The traveling meson, of course, is not aware that it is traveling and that time is passing faster for us.

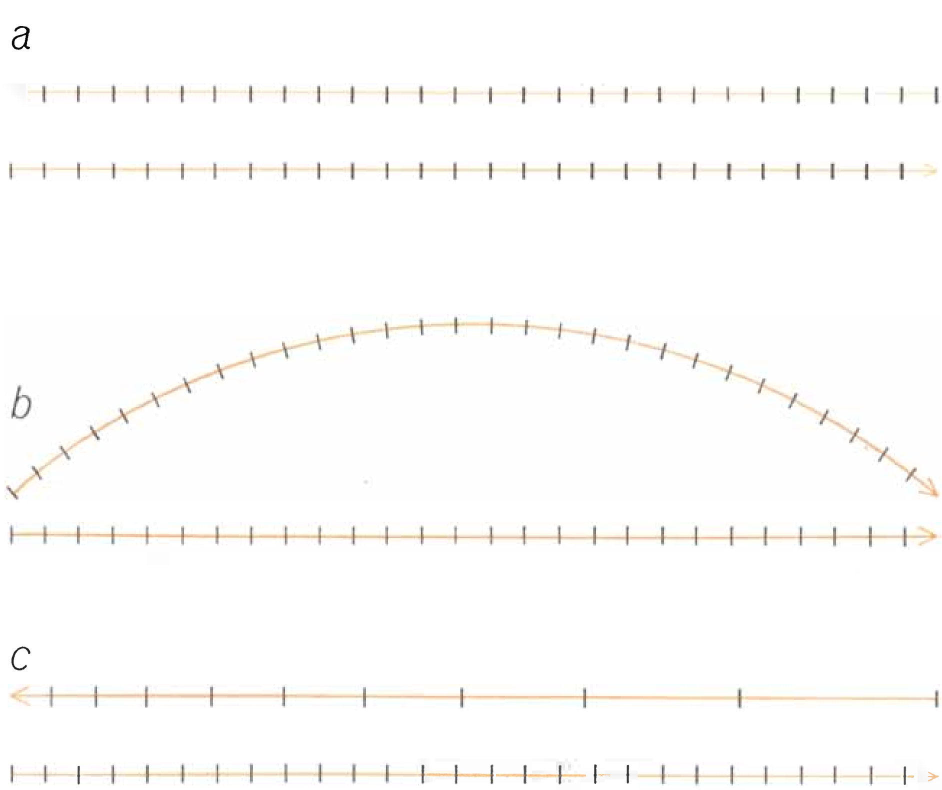
The evidence is unassailable: physical processes go slower in objects when they travel at high speed. There was no way of knowing this when Einstein wrote in 1905, yet new discoveries in physics (such as the mesons) have borne out his prophecy.

There is an awkward duality, however, in this statement that time—a succession of events in a physical process—passes slower for the traveler than for the bystander. Does the traveler really know that he is traveling? Does the bystander know that he is standing still? After all, you in your railroad car may be wrong: the train may be standing still and the man outside may be the one who is moving. The meson that seems to us to be traveling at high speed may in fact be at rest, and it may be we in the laboratory who are hurtling past it. Indeed, is there any sense in saying that one of us is at rest and the other moving, as if either of these descriptions was absolute? Surely the first axiom of relativity says that we cannot tell which of the two of us is the traveler and which the bystander? Is not the relation between two observers quite symmetrical?

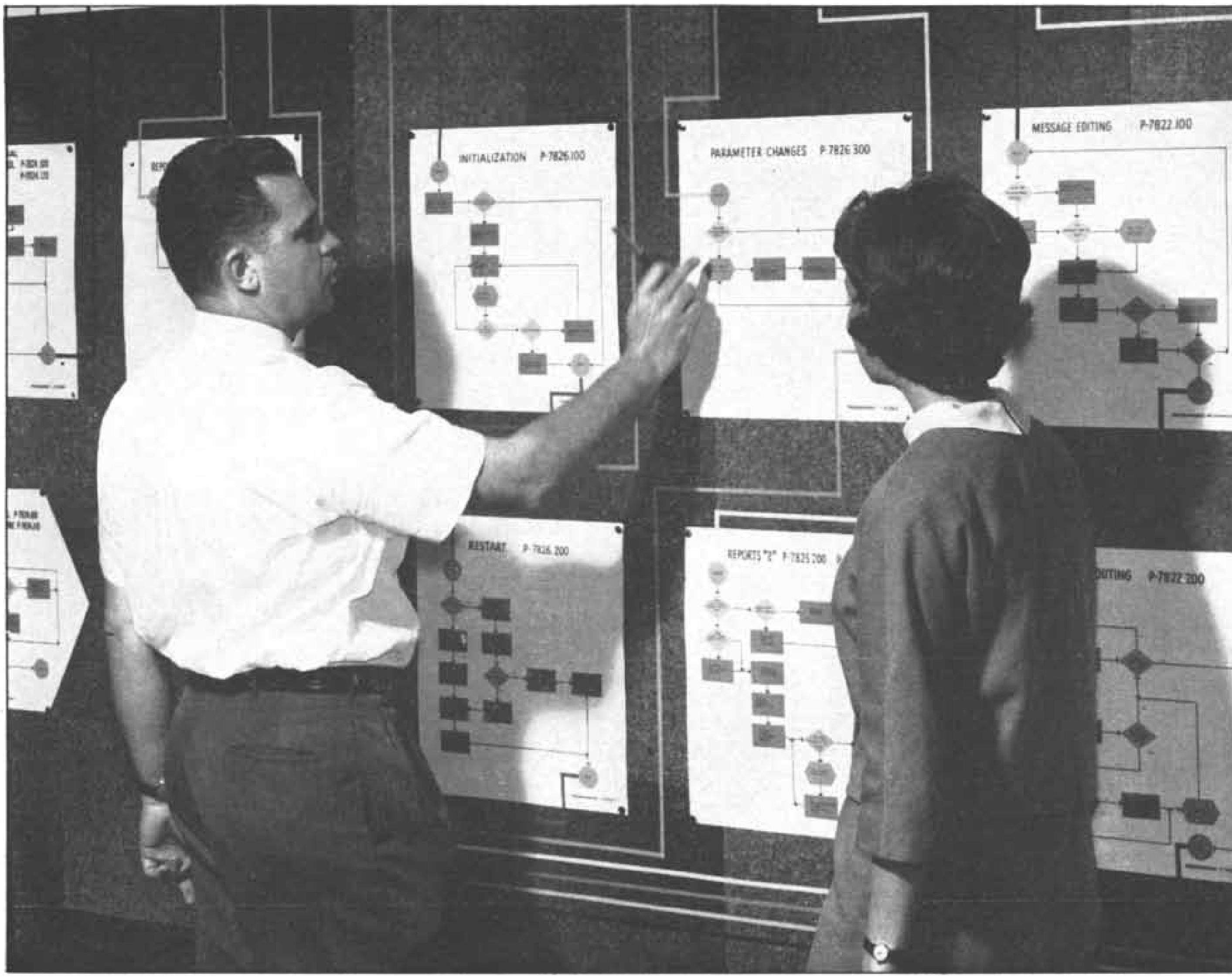
The first axiom of relativity does not say exactly this; and these objections are valid only if we stick exactly to what it says. What the first axiom does say is that when two observers are moving at a constant speed in a straight line, each relative to the other, neither can tell who is moving and who is standing still. The relation between two observers is symmetrical if, and only if, each seems to the other to be moving at a constant speed in a straight line.

Two such observers—for example, you in your railroad car and the man watching the train go by—are indeed in an odd relation. When you do an experiment to measure the speed of light in your car, the man watching the train sees the light take a longer path than you do; your clock therefore seems to him to run slower than his. But if he does an experiment in his laboratory to measure the speed of light, the conditions are reversed. To you passing in the train his laboratory seems to be moving, the path the light follows in his laboratory seems longer to you than it does to him, and you must therefore conclude that his clock runs slower than yours. This is neat and symmetrical; each of you thinks that the clock of the other is running slow. But this situation is also very odd. How can it happen that, when two hours have passed on your clock, it seems to you that only one hour has passed on the clock of the man beside the track—and yet, when one hour has passed on his clock, it seems to him that only half an hour has passed on yours?

This curious state of affairs is possible—and it is quite real—because you and the man beside the track never meet again! You can set your clocks together, side by side, once and once only; after that you separate forever. That is the basic condition of the first axiom of relativity: each of you is moving at a constant speed in a straight line relative to the other,



THREE TYPES OF RELATIVE MOTION discussed in the text are represented here in highly schematized form. Only one (*a*) satisfies the conditions of the first axiom of relativity: Two observers cannot tell which of them is moving if each seems to the other to be moving in a straight line (*arrow*) and at a constant speed (*the distance between any pair of vertical crossbars represents some arbitrary unit of time*), and they will never meet again. Two observers who separate and meet again are able to tell which of them is moving and which is at rest, but they cannot fulfill both conditions of the first axiom. Taking as the standard the reference system of one observer (*lower arrow in* b *and* c), who is therefore "at rest," the path of the traveler must curve if his speed is constant (*b*); or, if he is traveling in a straight line, he must turn back at some point, which first requires him to decelerate (*c*).



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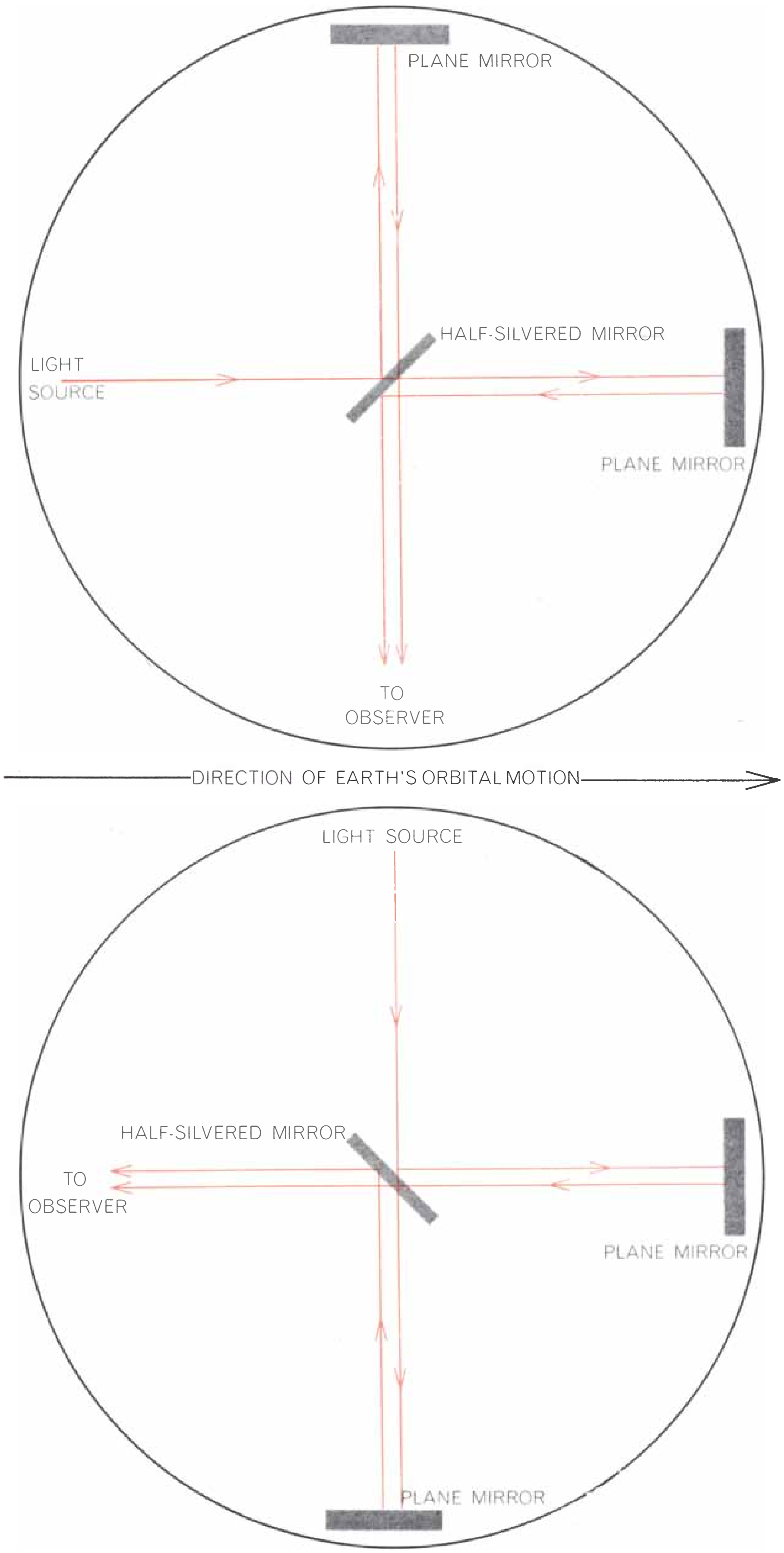
and therefore you can meet once and once only. When you meet, you can physically set your clocks to the same time. But from then on you can compare your clock with his and he can compare his clock with yours only by sending signals to each other. Any signal of this kind is essentially like a ray of light: each of you judges it to have traveled by a path of a different length and each of you therefore thinks that it has taken a different time. In comparing your clocks, each of you has to make an allowance for the apparent time of travel of the signal. Because you make different allowances, the comparison gives you different answers.

I repeat that this does not make the difference in the passing of time unreal. The meson at high speed in my universe still decays slower than the meson at rest; that is a physical fact. The fact is not falsified by our realization that, in a universe attached to the high-speed meson, it is the meson I think to be at rest that decays slower. Of course it does; in that universe it is traveling at high speed.

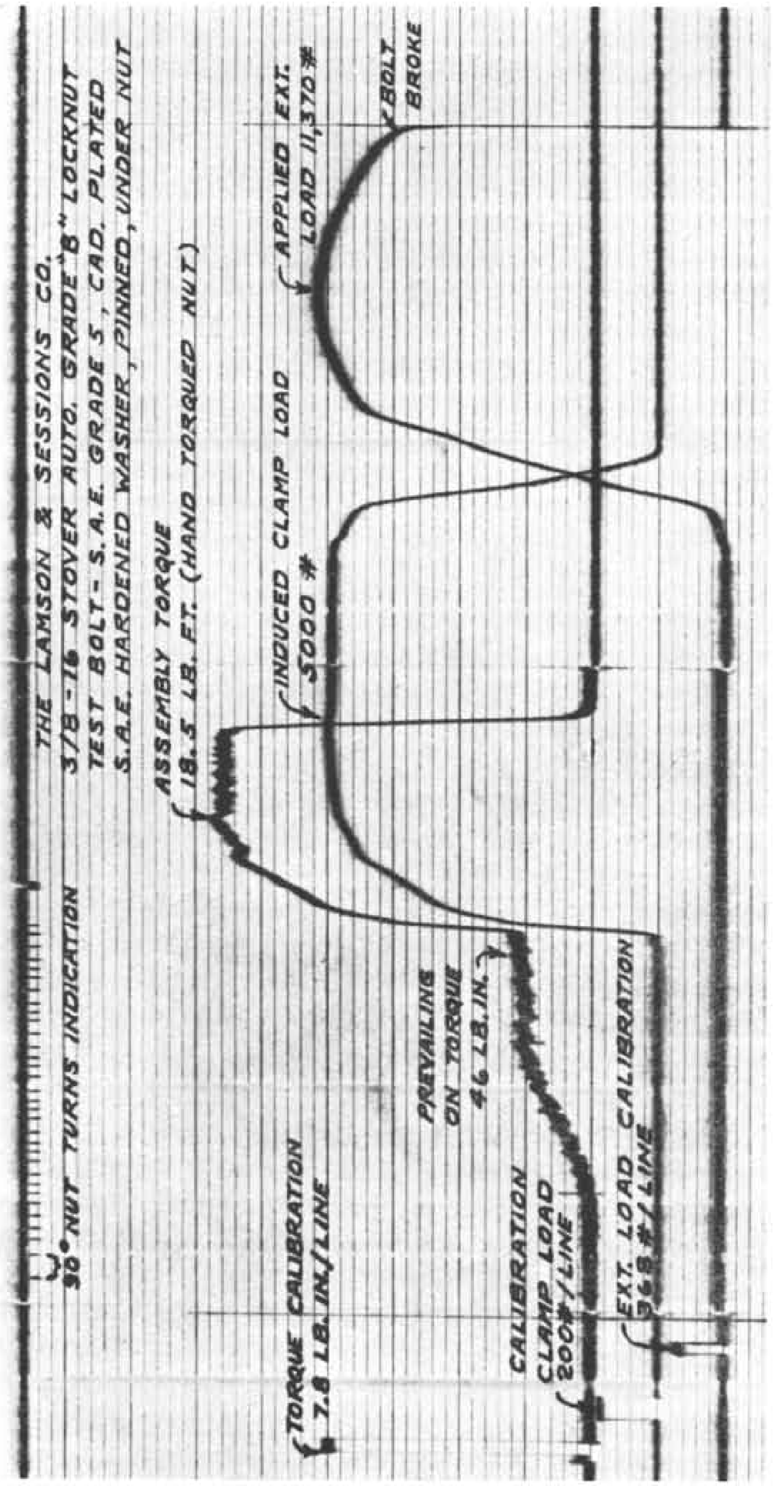
The physical reality is simple and robust. A process consists of a sequence of events: the movement of the hands of a clock, the oscillations of an atom, the decay of an unstable particle. There are many objects in my universe that undergo the same process: many clocks and many atoms and many mesons. These objects travel at different speeds in my universe. Then the physical reality is that, in my universe, every process runs slower the faster the object is traveling. The faster the traveler moves through my universe, the slower his pulse. This is a law of nature every observer finds in his universe.

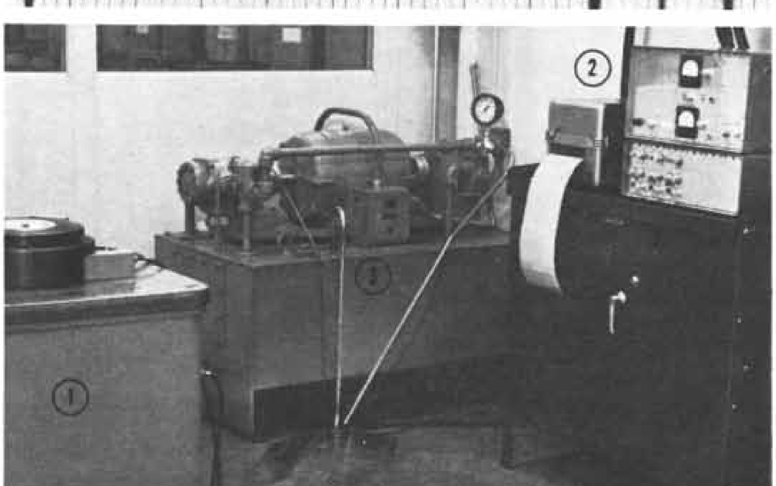
So far I have discussed observers who are flying away from each other, and therefore their time scales cannot be compared at one place; they are together, at the same place, only once. But surely we ought also to be able to discuss observers who separate and later meet again. They will be able to hold their clocks side by side twice, at the beginning and at the end of the trip, and to compare them directly both times. What will their clocks say? If their clocks show the same time when they part, can they show different times when they meet again at the same place?

It may seem at first sight that the two observers who part and then meet again must necessarily be in a symmetrical relation. Whatever journey each has made is, after all, relative; and it may therefore seem as if each observer is free to



MICHELSON-MORLEY EXPERIMENT performed in 1887 attempted to measure the velocity of the earth through the ether by measuring the difference in the velocity of two light beams traveling at right angles to each other. The round-trip path parallel to the earth's orbital motion should take longer than that perpendicular to this motion. Hence shifting the apparatus 90 degrees should produce a detectable shift in the pattern of interference fringes formed by the two beams. No shift of the required magnitude was found. Repetitions of the experiment have confirmed the conclusion that the speed of light is constant. This is one of the two principles on which the special theory of relativity rests.





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say that he has not traveled at all and that all the traveling has been done by the other. Indeed, we may ask, does not the first axiom of relativity say this? Does not the first axiom say that two observers cannot tell which of them has moved and which of them has stayed still?

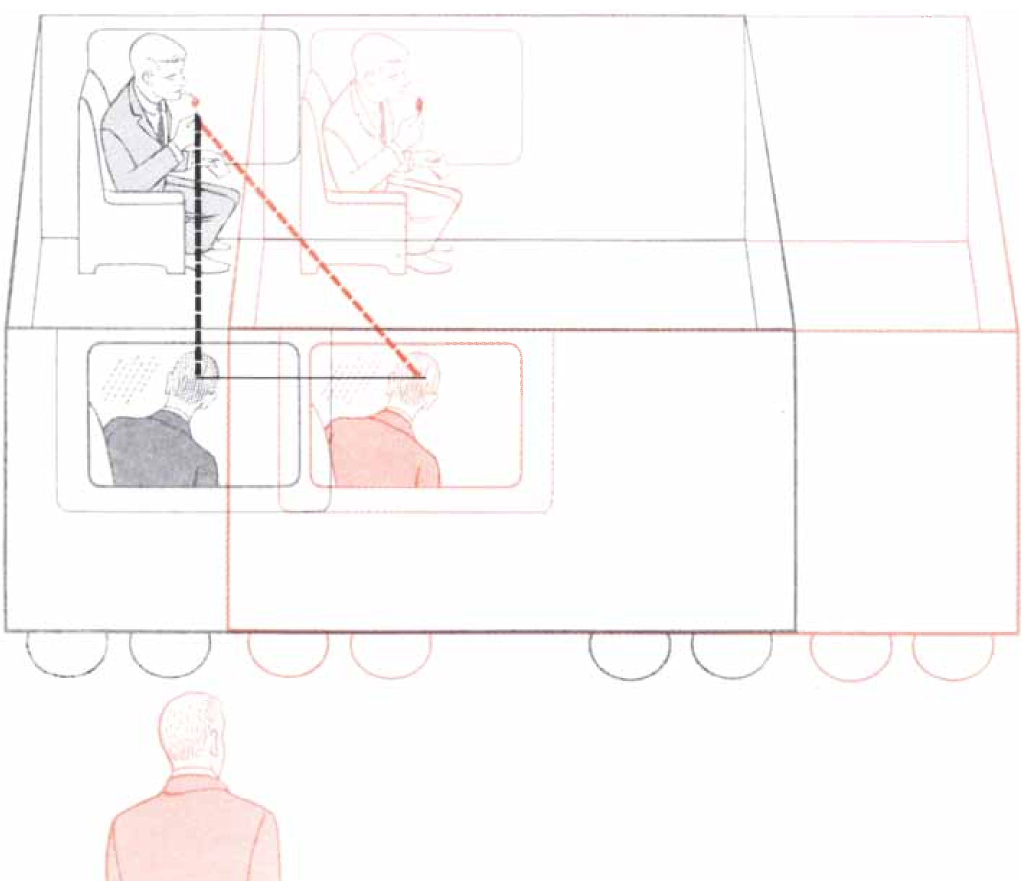
No, it does not. I repeat that what the first axiom of relativity says is something much sharper, something much more restricted and more precise. The first axiom says that if each of two observers seems to the other to be moving at a constant speed in a straight line, they cannot tell which of them is moving. But the axiom says nothing about observers in arbitrary motion. It says nothing about them if they do not move in straight lines and nothing about them if they do not move at a constant speed.

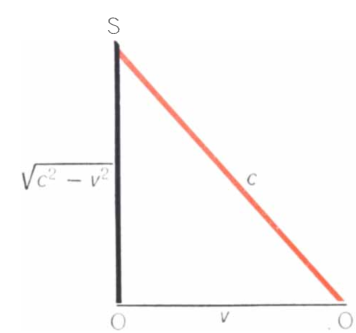
Here is the crux of the matter. Two observers who separate and meet again cannot fulfill the conditions of the first axiom of relativity throughout such a journey. Suppose one of them remains still. Then the other can travel in a straight line going and coming, but if he does this, he must turn back at some point—that is, he must change his speed. Or the traveler can move at a constant speed, but if he does this, he cannot move in a straight line—he must move in a curve if he is to come back to his starting point. Two observers who part and meet again can fulfill one condition of the first axiom of relativity, if they wish, but they cannot fulfill both.

And at once, as soon as a traveler departs from the conditions of the first axiom, he knows that he is moving. He feels the outside forces that produce a change of motion. If he is traveling in a straight line and has to come to rest, he knows physically that he is decelerating; he can tell that he is, by carrying an accelerometer and looking at it. Indeed, all he needs to carry is a bucket of water: if the surface begins to tilt, he knows that he is changing speed. In the same way, if the traveler is rounding a curve, he can tell that he is moving by the acceleration he feels—or by carrying an accelerometer or a bucket of water. We cannot detect a constant speed in a straight line: that is the first axiom of relativity. But we can detect any accelerated motion: that is a physical fact we have all experienced. Lying in a sleeping compartment in the dark at night, we may not be able to tell whether the train is moving or not. But we can tell when the train brakes, and we can tell when it rounds a bend. We can tell because we are thrown about; we act as our own accelerometer.

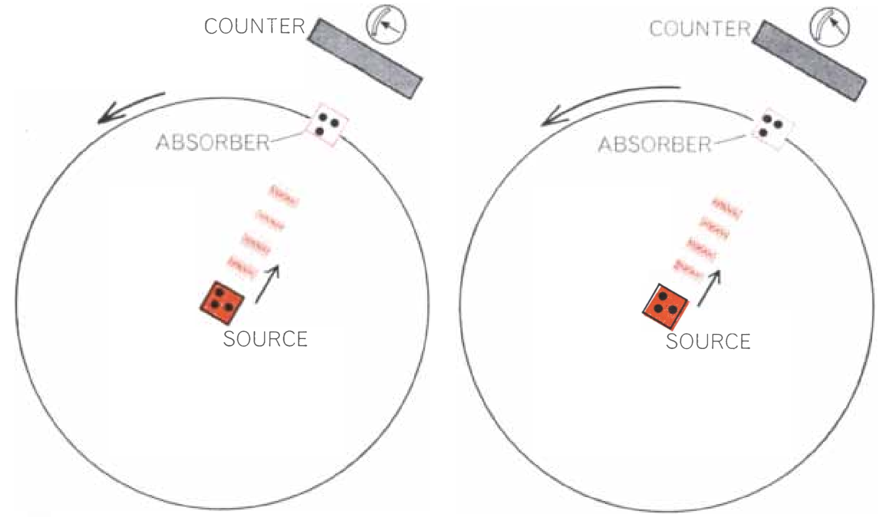
Therefore if I stay at home and you go on a journey and come back, the relation between us is not symmetrical. You can tell that you have traveled, even if you travel in a dark train—you can tell by carrying an accelerometer. And I can tell that I have stayed at home, because my accelerometer has recorded no change of speed or of direction. The traveler who makes a round trip can be distinguished from the stay-at-home.

Now consider what happens to your clock, the traveler's. Imagine your round trip broken down into a series of short, straight paths, along each of which you can keep your speed constant. Then





TIME RUNS DIFFERENTLY for two observers when one is moving relative to the other. The imaginary experiment depicted here is discussed in detail in the text. The path taken by the light from a match seems shorter to an observer inside the railroad car (*broken black line*) than the same path does to a stationary observer outside the car (*broken colored line*). The speed of light is the same for both observers; consequently time passes slower for the moving observer in the ratio of the shorter to the longer path. This relation can be represented in geometrical terms, as it is in the triangle at right, where c represents the speed of light, v the velocity of the train and O and O' the traveler's position when the light reaches him, according to the traveler (O) and to the bystander (O').



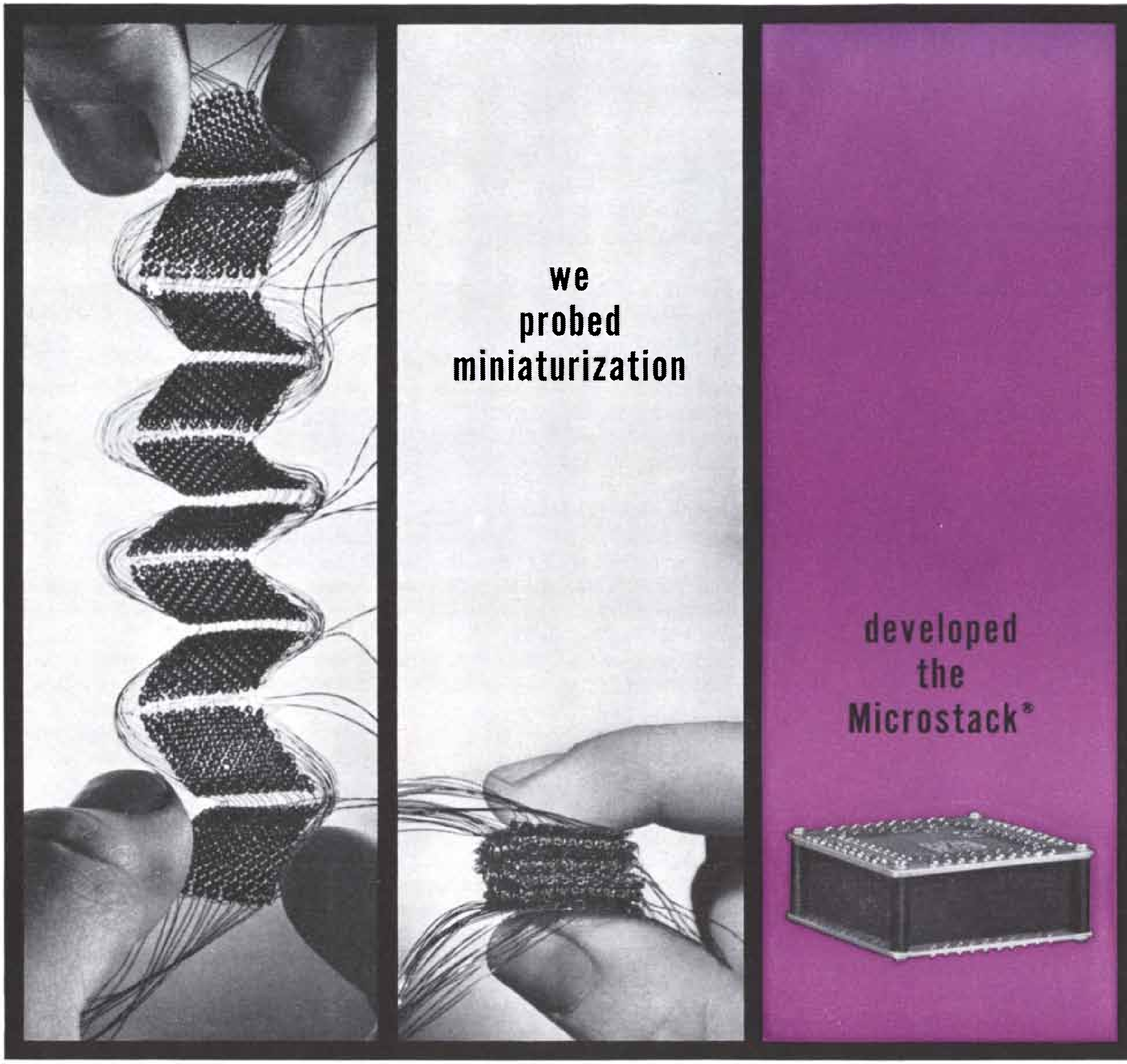
RELATIVISTIC EFFECTS of motion were detected using an experimental apparatus like that illustrated schematically in these diagrams. A source of radioactive iron-57 nuclei emitted gamma ray photons of a very sharply defined frequency. A resonant absorber containing iron-57 nuclei strongly absorbed the photons that were in resonance. A stationary counter counted the photons that reached it directly from the absorber (i.e., were emitted by the absorber) as well as any photons that might pass directly through the absorber from the source. The counting rate was higher when the disk was rotated at 500 revolutions per second (*right*) than when it was at 50 (*left*). The reduction in resonance allowed more photons to pass directly through the absorber from the source to the counter.

along each short path your clock seems to me to run slower than mine. When you return, your clock should be behind mine, by the sum of these losses; and you should have aged less than I. Can this be so? It can, and it is. The difference in our timekeeping does not contradict any symmetry you may find in the situation. It does not contradict your finding that, along any short path, my clock also seems to you to be running slower than yours. Your findings do not add up because you do not remain faithful to the first axiom of relativity: your view of my time changes every time you move abruptly from one straight path to another. Only my view of your time losses accumulates steadily, because only I remain faithful to the first axiom of relativity throughout.

All this was foreseen by Einstein in his paper on the special theory of relativity. Here is what he wrote in that first paper in 1905: "If there are two synchronized clocks at *A* and if one of these is moved along a closed curve with constant velocity v until it returns to *A*, which we suppose to take *t* seconds, then the latter clock on arriving at *A* will have lost $\frac{1}{2}t(v/c)^2$ seconds by comparison with the clock which has remained stationary. We conclude from this that a clock fixed at the earth's equator will run slower by a very small amount than an identical clock fixed at one of the earth's poles." No one could have guessed in 1905 that this prediction could be subjected to a practical test. It must have seemed inconceivable then that differences in time as minute as this could be measured—a difference of 10^{-7}, or one ten-millionth, of a second per day between a clock at the Equator and a clock at one of the poles in Einstein's hypothetical experiment. Yet such differences in time have become measurable in recent years. An experiment that exactly matches Einstein's model of the circular tour has been performed.

In this experiment the circular tour is conducted on quite a small scale compared with the grandiose ventures in space travel that are usually invoked to illustrate the principle. Thanks to a discovery by the German physicist R. L. Mössbauer, it is possible to tune a radioactive source of gamma ray photons into resonance with an absorber of those photons within a very sharp frequency interval. The experimental apparatus that employs the "Mössbauer effect" consists of an aluminum turntable, on the spindle of which is mounted a photon-emitter, a radioactive isotope of iron (iron 57). Around the circumference of the turntable a resonant absorber is mounted, made of the same isotope of iron.

The absorber plays the part of the moving clock; each photon it absorbs is one tick of the clocks in unison. Beyond the



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circumference is a stationary counter that records those photons that pass through the absorber. Each photon that gets through the absorber and is counted is a tick that the moving clock has missed. The Mössbauer effect is so sharp that this arrangement makes it possible to compare the difference in the "tick-ing" of the absorber when it moves at different speeds, to an accuracy of one part in 10^{12}. The number of photons counted is in fact significantly different when the turntable, only six inches across, is rotated at 50 revolutions per second and at 500 r.p.s., each time for 30 minutes. (At these rates the "clock" on the circumference is moving at about 50 and about 500 miles per hour.) Einstein's formula predicts a slowing down of $\frac{1}{2} \times 10^{-9}$ seconds between one of these rates and the other, under the conditions of the experiment. This is precisely the amount that J. J. Hay and his colleagues at the Atomic Research Establishment at Harwell in England found, within the appropriate statistical limits [see "The Mössbauer Effect," by Sergio De Benedetti; SCIENTIFIC AMERICAN, April, 1960].

There is no doubt, then, that the clock paradox is true. A set of radioactive atoms on the perimeter of the whirling turntable has experienced fewer decays than an identical set of atoms that has remained at rest. A clock carried on a round trip is found, when you bring it back, to have run slower than the clock I have kept at home. A twin on a round trip ages less, in the normal sense of physical aging, than the twin who has stayed at home.

Let me summarize this. The clock paradox compares the time that elapses for a traveler on a round trip with the time that elapses for his stay-at-home twin. Time runs slower for the traveler: he ages less than the stay-at-home. This seems a paradox, because we ask how we can tell the traveler from the stay-at-home once both are reunited. The paradox is resolved when we show that we can tell them apart—that the traveler on a round trip undergoes accelerations that he observed and recorded and that distinguish him from the stay-at-home.

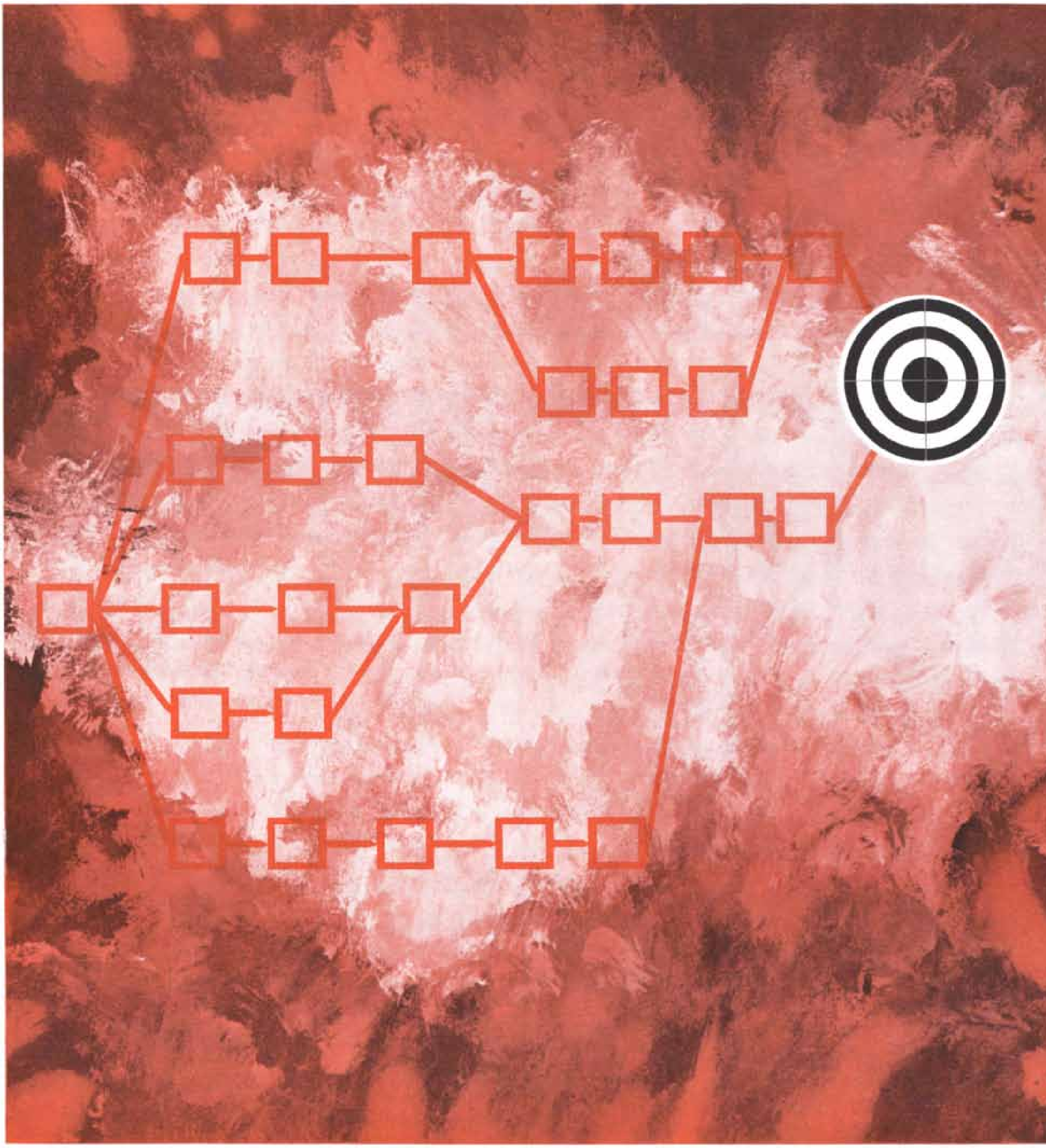
Only if the traveler remained faithful to the first axiom of relativity would there be symmetry between him and the stay-at-home. That is, the traveler would have to travel at a constant speed in a straight line. But if he did that, he would never get home; there would be no round trip.

So much for the paradox and its resolution. And yet we ought not to be quite content with this. There remains a question: Why does the special theory of relativity single out, of all possible modes of movement, the movement in a straight line at a constant speed? Why cannot the traveler tell if he is in this state of movement or at rest? And why can he tell at once if he is in any other state of movement?

As far as we know there is no reason in the world, except that the world is like this. The empirical fact of nature is like this and not otherwise; our system of mechanics works on this basis and not on any other. Thus when we analyze the paradox of the two clocks, we become aware that at the center of it lies a major postulate about our physical world: the postulate that motion in a straight line at a constant speed is, in some sense, the basic state. This is not new in relativity; on the contrary, it was stated formally in the laws of motion propounded by Isaac Newton in the 17th century. Newton's laws state that a body continues to remain either at rest or in uniform motion in a straight line, unless it is disturbed from outside. Essentially this is already equivalent to the first axiom of relativity, that one cannot tell if one is at rest or in uniform motion in a straight line.

But Newton's laws in turn merely set out explicitly what philosophers had begun to say 300 years earlier. The turning point was before Newton, among the dissident philosophers of Paris in the 14th century. Until that time the physics of Thomas Aquinas had followed the Greeks, and particularly Aristotle, in asserting that an arrow continues on its flight only because the air pushes it from point to point. This was first contradicted by Jean Buridan and other Parisian philosophers in the 14th century, when they propounded the doctrine of impetus—the doctrine that the arrow is carried throughout its flight by its first impetus. They first understood that motion, the flight of an arrow, persists of itself.

Modern physics is founded on this principle: the natural and continuing state of things is uniform motion in a straight line. In contrast, the Greeks believed that the natural state is motion in a circle. In our physics, if a clock moves in a circle, its motion is forced, it suffers an acceleration and as a result it loses time on the round trip. So the paradox of the clocks reaches back to, and makes vivid, the difference between our conception of the natural world and the Greek conception.



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MATHEMATICAL GAMES

Curves of constant width, one of which makes it possible to drill square holes

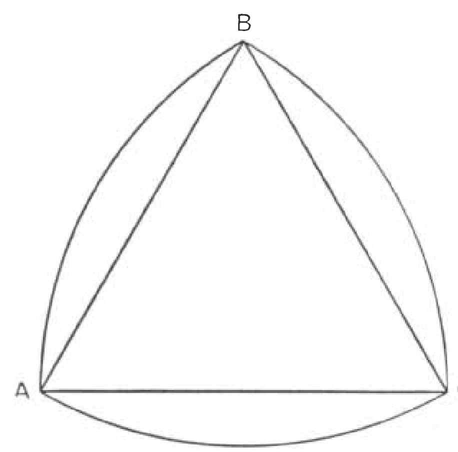
by Martin Gardner

If an enormously heavy object has to be moved from one spot to another, it may not be practical to move it on wheels. Axles might buckle or snap under the load. Instead the object is placed on a flat platform that in turn rests on cylindrical rollers. As the platform is pushed forward, the rollers left behind are picked up and put down again in front.

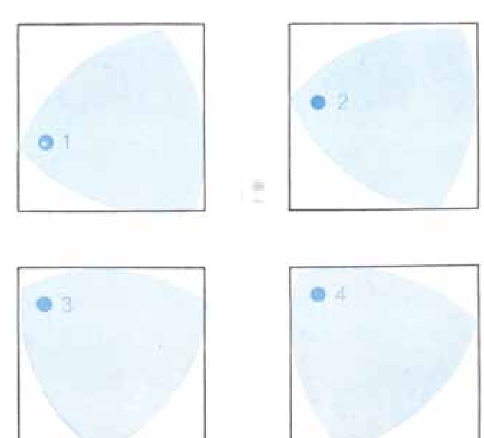
An object moved in this manner over a flat, horizontal surface obviously does not bob up and down as it rolls along. The reason is simply that the cylindrical rollers have a circular cross section, and a circle is a closed curve possessing what mathematicians call "constant width." If a closed convex curve is placed between two parallel lines and the lines are moved together until they touch the curve, the distance between the parallel lines is the curve's "width" in one direction. An ellipse clearly does not have the same width in all directions. A platform riding on elliptical rollers would wobble up and down as it rolled over them. Because a circle has the same width in all directions, it can be rotated between two parallel lines without altering the distance between the lines.

Is the circle the only closed curve of constant width? Most people would say yes, thus providing a sterling example of how far one's mathematical intuition can go astray. Actually there is an infinity of such curves. Any one of them can be the cross section of a roller that will roll a platform as smoothly as a circular cylinder! The failure to recognize such curves can have and has had disastrous consequences in industry. To give one example, it might be thought that the cylindrical hull of a half-built submarine could be tested for circularity by just measuring maximum widths in all directions. As will soon be made clear, such a hull can be monstrously lopsided and still pass such a test. It is precisely for this reason that the circularity of a submarine hull is always tested by applying curved templates.

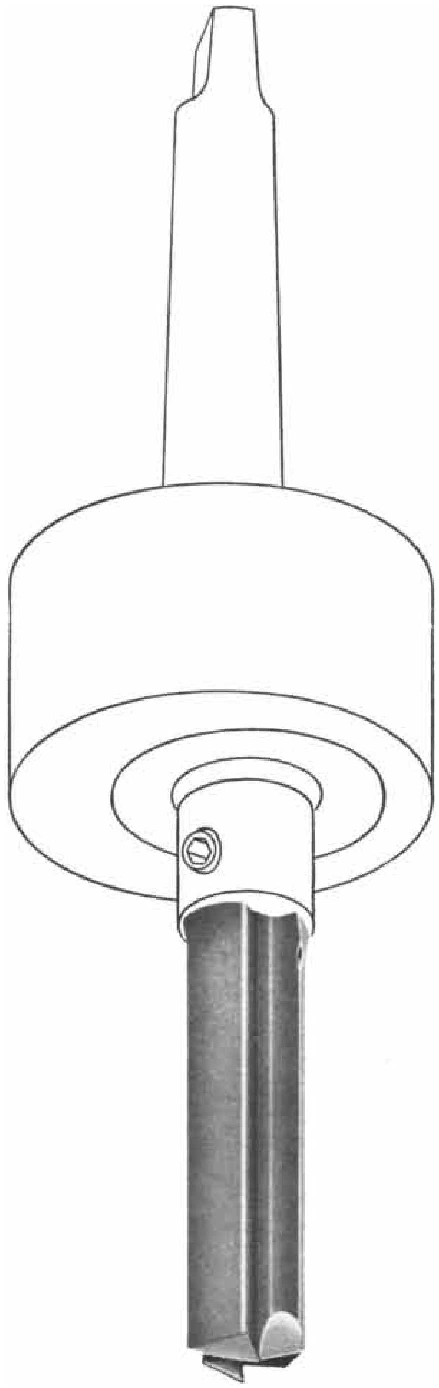
The simplest noncircular curve of constant width has been named the Reuleaux triangle after Franz Reuleaux (1829–1905), an engineer and mathematician who taught at the Royal Technical High School in Berlin. The curve itself was known to earlier mathematicians, but Reuleaux was the first to demonstrate its constant-width properties. It is easy to construct. First draw an equilateral triangle, *ABC* [*see upper illustration below*]. With the point of a



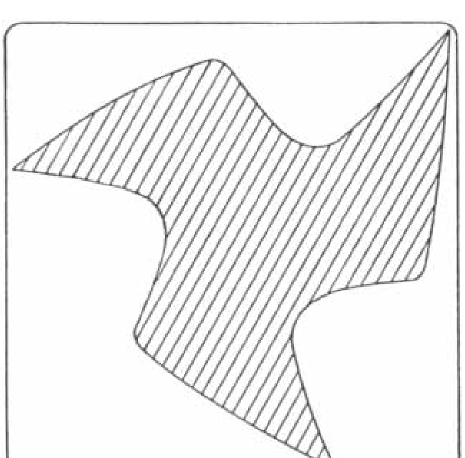
Construction of Reuleaux triangle



Reuleaux triangle rotating in square



Watts chuck and drill



Cross section of drill in hole

compass at *A*, draw an arc, *BC*. In a similar manner draw the other two arcs. It is obvious that the "curved triangle" (as Reuleaux called it) must have a constant width equal to the side of the interior triangle.

If a curve of constant width is bounded by two pairs of parallel lines at right angles to each other, the bounding lines necessarily form a square. Like the circle or any other curve of constant width, the Reuleaux triangle will rotate snugly within a square, maintaining contact at all times with all four sides of the square [*see lower illustration on page 148*]. If the reader cuts a Reuleaux triangle out of cardboard and rotates it inside a square hole of the proper dimensions cut in another piece of cardboard, he will see that this is indeed the case.

As the Reuleaux triangle turns within a square, each corner traces a path that is almost a square; the only deviation is at the corners, where there is a slight rounding. The Reuleaux triangle has many mechanical uses, but none is so bizarre as the use that derives from this property. In 1914 Harry James Watts, an English engineer then living in Turtle Creek, Pa., invented a rotary drill based on the Reuleaux triangle and capable of drilling square holes! Since 1916 these curious drills have been manufactured by the Watts Brothers Tool Works in Wilmerding, Pa. "We have all heard about left-handed monkey wrenches, fur-lined bathtubs, cast-iron bananas," reads one of their descriptive leaflets. "We have all classed these things with the ridiculous and refused to believe that anything like that could ever happen, and right then along comes a tool that drills square holes."

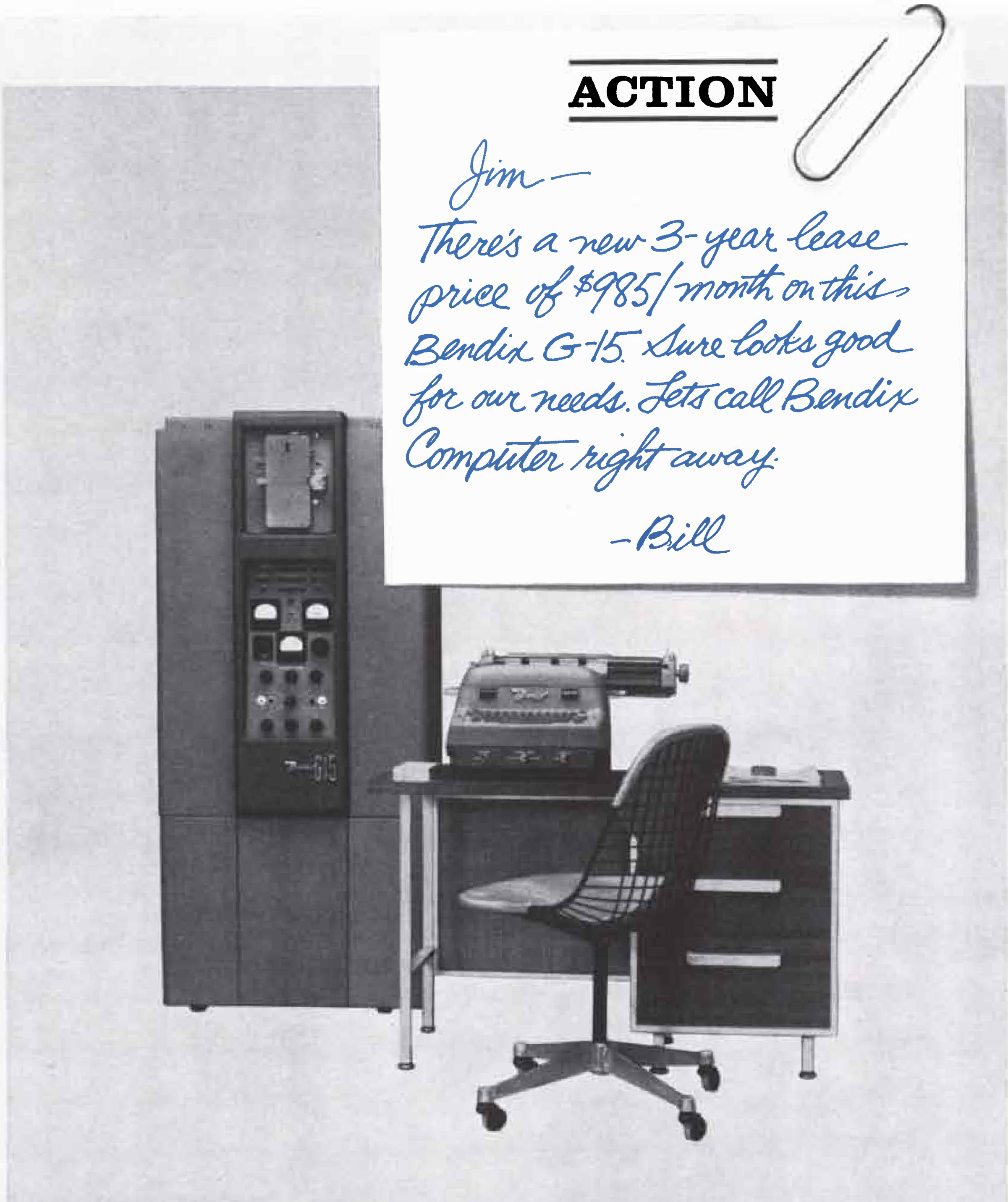
The Watts square-hole drill is shown at the left. Below it is a cross section of the drill as it rotates inside the hole it is boring. A metal guide plate with a square opening is first placed over the material to be drilled. As the drill spins within the guide plate, the corners of the drill cut the square hole through the material. As you can see, the drill is simply a Reuleaux triangle made concave in three spots to provide for cutting edges and outlets for shavings. Because the center of the drill wobbles as the drill turns, it is necessary to allow for this eccentric motion in the chuck that holds the drill. A patented "full floating chuck," as the company calls it, does the trick. (Readers who would like more information on the drill and the chuck can check U.S. patents 1,241,175; 1,241,176; and 1,241,177; all dated September 25, 1917.)

The Reuleaux triangle is the curve of constant width that has the smallest area for a given width (the area is $\frac{1}{2}(\pi - \sqrt{3})w^2$, where w is the width). The corners are angles of 120 degrees, the sharpest possible on such a curve. These corners can be rounded off by extending each side of an equilateral triangle a uniform distance at each end [*see top illustration on page 152*]. With the point of a compass at *A* draw arc *DI;* then widen the compass and draw arc *FG*. Do the same at the other corners. The resulting curve has a width, in all directions, that is the sum of the same two radii. This of course makes it a curve of constant width. Other symmetrical curves of constant width result if you start with a regular pentagon (or any regular polygon with an odd number of sides) and follow similar procedures.

There are ways to draw unsymmetrical curves of constant width. One method is to start with an irregular star polygon (it will necessarily have an odd number of points) such as the seven-point star shown in black in the bottom illustration on page 152. All of these line segments must be the same length. Place the compass point at each corner of the star and connect the two opposite corners with an arc. Because these arcs all have the same radius, the resulting curve (shown in color) will have constant width. Its corners can be rounded off by the method used before. Extend the sides of the star a uniform distance at all points (shown with broken lines) and then join the ends of the extended sides by arcs drawn with the compass point at each corner of the star. The rounded-corner curve, which is shown in black, will be another curve of constant width.

The illustration at the top left on page 154 demonstrates another method. Draw as many straight lines as you please, all mutually intersecting. Each arc is drawn with the compass point at the intersection of the two lines that bound the arc. Start with any arc, then proceed around the curve, connecting each arc to the preceding one. If you do it carefully, the curve will close and will have constant width. (Proving that the curve must close and have constant width is an interesting and not difficult exercise.) The preceding curves were made up of arcs of no more than two different circles, but curves drawn in this way may have arcs of as many different circles as you wish.

A curve of constant width need not consist of circular arcs. In fact, you can draw a highly arbitrary convex curve



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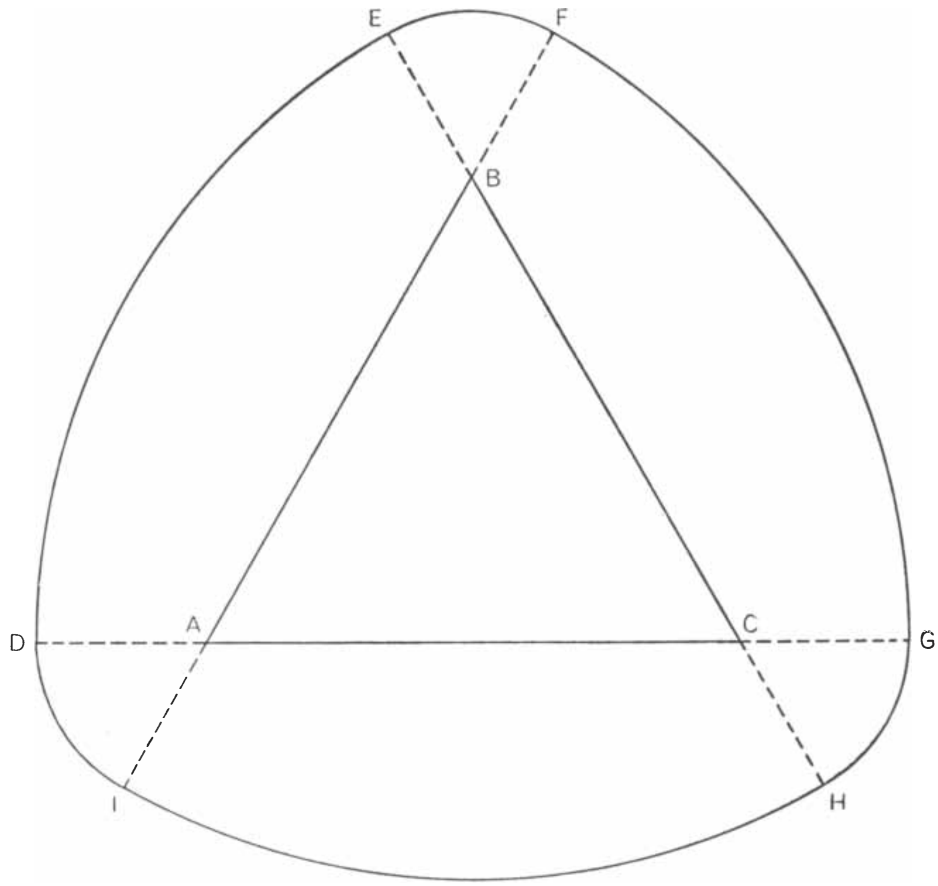
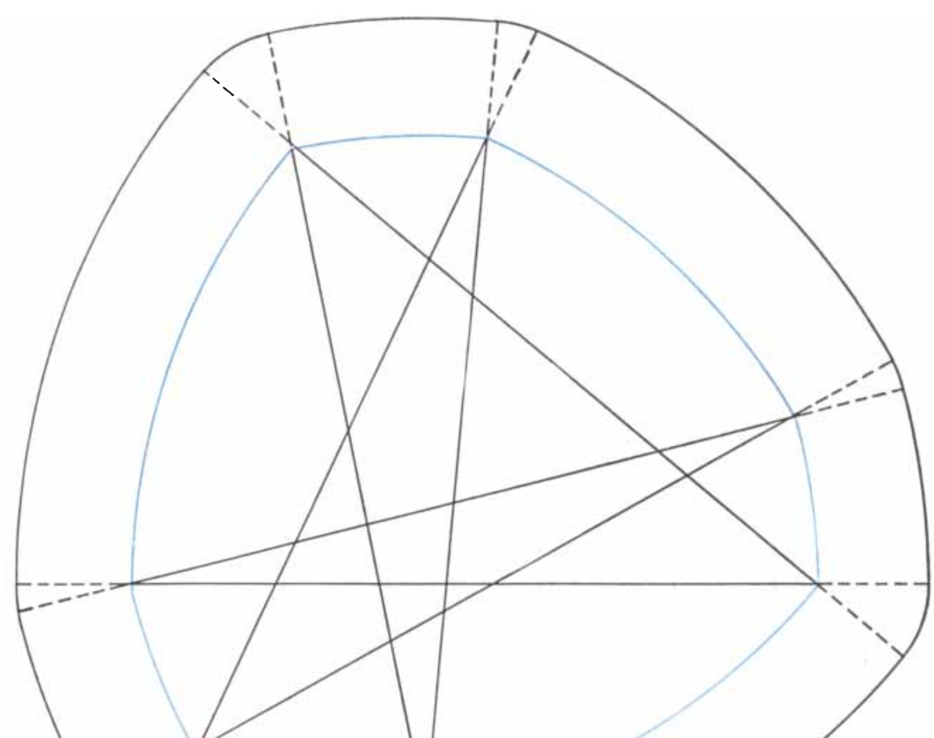


Symmetrical rounded-corner curve of constant width



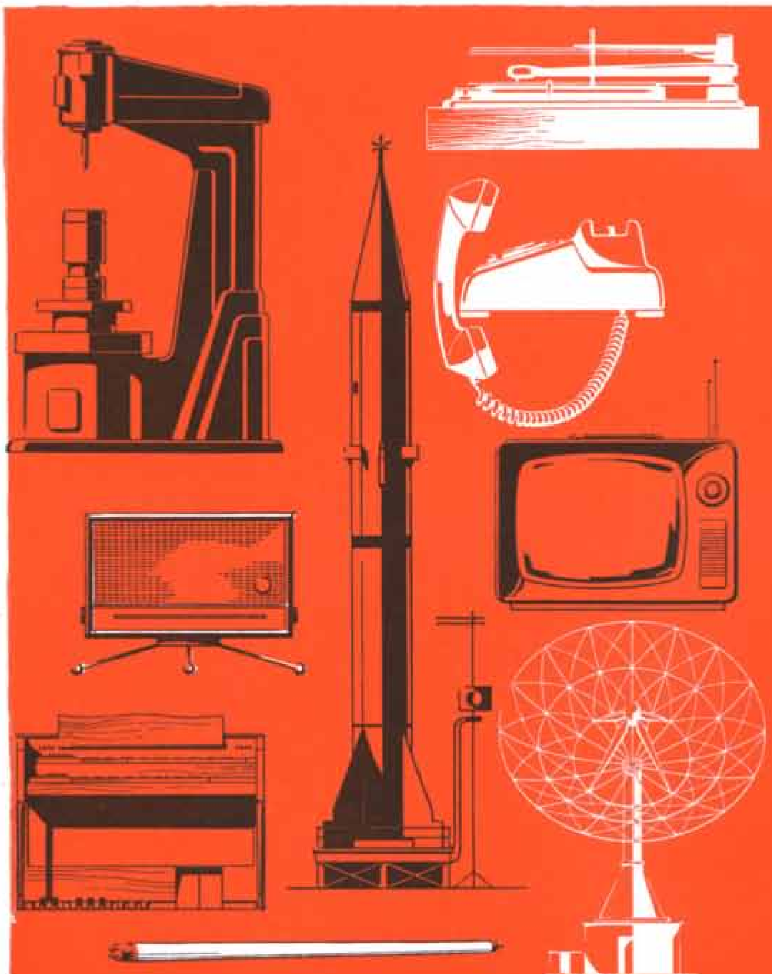
Star-polygon method of drawing a curve of constant width

from the top to the bottom of a square and touching its left side [*arc* ABC *in the illustration at top right on page 154*], and this curve will be the left side of a uniquely determined curve of constant width. To find the missing part, rule a large number of lines, each parallel to a tangent of arc *ABC* and separated from the tangent by a distance equal to the side of the square. This can be done quickly by using both sides of a ruler. The original square must have a side equal to the ruler's width. Place one edge of the ruler so that it is tangent to arc *ABC* at one of its points, then use the ruler's opposite edge to draw a parallel line. Do this at many points, from one end of arc *ABC* to the other. The missing part of the curve is the envelope of these lines. In this way you can obtain rough outlines of an endless variety of lopsided curves of constant width.

It should be mentioned that the arc *ABC* cannot be completely arbitrary. Roughly speaking, its curvature must not at any point be less than the curvature of a circle with a radius equal to the side of the square. It cannot, for example, include straight line segments. For a more precise statement on this, as well as detailed proofs of many elementary theorems involving curves of constant width, the reader is referred to the excellent chapter on such curves in *The Enjoyment of Mathematics,* by Hans Rademacher and Otto Toeplitz.

If you have the tools and skills for woodworking, you might enjoy making a number of wooden rollers with cross sections that are various curves of the same constant width. Most people are nonplused by the sight of a large book rolling horizontally across such lopsided rollers without bobbing up and down. A simpler way to demonstrate such curves is to cut from cardboard two curves of constant width and nail them to opposite ends of a wooden rod about six inches long. The curves need not be of the same shape, and it does not matter exactly where you put each nail as long as it is fairly close to what you guess to be the curve's "center." Hold a large, lightweight empty box by its ends, rest it horizontally on the attached curves and roll the box back and forth. The rod wobbles up and down at both ends, but the box rides as smoothly as it would on circular rollers!

The properties of curves of constant width have been extensively investigated. One startling property, not easy to prove, is that the perimeters of all curves with constant width n have the same length. Since a circle is such a



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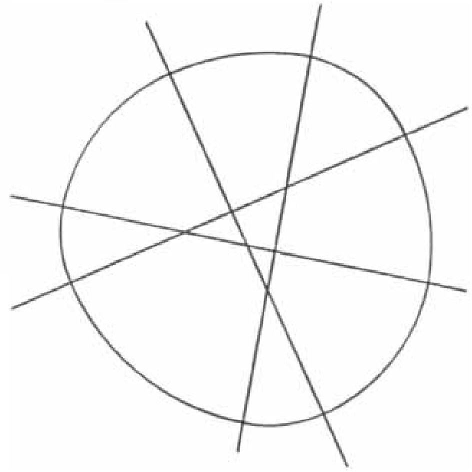
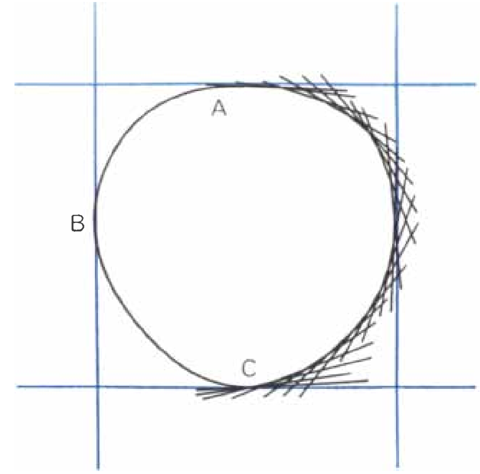


Crossed-lines method



Random curve and tangents

curve, the perimeter of any curve of constant width n must of course be πn, the same as the circumference of a circle with diameter n.

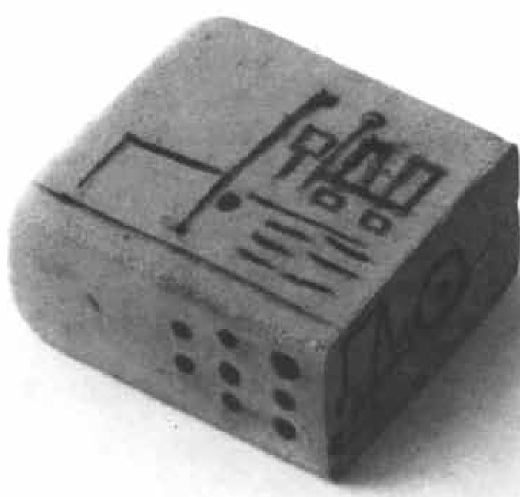
The three-dimensional analogue of a curve of constant width is the solid of constant width. A sphere is not the only such solid that will rotate within a cube, at all times touching all six sides of the cube; this property is shared by all solids of constant width. The simplest example of a nonspherical solid of this type is generated by rotating the Reuleaux triangle around one of its axes of symmetry [*see drawing at left below*]. There is an infinite number of others. The solids of constant width that have the smallest volumes are derived from the regular tetrahedron in somewhat the same way the Reuleaux triangle is derived from the equilateral triangle. Spherical caps are first placed on each face of the tetrahedron, then it is necessary to alter three of the edges slightly. These altered edges may either form a triangle or radiate from one corner. The solid at the right in the illustration below is an example of a curved tetrahedron of constant width.

Since all curves of the same constant width have the same perimeter, it might be supposed that all solids of the same constant width have the same surface area. This is not the case. It was proved, however, by Hermann Minkowski (the Polish mathematician who made such great contributions to relativity theory) that all *shadows* of solids of constant width (when the projecting rays are parallel and the shadow falls on a plane perpendicular to the rays) are curves of the same constant width. All such shadows have equal perimeters (π times the width).

Michael Goldberg, an engineer with the Bureau of Naval Weapons in Washington, has written many papers on curves and solids of constant width, and he is recognized as being this country's leading expert on the subject. He has introduced the term "rotor" for any convex figure that can be rotated inside a polygon while at all times touching every side.

The Reuleaux triangle is, as we have seen, the rotor of least area in a square. The least-area rotor for the equilateral triangle is shown in the top illustration on page 156. This lens-shaped figure (it is not, of course, a curve of constant width)

Two solids of constant width



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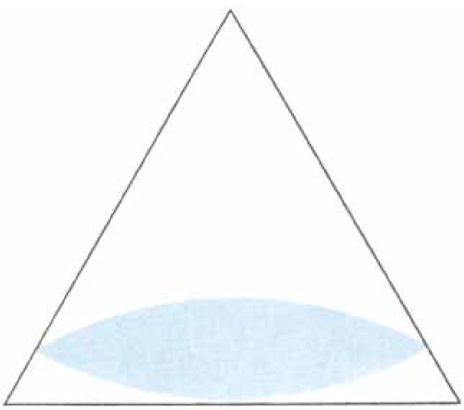
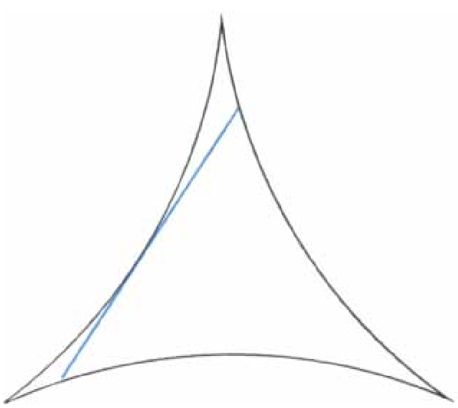
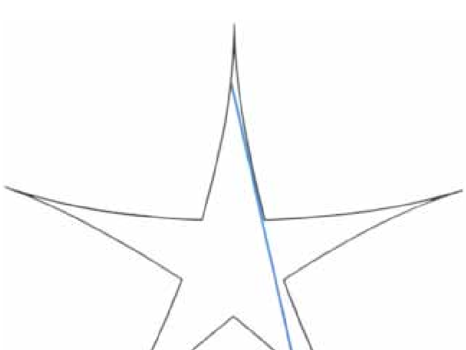
is formed with two 60-degree arcs of a circle having a radius equal to the triangle's altitude. Note that as it rotates its corners trace the entire boundary of the triangle, with no rounding of corners. Mechanical reasons make it difficult to rotate a drill based on this figure, but Watts Brothers makes other drills, based on rotors for higher-order regular polygons, that drill sharp-cornered holes in



Least-area rotor in equilateral triangle



Line rotated in deltoid curve



Besicovitch' proof

the shape of pentagons, hexagons and even octagons.

Closely related to the theory of rotors is a famous problem named the Kakeya needle problem after the Japanese mathematician Sôichi Kakeya, who first posed it in 1917. The problem is as follows: What is the plane figure of least area in which a line segment of length 1 can be rotated 360 degrees? The rotation obviously can be made inside a circle of unit diameter, but that is far from the smallest area.

For many years mathematicians believed the answer was the deltoid curve shown in the middle illustration on this page. (The deltoid is the curve traced by a point on the circumference of a circle as it rolls around the inside of a larger circle, when the diameter of the small circle is either one-third or two-thirds that of the larger one.) If you break a toothpick to the size of the line segment shown, you will find by experiment that it can be rotated inside the deltoid as a kind of one-dimensional rotor. Note how its end points remain at all times on the deltoid's perimeter.

In 1927, 10 years after Kakeya popped his question, the Russian mathematician Abram Samoilovitch Besicovitch (then living in Copenhagen) dropped a bombshell. He proved that the problem had no answer. More accurately, he showed that the answer to Kakeya's question is that there is *no* minimum area. The area can be made as small as one wants. Imagine a line segment that stretches from the earth to the moon. We can rotate it 360 degrees within an area as small as the area of a postage stamp. And if that is too large, we can reduce it to the area of Lincoln's nose on a postage stamp.

Besicovitch' proof is too complicated to give here, but one can get the general idea by studying the bottom illustration on this page (reproduced from C. Stanley Ogilvy's book *Through the Mathescope*). By sliding the line segment back and forth from point to point, it can be turned completely around within the figure, which has an area smaller than the deltoid. By increasing the number of cusps the area can be made as small as desired. Of course, as the area diminishes and the cusps increase we have to work longer in moving the line segment back and forth from cusp to cusp, but we can make the area as small as we please and still do the trick in a finite number of moves.

For readers who would like to work on a much simpler problem and one that *does* have an answer: What is the smallest *convex* area in which a line segment of length 1 can be rotated 360 degrees? (A convex figure is one in which a straight line, joining any two of its points, lies entirely on the figure. Squares and circles are convex; Greek crosses and crescent moons are not.) The answer will be given next month.

The answers to last month's problems follow.

1. To form the lowest integral fraction that will give a specified number as a repeating decimal (provided that the number does not consist entirely of 9's), draw a line beneath the number, then under the line place the same number of 9's as there are digits in the number. Reduce to lowest terms. Thus 27 is endlessly repeated as the quotient of 27/99, which reduces to 3/11.

2. Only four numbers are equal to the sum of the cubes of their digits: 153, 370, 371 and 407.

3. Dr. Matrix' cell number is 45. When a decimal point is placed between the digits, it becomes 4.5, the average of 4 and 5. The answer is unique.

4. The floor of Dr. Matrix' cell is three by six yards. The only other rectangle of integral sides, with a perimeter equal to area, is the four by four, but Dr. Matrix specifically stated that the floor was not square. The problem has historical interest. B. L. van der Waerden, in his beautiful book *Science Awakening*, quotes the following passage from Plutarch: "The Pythagoreans also have a horror for the number 17. For 17 lies exactly halfway between 16, which is a square, and the number 18, which is the double of a square, these two being the only two numbers representing areas for which the perimeter (of the rectangle) equals the area."

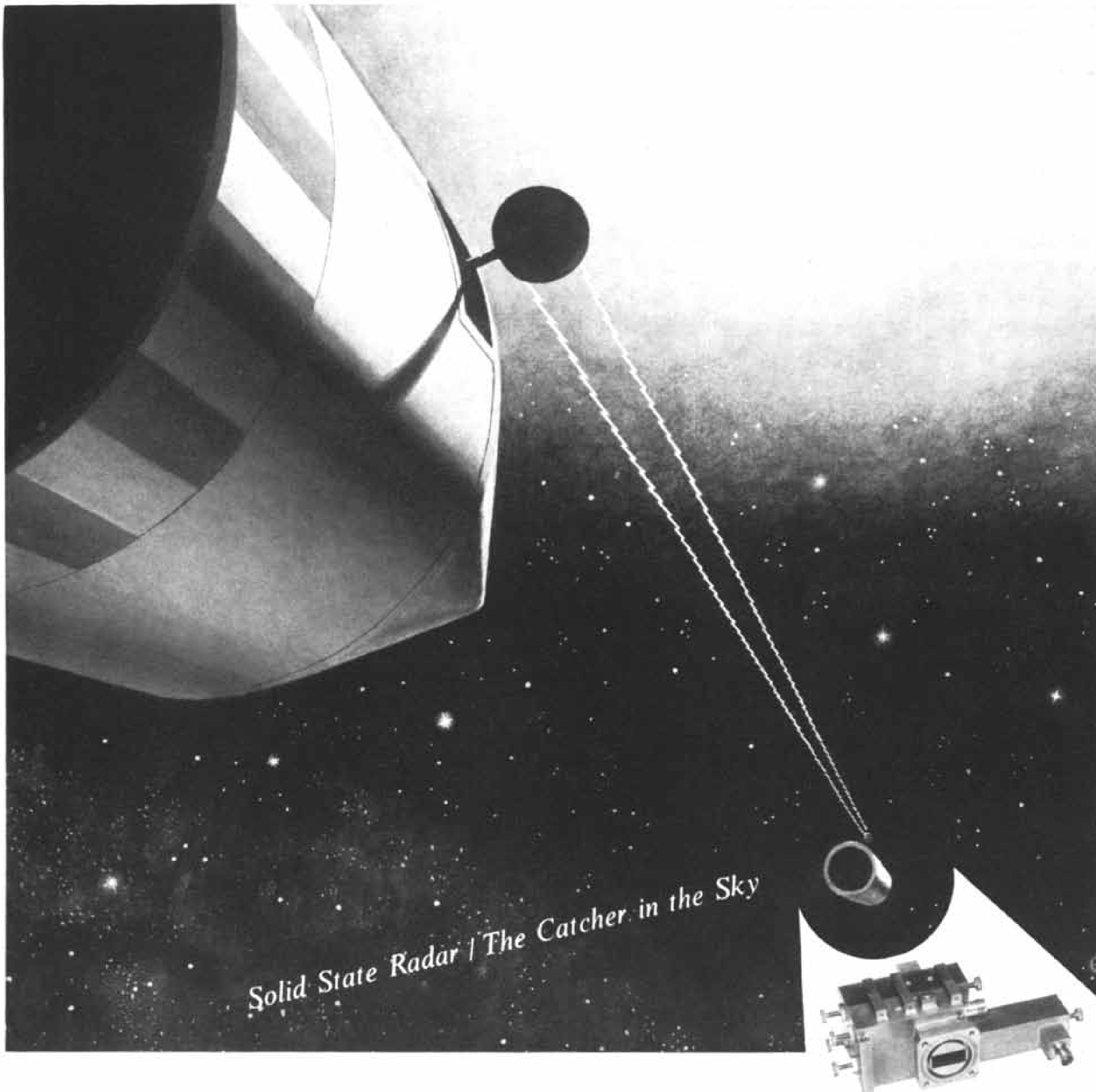
The problem yields readily to simple Diophantine analysis. Let x and y be the rectangle's sides. The area, xy, equals the perimeter, $2x + 2y$. When written like this,

$$y = 2 + \frac{4}{x - 2},$$

it is apparent that y is integral only if x is 3, 4 or 6. This leads to the two possible answers.

5. The letters of CHESTY can be rearranged to make only one other word: SCYTHE.

6. Iva Toshiyori's remark ("The day before yesterday I was 22, but next year I'll be 25") makes sense only if she made it on January 1 and her birthday is December 31.



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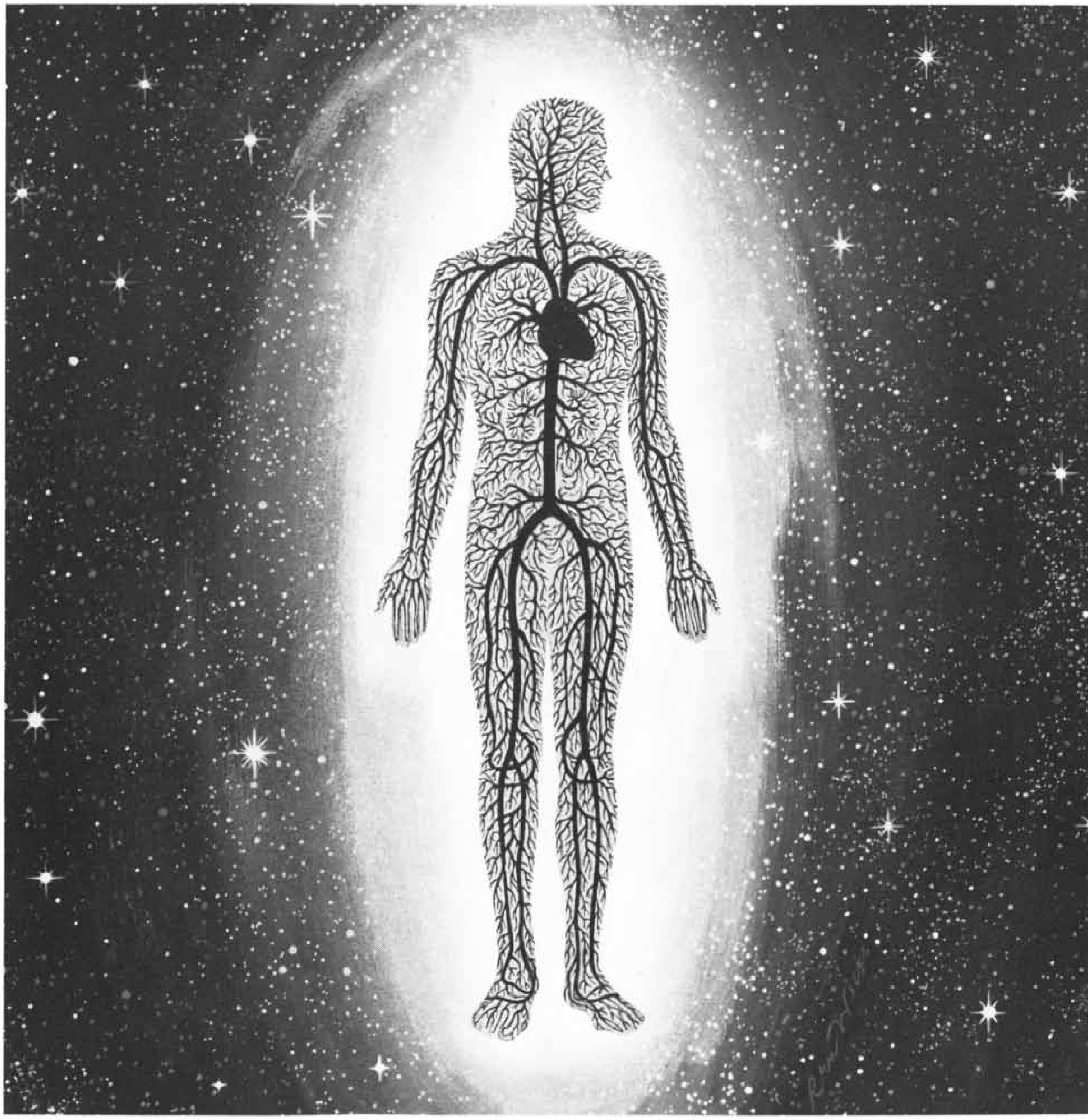


THE AMATEUR SCIENTIST

How to collect and preserve the delicate webs of spiders

Conducted by C. L. Stong

Almost everyone is fascinated by the marvelous geometry of certain spider webs, but almost no one has undertaken to collect such webs. The reason is not far to seek: spider webs are synonymous with insubstantiality, and cannot be gathered like sea shells. One solution to the problem has been devised by Laura Barr Lougee, a former director of design for the Cranbrook Institute of Science in Michigan who is now living and working in Parsonsfield, Me. Mrs. Lougee sprays the webs with lacquer and then lifts them from their moorings on a sheet of paper. By this expedient she has been able to spend many hours studying the logic of the webs. Mrs. Lougee writes: "Some of my museum work projected me into the role of a spider web fancier. As I began looking for webs, I soon realized that the world is festooned with silken threads spun into fantastic designs. They are on the inside and outside of buildings, between the stems of grasses, between branches and leaves and under the bark of trees. They are on the ground and under it and among rocks, even on a rocky seacoast, where they are suspended just out of reach of the tide.

"Each web is a functional structure whose purpose is to trap insects. Spiders are the world's most effective control of insect populations—far more efficient and less dangerous to man and other organisms than any insecticide. The spiders' traps are marvels of engineering. A basic type of structure is built by each genus of spider, but an individual spider adapts its architectural design and engineering plan to a particular environment. The site determines some of the structural elements. Inconsistencies are based on the outline of the site, on wind direction and wind speed, on intervening obstacles, on the amount of precipitation and on other modifying factors. As a result the foundation strands of the webs differ, and the spider spins its standard pattern within varying frameworks.

"Large spans require strong reinforcement, and in windy areas and along shores of lakes I have been able to collect with less breakage because there the webs are stronger than they are in the shelter of deep woods, even though the webs are built by the same genus of spider. Consideration seems to be given to the location that offers the best potential source of food. Lighted windows attract certain insects, and it is across these openings that hangs the 'orb web' spun by the spider *Araneus marmoreus* [*see illustration on next page*]. In the basement of a barn it is around a lone window that the orbs of this spider are strung; in the unlighted areas of the barn I have found only the haphazard strands of the spiders of the theridiid family. In a completely dark basement I have discovered no *Araneus marmoreus* webs but have seen many sheets spun by theridiids and the orb webs of the nearly blind cave spiders [*see top illustration on page 162*]. Apparently *Araneus marmoreus* seeks light and the insects that light attracts. Perhaps this indicates that different families of spiders prefer to eat particular kinds of insects.

"There is a rich variety in the design of spider webs. The design that is literally closest to home is the apparently tangled maze of the house spider *Theridium tepidariorum.* Actually this irregular mesh is based on a predetermined plan and is a most efficient trap.

"Some webs that are spun on the ground look like small glass carpets when they are wet with morning dew. These are sheets woven into funnels that lead down into the ground [*see middle illustration on page 162*]. Strands of silk are strung above each web; flying insects bump into them and drop into the trap below. Grass spiders (*Agelenidae*) work throughout the summer perfecting and strengthening their webs, until by fall the webs are at their peak of efficiency and beauty.

"Some spiders (genus *Erigone*) build sheet webs in bushes and tree branches. These are horizontal platforms with trip-threads crisscrossed above them. The spider waits under the floor and, as insects fall onto the trap, pulls them through the sheet. The rips are repaired immediately, with the result that the sheets last a long time.

"The woods in my locality are full of dome webs spun by *Linyphia marginata* that sparkle like silken parachutes among the branches of high trees and low shrubs. These are roofed-over sheet webs. The spider hangs under the dome to catch insects that land on top of the dome and also those that are knocked to the floor by the almost invisible threads strung between floor and ceiling [*see bottom illustration on page 162*].

"The triangle web is a compact, stripped-down structure and an ingenious trap. It is wedge-shaped and has four spokes radiating from a single strand [*see illustration on page 164*]. The builder of this neat and simple structure, a member of the genus *Hyptiotes,* waits on the slackened strand away from the web, and when an insect brushes against the threads, the spider vigorously pulls the guy line taut and shakes the web, thoroughly entangling the victim in sticky silk.

"The most spectacular webs are of course those spun by the orb weavers. The spokes of these webs are dry silk laced with spiral strands covered by viscous droplets. To form and space the drops evenly along the threads the weaver applies a widespread phenomenon of nature: the standing wave. First the spider attaches a thread coated with a thin glue to a radius, pulls it taut and attaches it to the next spoke. Then, before repeating the operation between the next two radii, the line is plucked as if it were a guitar string. The vibration sets up standing waves—evenly spaced intervals of maximum vibration along the fiber that are separated by nodes. The glue flows to the nodal points, where it collects as minute and remarkably uniform droplets.

"The fragile orb webs are often torn by insects, wind, rain and at least one

Orb web from a basement window

human female web collector, but the patient weavers rebuild as necessary, sometimes as often as once a day. After a driving rain that demolished virtually every web strung among the trees in our woods, I was able to collect samples of early phases of reconstruction within 10 minutes after the storm.

"Sometimes the long guy lines that sustain the orb itself are used by neighboring spiders as mutual supporting strands. It has been established that each spider's world is within the boundaries of its own snare. An orb spinner does not voluntarily leave the confines of its trap and there is no visiting among the spiders. In fact, a trespasser is quickly attacked. An interesting exception takes place during the mating season. During this period a male spider plucks the female's web in such a way that he is immediately recognized and not mistaken for prey.

"Orb webs come in many sizes; the size is in direct proportion to the length of the builder's legs. There are modifications in the hub designs constructed by the different varieties of orb spinners. Experienced observers can identify the builder by its handiwork. The accompanying webs show some typical patterns [*see page 166*].

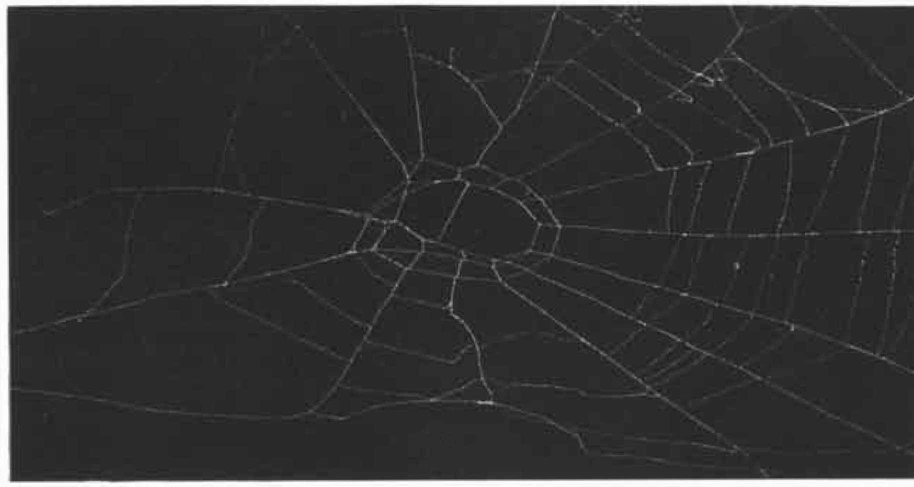
"My principal technique for collecting webs should be easy for anyone to master. I simply spray the web with lacquer and mount it on a sheet of paper. I trudge through the woods for hours carrying my spray can and searching for the virtually invisible silken traps. My middle-aged eyes require a bit of aid. At each likely web site I don my bifocals and examine what often turns out to be blank space. Staring into empty air at close range makes one feel ludicrous enough, but spraying that air with paint appears even more so to onlookers who cannot discern the beautiful patterns that occasionally materialize.

"There are many ways to collect webs, but with my technique the web is first sprayed with a color that will make a contrast with the chosen background for better visibility. The spraying must be done at quite a distance from the web or the jet of air may damage the structure. The color must be built up gradually with several thin coats of fine mist, so that the growing weight of the lacquer does not make the strands sag or otherwise disfigure the structure.

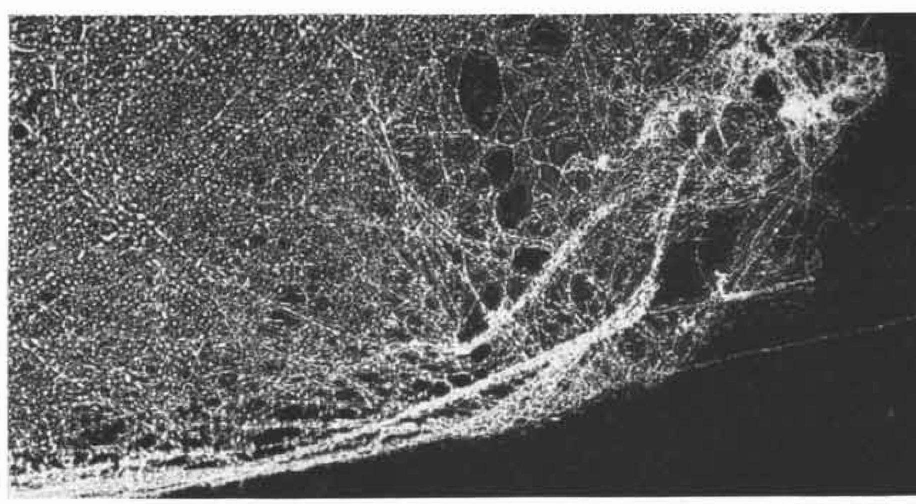
"After the web is colored a sheet of paper or cardboard is placed behind it; the web is composed against the sheet

and then the paper is carefully brought forward into contact with the fibers. The long structural strands are cut at the edges of the paper and the web is removed from its site.

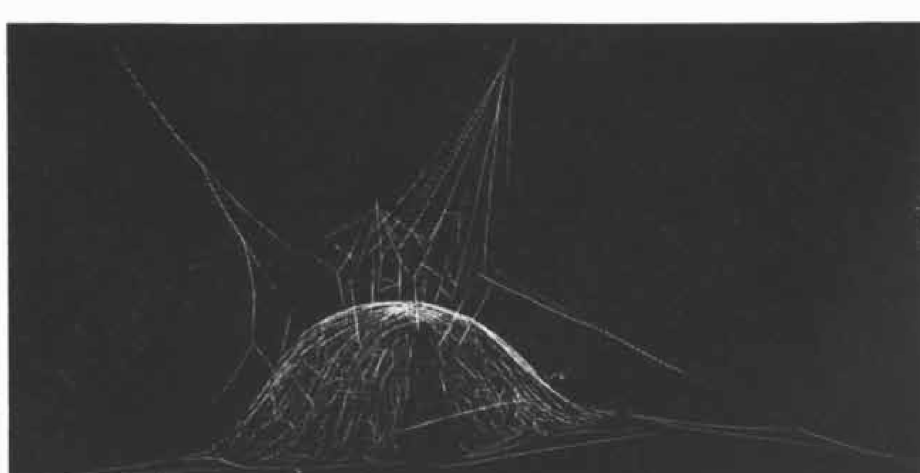
"There are a few pitfalls. Smooth paper presents problems; most webs do not cling to it readily. Such paper can be used if the rim of the sheet is sprayed with rubber cement. The tacky border will then catch and hold the radial strands. The instant any structural strands are broken or pulled out of alignment the entire web disintegrates. An-



Cave spider's orb web



Portion of sheet web enlarged about two diameters



Drawing of dome web

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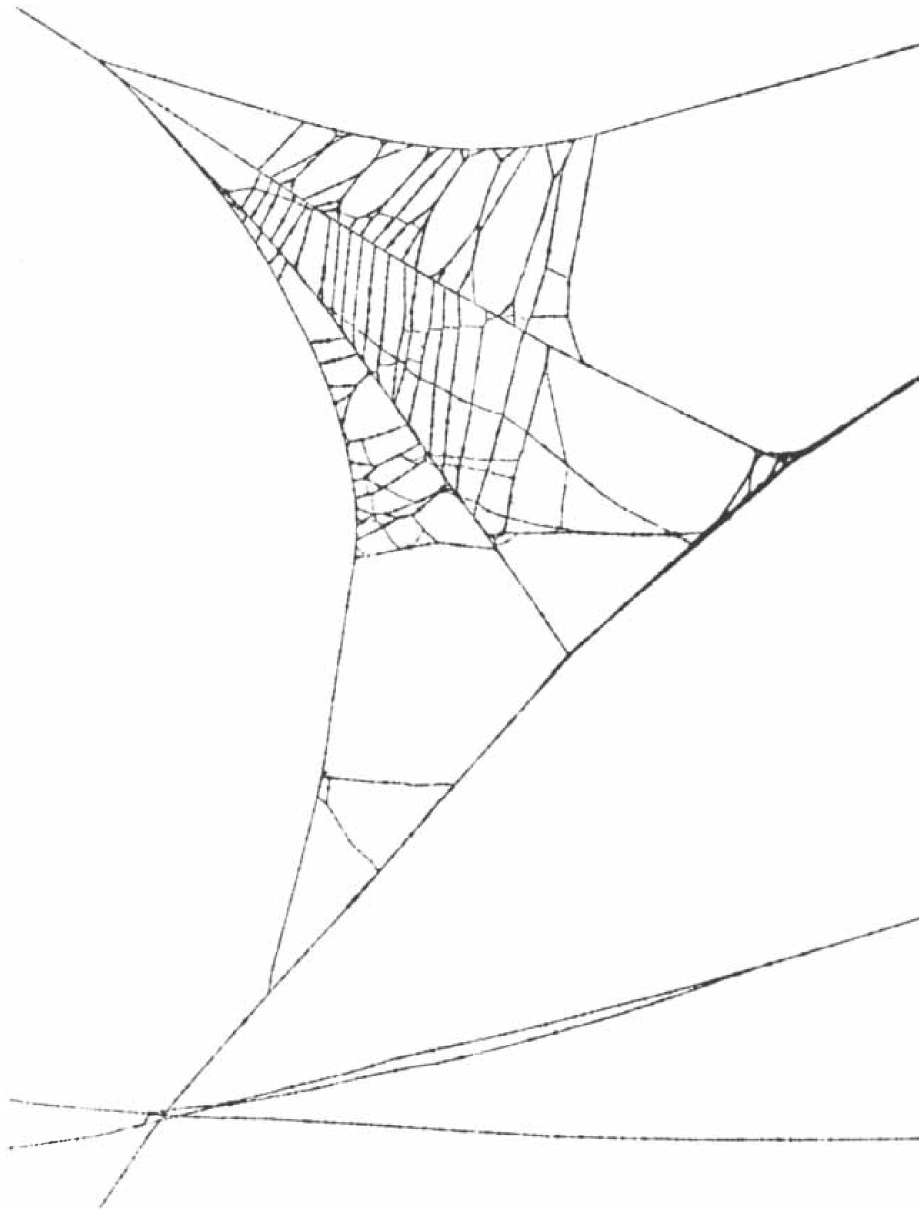


Triangle web

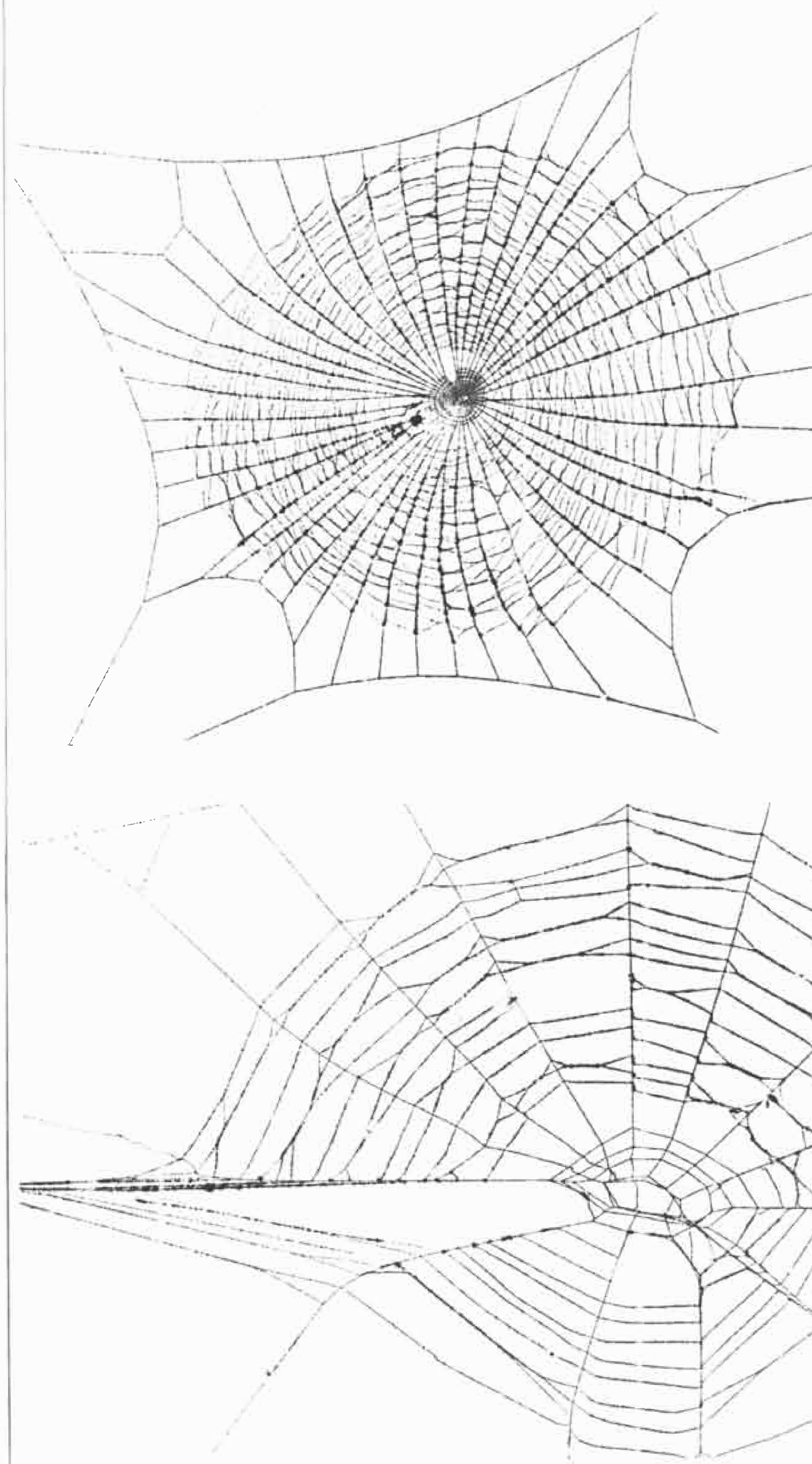
other way to assure adhesion to the background is to spray one side of the web with rubber cement before collecting it against the paper. Flocked paper makes one of the best background materials because the nap tends to hold the fragile silk in place. After the web is mounted on its background the entire sheet can be strengthened by spraying with clear Krylon or a similar plastic.

"Even people who abhor spiders acknowledge that spider webs are compositions of remarkable beauty when they are transferred from the corners of rooms and attic beams to backgrounds of color and placed in appropriate frames on walls. Demolishing webs may dismay the spiders, but it does not entirely dishearten them; they promptly rebuild the webs. Webs are expendable but spiders are not, so care should be taken to safeguard the lives of these hardworking creatures.

"It is particularly interesting to study the webs in relation to the species that spin them. At one point in the evolution of arachnology attempts were made to classify spiders by the type of web they weave. Subsequently it was found that some closely related species spin webs of radically different types and that some distantly related species construct similar webs. On the other hand, the web spun by a given spider is consistently characteristic of its species and even of the age of the spinner. Some adult orb weavers spin webs as large as nine feet in diameter; the young of the species make similar webs that measure only a few inches across. By collecting and cataloguing specimen webs in looseleaf binders it is possible to follow the growth and development of a species throughout a season. Unfortunately the existing collecting techniques preserve specimens in only two dimensions. This

works well in the case of orb, triangle and sheet webs. One wishes that a method could be developed for preserving the three-dimensional structures, such as funnel and dome webs, without distortion.

"Pending such a development, I shall continue collecting specimens in two dimensions. As one would suppose, my preoccupation has done little to enhance my reputation as wife, mother and housekeeper. After all, my investigations have put me squarely on the side of the much maligned spider. I have come to enjoy touting it as a benefactor to man and particularly to his wife."



Orb webs from deep in the woods (top) *and a windy lake shore* (bottom)

MATERIALS TECHNOLOGY

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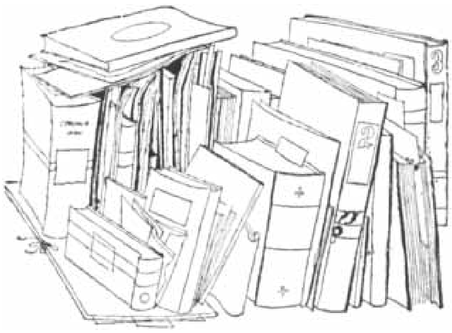

BOOKS

A debatable account of the origin of races

by Theodosius Dobzhansky

THE ORIGIN OF RACES, by Carleton S. Coon. Alfred A. Knopf, Inc. ($10).

The Origin of Races is an important book. It is also a controversial one. It is important because it provides a detailed and critical review of what is known about fossil man, and in such a way as to create order and a system in a field of study that has traditionally suffered from an accumulation of disconnected and undigested observations. It is the subject of controversy because Professor Coon states some of his conclusions in a way that makes his work susceptible to misuse by racists, white supremacists and other special pleaders. This misuse began even before the book was published, and it is continuing. Some of the points that cause the trouble are rather subtle, and they merit careful consideration and analysis.

Human evolution and human origins are naturally more interesting to most humans than the evolution of other organisms. It is hardly surprising, therefore, that a considerable effort has been made to find the fossil remains of men and their ancestors. Every scrap of bone that is found is studied and described in the minutest detail. Although human fossils are relatively rare, they have been unearthed at dozens of sites distributed over every continent except Antarctica. The remains of several hundred individuals are represented, often, of course, by different parts of the skeleton. The rate of discovery has been so high in recent years that it is not unreasonable to hope that future finds will throw new light on critical chapters in the story of human evolution. Of the 724 pages in Professor Coon's book, 438 (chapters 7 through 12) are devoted to a painstaking description of the available hominid fossils. This is unquestionably the most valuable part of the book; no other work in English, nor as far as I know any in another language, gives as complete and up-to-date an account of the matter. The introductory chapters (1 through 6) outline the principles of the theory of evolution, particularly as it applies to man, and review briefly the living and fossil primates and man's relation to them. A short 13th chapter summarizes the conclusions. Professor Coon is an experienced and clear writer; the bones he describes may be as dry as dust, but his account of them is so engrossing that the interest of the reader will not flag.

The interest of humans in human evolution is not, however, an unadulterated blessing. Investigators working in this field are often tempted to draw from the bones they study conclusions that these scraps of evidence cannot really support. One difficulty, which at first might seem unimportant, is that the discoverers of hominid fossils like to give to their finds generic and specific names in Latin. The name *Pithecanthropus erectus* is assigned to fossils found in Java; *Sinanthropus pekinensis,* to those found in the vicinity of Peking. Did the Java and Peking men belong to different zoological genera and species? Not at all; judging from their bones they differed only about as much as do some of the races of men now living. Neanderthal man has been assigned to the separate species *Homo neanderthalensis,* and on occasion even to a separate genus, *Protanthropus neanderthalensis.* On the basis of Latin names it appears that there existed some two dozen hominid species and genera during the geologically rather short Pleistocene epoch.

Does it really matter what Latin name one bestows on a fossil? Unfortunately it does. It flatters the discoverer's ego to have found a new hominid genus, or at least a new species, rather than a mere new race. But generic and specific names are not just arbitrary labels; they imply a biological status. Living men constitute a single species: *Homo sapiens.* Now, *Homo sapiens* can be descended from only one ancestral species living at any given time in the past. To be sure, some plant species arise from the hybridization of two ancestral species, followed by a doubling of the complement of chromosomes, but it is most unlikely that mankind could have arisen by such a process. It follows, then, that if two or several hominid species lived at a given time in the past, only one of them can possibly be our ancestor. All other species must be assumed to have died out without leaving descendants.

This creates an issue that for years was quite troublesome to students of human origins. Consider, for example, the fact that in Europe some 30,000 years ago Neanderthal man was replaced by men whose bones so closely resemble our own that almost all authorities consider them a race of *Homo sapiens.* If the Neanderthalers belonged to a really different species, they were probably wiped out by *Homo sapiens.* If, however, this was an early episode of genocide, where did the invading *Homo sapiens* come from? The rest of the world was at that time, and in earlier times, inhabited by hominids with other specific or generic names. There are similar puzzles to be found in other parts of the world; to give just one more example, what happened to Peking man, and where did the ancestors of the present inhabitants of eastern Asia come from?

A solution to these puzzles was suggested about two decades ago by the eminent human anatomist and paleontologist Franz Weidenreich. He realized that, in spite of the riot of Latin names given to the fossils, the world was inhabited, at least since the middle Pleistocene, by only one human or prehuman species at any one time. Our middle Pleistocene ancestors all belonged to a species that we may call *Homo erectus.* In time this species was gradually transformed into *Homo sapiens.* Weidenreich's solution seemed rather too radical to some authorities, but it was accepted by Professor Coon and others, including this reviewer. Coon has acknowledged Weidenreich's contribution by dedicating his book to Weidenreich's memory.

As so often happens in science, the solving of one problem opens up several new ones. Living men are a single species, but men in different parts of the world are not alike. Most biological species are composed of races, and *Homo sapiens* is no exception. Even though *Homo erectus* inhabited a much smaller territory than *Homo sapiens* (for example, it did not colonize the New World), there were also races of *Homo erectus*. Two of these races have been mentioned above: *Homo erectus erectus* of Java and *Homo erectus pekinensis* of China. In comparing the races of *erectus* with those of *sapiens* Weidenreich noted that the bones of Java man have some features in common with those of modern Australoids, and that Peking man shares some skeletal traits with Mongoloids. Weidenreich's idea has been developed much further by Coon. It is, in fact, pivotal to his interpretation of human evolution as presented in his book. This interpretation may well be right, although it is certainly not proved, and specialists will dispute him on many of its points. What is important is how he states it.

Coon divides living *Homo sapiens* into five races, or "subspecies": Australoids, Mongoloids, Caucasoids, Congoids (African Negroes) and Capoids (Bushmen and Hottentots). He thinks that these races have existed for a very long time; indeed, he believes that some of their skeletal traits were present in the races of the ancestral species *Homo erectus*. Following Weidenreich, Coon connects the Australoid race of *sapiens* with the Java race of *erectus* and the Mongoloid race with the race *erectus pekinensis;* similarly, the Caucasoid race of *sapiens* is linked to a European form of *erectus* and to the early Neanderthalers, and the Congoid race to the Rhodesian man, who becomes *Homo erectus rhodesiensis*.

So far so good. Now, however, Coon says: "*Homo erectus* then evolved into *Homo sapiens* not once but five times, as each subspecies, living in its own territory, passed a critical threshold from a more brutal to a more *sapient* state." Moreover, they passed this "threshold" at different times, the Caucasoid race becoming *sapiens* first, during the second interglacial period, whereas the Congoids arrived in the *sapiens* fold some 200,000 years later, or only 40,000 to 50,000 years ago. At this point Coon leaps straight from bones to culture. To him it is "a fair inference that fossil men now extinct were less gifted than their descendants who have larger brains, that the subspecies which crossed the evolutionary threshold into the category of *Homo sapiens* the earliest have evolved the most, and that the obvious correlation between the length of time a subspecies has been in the *sapiens* state and the levels of civilization attained by some of its populations may be related phenomena." He relents somewhat on the last page of the book and points out that until recently all five "subspecies" of *Homo sapiens* included some populations living as hunters and gatherers, and that some of the most backward populations belonged to the putatively advanced Mongoloid and Caucasoid subspecies.

Can these sweeping conclusions be sustained? The arguments in favor of the view that there were exactly five races of *Homo erectus* and that there are exactly five living races of *Homo sapiens* are not convincing, let alone conclusive. A race is an entity that is not clearly defined biologically. The number of races of living men has been set by different anthropologists anywhere from two to more than 200. In a book published by Coon jointly with Stanley M. Garn and Joseph B. Birdsell in 1950 the number of "racial stocks" is given as 30. In a more recent book Garn recognizes nine "geographical races" and 32 "local races." As noted above, Coon calls his five races "subspecies." This is a term used in zoological systematics but not in anthropological; however, a subspecies is merely a race given a name in Latin in accordance with the rules of zoological nomenclature. It is biologically no more and no less clearly defined. The fivefold division encounters just as many difficulties as all the others; for example, Coon places the Polynesians in his Mongoloid subspecies and the Melanesians in his Australoid, a far from convincing arrangement. When it comes to *Homo erectus*, the basis for assuming five subspecies is flimsy in the extreme.

Let us suppose, for the sake of argument, that *Homo sapiens* consists of exactly five subspecies, and that there were just five subspecies of *Homo erectus*. What, then, is the meaning of the claim that *erectus* evolved into *sapiens* not once but five times? Coon's interpretation is, as he acknowledges, an extension of that of Weidenreich. But this is not a matter of priority; it is something more important. Weidenreich was an adherent of the theory of orthogenesis, according to which evolutionary changes are directed from within the organism by a sort of inner urge. To Weidenreich the name *Homo erectus* stood for a stage in the evolutionary progression of the hominid stock; a race of *erectus*, if it survived at all, was predestined to evolve into *sapiens*. Today most evolutionists consider the theory of orthogenesis obsolete. Coon, in the second and third chapters of his book, interprets the evolutionary development of the human stock in terms of the modern biological theory of evolution. Evolution is not orthogenesis; the directing agency of evolution is natural selection, which makes a living species respond to the challenges of its environment by genetic modifications. The independent but parallel development of five separate lines into a single species is no less puzzling than the old "*sapiens* problem," which arose, as we have seen, because the discoverers of human fossils were overgenerous in assigning generic and specific names.

It *is* a fair inference that *Homo sapiens* is genetically better adapted to human ways of life than *Homo erectus* was. We can agree with Coon that natural selection has favored, in human races everywhere in the world, a *sapiens*-like genotype over the *erectus*-like one. This can be stated most clearly as follows. The transformation of prehuman populations into human populations involved a feedback process between the genotype and the environment; *sapiens* genes favored the development of capacities for symbolic thinking, language and eventually for civilization. These human adaptations in turn made human genes essential for survival and opened the way for further adaptations.

The possibility that the genetic system of living men, *Homo sapiens*, could have independently arisen five times, or even twice, is vanishingly small. A biological species can be likened to a cable consisting of many strands; the strands—populations, tribes and races—may in the course of time subdivide, branch or fuse; some of them may fade away and others may become more vigorous and multiply. It is, however, the whole species that is eventually transformed into a new species. Adaptively valuable gene patterns arise in different populations of the species. The populations, or races, in which these evolutionary inventions have occurred then increase in number, spread, come in contact with other populations, hybridize with them, form superior new gene patterns that spread from new centers and thus continue the process of change. Coon is too competent an anthropologist not to know that man is, and apparently always was, a wanderer and a colonizer, and that as people come in contact gene exchange takes place. But if this is true, the assumed separate evolution of the five subspecies becomes a practical impossibility. Coon believes that the ancestors of his Capoid race lived in Africa somewhere to the north of the ancestors of the Congoid race. At present the Capoids live to the

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south of the Congoids. Are we to assume that these peoples practiced racial segregation during their wanderings?

Organizations engaged in propaganda against the desegregation decision of the Supreme Court have seized on the supposed demonstration that Negroes are some 200,000 years behind the whites in their evolutionary development. What Coon himself says is that some of his subspecies, particularly the Caucasoid and the Mongoloid, ceased to be *Homo erectus* and became *Homo sapiens* much earlier than the other subspecies. He does not, however, contend that the transition from *erectus* to *sapiens* was sudden or instantaneous. Assigning a date to this transition is therefore a ticklish task. Since the transition was gradual, cutting a continuous process into two or more sections called "species" is arbitrary. Coon so chooses his criteria for the application of the names *erectus* and *sapiens* that the latter appears to be much more ancient in Europe than it is in Africa. Other anthropologists will dispute his choices. For example, the fossils of Solo man in Java and of Broken Hill man in Africa are classified by Coon as *erectus,* whereas others classify them as *sapiens*. These remains are geologically rather recent, which in Coon's view indicates that the transition from *erectus* to *sapiens* occurred much later in Java and in Africa than it did in Europe. Coon seems not to notice that this leads him into a major inconsistency. His classification makes *Homo erectus* contemporaneous with *Homo sapiens* for some 200,000 years, although the two lived in different parts of the world. The division of an evolutionary line into species succeeding each other in time is arbitrary, but the division of contemporaneous forms into species is not. If *erectus* lived at the same time as *sapiens,* it must have been genetically isolated from *sapiens*. Yet its modern descendants are not genetically isolated; they belong to the same species. For a single species to have arisen from two species that could not interbreed would indeed be extraordinary.

Attempts to assign dates to *Homo erectus'* becoming *Homo sapiens* in Europe, in Africa or elsewhere are misleading in another respect. The transmutation of *erectus* into *sapiens* is not like receiving an academic degree or being admitted to an exclusive club. One basic consideration that should always be kept in mind is that evolution is a continuous process. Suppose the skeletal characteristics that are chosen as being characteristic of *erectus* make us label the bones of an individual who lived in Africa 40,000 years ago as belonging to that species. It surely does not follow that this *erectus* resembled in every respect, including its mental capacities, all other members of the species that lived in Europe and elsewhere at much earlier times. If it were true that the Caucasoids 200,000 years ago attained the state that the Congoids achieved only 40,000 years ago, would it not follow that the rate of the evolutionary development of the Congoids was since then about five times faster than that of the Caucasoids? This is surely not a conclusion that white supremacists would embrace with pleasure.

Professor Coon's book will stand as a milestone in the study of fossil man. Specialists will dispute many of his interpretations of particular fossils, and new discoveries will almost certainly change many parts of the picture. But after Coon the hodgepodge of species and genera of fossil hominids will give way to a biologically more meaningful system. Mankind is and was, at least from the middle Pleistocene to the present time, a single polytypic species consisting of varying numbers of races of varying degrees of distinctness. It is most unfortunate that some semantic mischief in Coon's work has made it usable as grist for racist mills. A scientist should not and cannot eschew studies on the racial differentiation of mankind, or examine all possible hypotheses about it, for fear that his work will be misused. But neither can he disclaim all responsibility for such misuses. Scientists living in ivory towers are quaint relics of a bygone age. The work and writing of scientists is used, and anthropology—the science of man—is particularly vulnerable to misuse. Race prejudice is a psychological and social disease and is not based on reason, yet those who suffer from it have repeatedly sought the support of bogus "science." There are absolutely no findings in Coon's book that even suggest that some human races are superior or inferior to others in their capacity for culture or civilization. There are, however, some unfortunate misstatements that are susceptible to such misinterpretation.

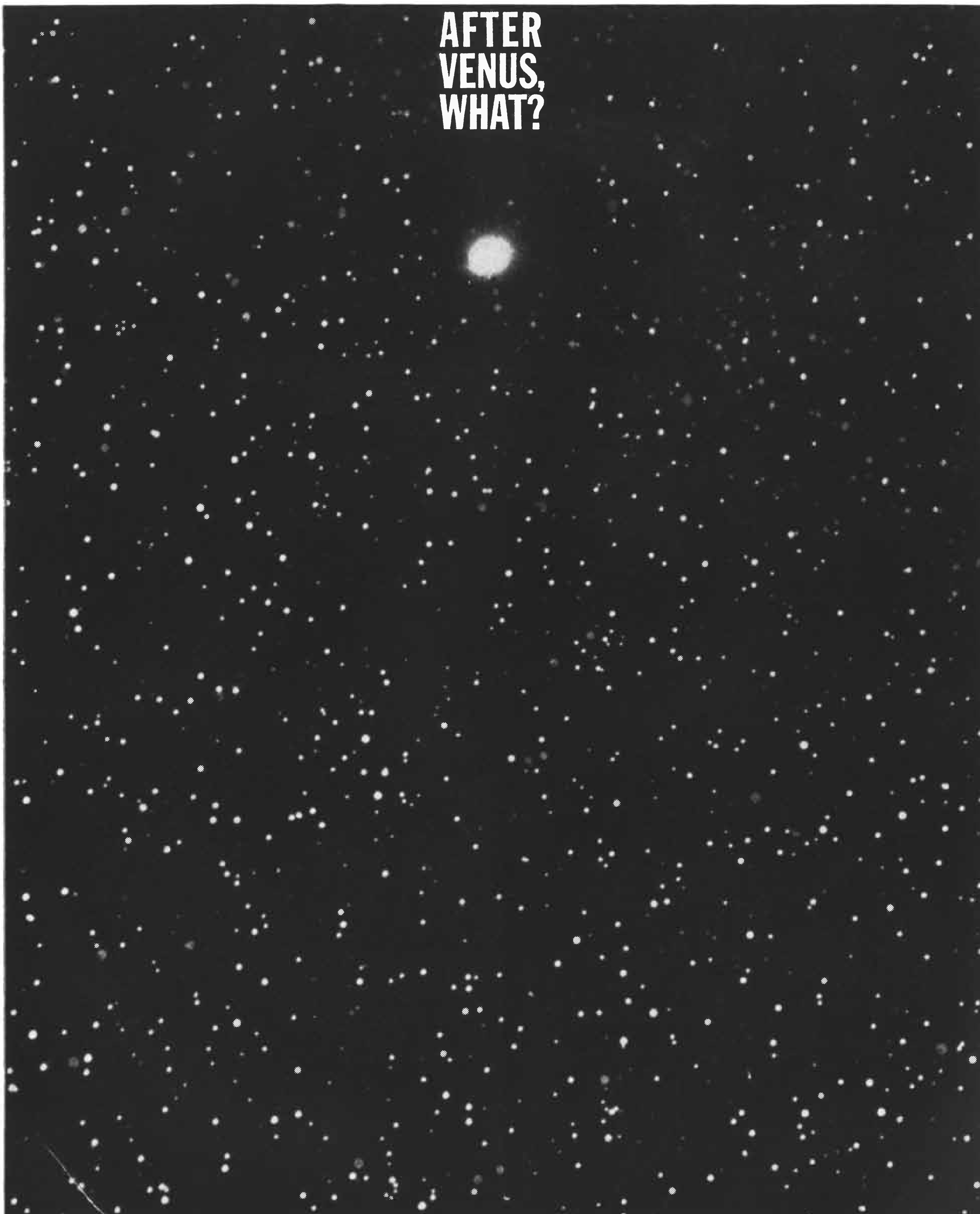
Short Reviews

KILL AND OVERKILL: THE STRATEGY OF ANNIHILATION, by Ralph E. Lapp. Basic Books, Inc. ($4.95). A fluent, knowledgeable, impressive account of U.S. nuclear policy and practices over the past 17 years. Lapp has done this kind of thing before, as have others, but the case has never been put so powerfully. His point of departure is the build-up of arms that has brought us to the stage where our stockpile of nuclear weapons has been estimated at an equivalent of 30,000 megatons of TNT —10 tons for every human being on earth. A speech made early in 1960 by the then Senator John F. Kennedy provided this information and denounced the policy; yet the factories that make nuclear explosives are running night and day, and the rate of our weapons production is still accelerating.

Lapp points to the marriage of science and politics, with neither partner understanding or trusting the other yet dependent on it. He quotes Harrison Brown's comment that "tens of thousands of scientists and technicians have devoted all of their professional lives to the invention and construction of weapons. A majority of those who went to work after World War II are convinced that weaponry is a way of life for themselves and expect the United States–Soviet contest to continue forever." He assesses the nature of blast, fire and fallout that would accompany a nuclear war and asserts that civil defense officials and others in government have misled the public as to the true state of things. He describes the game of nuclear war as being played by men with the emotional maturity of computers and by computers with the moral sensibilities of their users. The language devised for these games mirrors the players: "population response" (a "protective euphemism for slaughter"), "megadeaths," "bonus kills" (deaths from fallout) and so on.

Does "deterrence" have any meaning, Lapp asks, as tensions build, as human behavior falls increasingly under stress, as the temptation grows to strike the opponent a knockout blow before he has a chance to retaliate? When missiles can be sent across oceans from one continent to another in less than 30 minutes, is there time for a rational decision? Under such circumstances deterrence itself becomes a kind of race, with each competitor ever ready to jump the gun so as to be first off the mark lest he never get started. Effective missile defenses are not remotely within sight; able scientists who have worked on the problem—Hans Bethe and the late John von Neumann among them—have expressed no doubt on this score. But vast sums are being spent on this will-o'-the-wisp, and vain hopes of salvation are encouraged.

Lapp admits that he has always been an advocate of civil defense, but in this book his heart is obviously no longer in the shelter. Indeed, he says that a large-scale shelter program might intensify the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arms race, become a strategic weapon, make the combatants more reckless. "In the last analysis, the only shelter, the only defense, in which mankind can find any real, enduring hope is disarmament."

Lapp devotes the last chapter of his book to recommendations of what the U.S. might do unilaterally to slow the arms race: revise the missile program to make the force truly retaliatory (place our main reliance on Polaris submarines); stop future production of bomb material ("We already have enough nuclear explosives to overkill the Soviet Union at least 25 times"); declare the realm of space out of bounds for military operations; establish an international communications system that would help to prevent an accidental war; make a study under the auspices of the United Nations of the effects of a nuclear war, and publish the results for the enlightenment of everyone.

Science and Civilisation in China. Volume IV: Physics and Physical Technology; Part 1: Physics, by Joseph Needham with the collaboration of Wang Ling and the special co-operation of Kenneth Girdwood Robinson. Cambridge University Press ($15). "China to Europeans," writes Needham in his introduction to the fourth volume of his monumental survey, "has been like the moon, always showing the same face—a myriad peasant-farmers, a scattering of artists and recluses, an urban minority of scholars, mandarins and shopkeepers. Thus do civilisations acquire 'stereotypes' of one another." Here, with undiminished energy and enthusiasm, he continues to demolish the stereotypes, to carry forward his huge program of historical revision. The subjects are mechanics and dynamics, the physics of heat, light, sound, magnetism and electricity. Chinese physical thought and practice in these departments were both highly uneven and shaped by certain characteristic traditions. Just as their mathematics was algebraic rather than geometric, Chinese physics was wedded to a "prototypic wave-theory and perennially averse to atoms, always envisaging an almost Stoic continuum." These tendencies and predilections sometimes promoted but more often retarded their understanding of how things work. Mechanics was weakly studied and formulated; Chinese accomplishments in dynamics are entirely negligible. On the other hand, optics, acoustics and magnetism were well developed, the crown of their labors in these branches being the invention of the magnetic compass, which took place no later than 1080, a century earlier than the first European mention of the instrument.

This volume, reasonable in size and weight (in response to the complaints of faithful readers who found that some of its predecessors were so massive that they could scarcely be read without danger to life or limb except on a lectern), is an edifying achievement. It is a mixture of solid historical fact, profound scientific understanding and interpretation, discursive conjectures and speculations, curiosities and paradoxes, special pleading and disinterested reasoning. One can learn how glass was made, how the "commissioners for shadow measurement" established stations to determine summer and winter solstice shadows, how the Chinese designed musical instruments, how they made lenses and mirrors (including the extraordinary mirrors of unequal curvature, known as magic mirrors, the reflecting surface of which reproduced the design on the back), eyeglasses and spectacles. One's fancy is caught by such items as Chhen Yuan-Ching's encyclopedia entitled "Guide through the Forest of Affairs," and particularly by a volume on geomantics and its relation to problems of navigation, *The Nine-Heaven Mysterious-Girl Blue-Bag Sea Angle Manual*.

Mostly one is enthralled by Needham's tracing of the origins and development of the magnetic compass. Here he really lets himself go, and the reader is swept along with him. It is too good a story, and too complex, to permit of a brief summary. But the reviewer cannot refrain from at least mentioning that the Chinese compass, and the Chinese work on magnetism, touched on or involved the following ideas and devices: a diviner's board used with, or related to, "a technique which consisted in throwing a set of chessmen on a board and noting where they came to rest, these pieces being identified with various celestial bodies"; the discovery of the directive power of a lodestone; the decision to make some of the chessmen of lodestone because of its obviously magic attractive power; the decision to model the constellation of the Great Bear in magnetite in the shape of a spoon (which because of its bowl would pivot when thrown on a board); the final idea of cutting out the spoon in an oriented direction. These steps, part of a sequence of magic hocus-pocus, were the forerunners of the magnetic compass—an amazing offspring of astronomy and astrology, divination, chess, combat and gambling games. Only for those who have no acquaintance with the earlier volumes of Needham's great work is it necessary to point out that this

volume, like the earlier ones, is superbly illustrated, supported by hundreds of charts, diagrams and tables and equipped with a formidable bibliographical apparatus worthy in every way of a people who 1,000 years ago were already producing 1,000-volume encyclopedias.

MATHEMATICS FOR PLEASURE, by Oswald Jacoby, with William H. Benson. McGraw-Hill Book Co., Inc. ($4.95). The senior author (a topflight card player and an actuary) and his collaborator (a teacher of mathematics at Dickinson College) have put together an above-average collection of mathematical puzzles. Five main categories are represented: puzzles, algebraic problems, explorations in probability, inference and reasoning conundrums, Diophantine equations. The types of problem considered are familiar and conventional, and not a few are taken from a well-known problem composer, Hubert Phillips of London ("Caliban"), but many of the exercises require very hard thinking. The authors are to be particularly commended for the full, satisfyingly explicit solutions.

THE MATHEMATICAL MAGPIE, assembled and edited by Clifton Fadiman. Simon and Schuster, Inc. ($4.95). A collection of short stories, essays, epigrams, cartoons, verse and assorted oddments, each of which has something to do with mathematics. What guides a magpie in its choice of baubles and gewgaws is beyond the science of ethology; no less puzzling is Fadiman's collection, beyond the fact that, although he is, in his own words, no mathematician, he finds everything about the subject fascinating. The result is not nearly so happy as his preceding anthology, *Fantasia Mathematica.* Many of the selections are so dull that a man of Fadiman's taste and discrimination would not have deigned to sniff at, let alone admire, them if they hadn't had something to do with shapes or numbers or symbols.

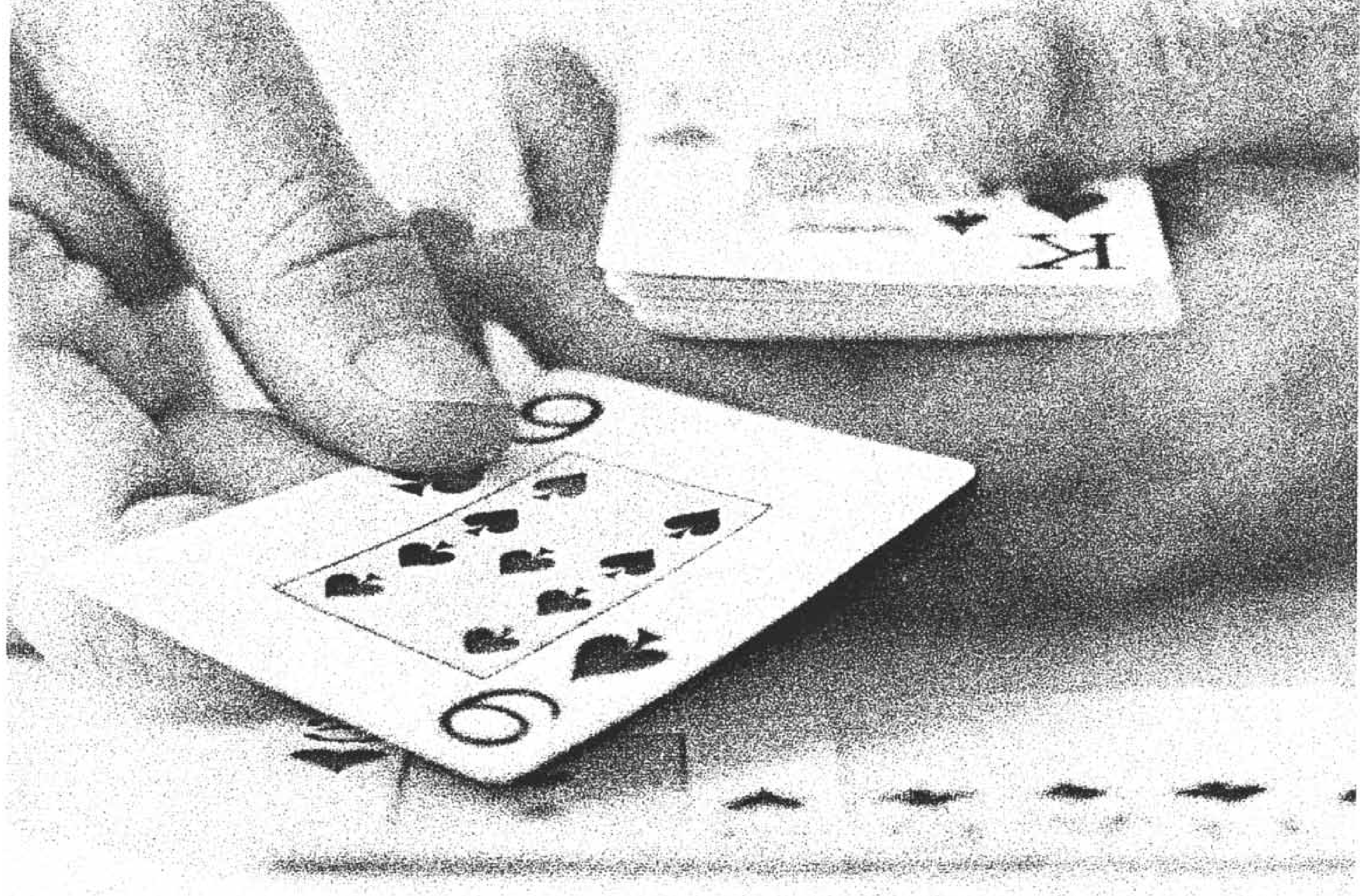
SLEEPING AND WAKING, by Ian Oswald. American Elsevier Publishing Company, Inc. ($7.50). Knitting up the raveled sleeve of care is no simple matter, as any insomniac can testify and as this fascinating book confirms. It considers a broad range of topics such as the physiological basis of sleep, sleep and consciousness, sleep and imagery, the borderland between sleep and waking, the nature of dreams, sleep as a provoked response (e.g., by emotion, monotony, hypnosis or "brainwashing"), the effects of lack of sleep, insomnia, sleep therapy. Many sections of the book—for example those that deal with the electroencephalographic features of sleep, sensory thresholds, the decline of cerebral vigilance, movement in sleep, muscular tonus—are addressed to the specialist and are technical. But there are other parts that almost anyone will find engrossing. It can safely be said that the one thing the book will not do is put you to sleep.

THE EYE: VOLUMES II, III and IV, edited by Hugh Davson. Academic Press ($48). These three volumes complete a spacious survey of the physiology of the eye. Volume I, previously reviewed in this department, deals with the basic physiology and biochemistry of vision; Volume II considers the visual process; Volume III treats of the muscular mechanisms: movements of the eye, accommodation of the pupil, and secretion of tears and blinking; Volume IV concerns itself with visual optics and the optical space sense. A major technical work for research workers and teachers of physiology, psychology and ophthalmology.

THE PHYSICS OF RAINCLOUDS, by N. H. Fletcher. Cambridge University Press ($11.50). An up-to-date, technical survey of the physical processes that occur in rainclouds, together with some discussion of rain-making techniques. A good deal of research has been done in this field in the past 15 years with the help of radar and aircraft, particularly in Australia. Much of this volume is based on the author's firsthand knowledge of the Australian researches. Illustrations and an extensive bibliography.

STRUCTURE AND FORM IN MODERN ARCHITECTURE, by Curt Siegel. Reinhold Publishing Corporation ($16.50). An illustrated survey that examines the influence of modern construction techniques on architectural design. Diagrams and photographs convey a notion of principles, aesthetic aims, the new uses of materials and related matters, and with the text effectively help to explain how such systems as skeleton construction, V-shaped supports and space structures express the fundamental laws of statics and mechanics.

TIME AND ITS MYSTERIES. Collier Books (95 cents). A paper-backed reprint of eight lectures given under the auspices of the James Arthur Foundation of New York University, originally published as two volumes. It includes several good essays on topics such as the nature



of time (Robert A. Millikan), the lifetime of a galaxy (Harlow Shapley), the beginnings of time measurement (James H. Breasted), time and individuality (John Dewey), time and the growth of physics (Arthur Holly Compton). Although the lectures were delivered 20 or more years ago, and time itself seems to have accelerated in the nuclear age, the essence of the subject remains as difficult and elusive, as confounding to scientists, philosophers and plain men as it has ever been, and it is gratifying to have these two hard-to-find little volumes back in print.

THE WORLD OF ICE, by James L. Dyson. Alfred A. Knopf, Inc. ($6.95). An attractively written account of the world of ice: snow, glaciers, polar ice packs, icebergs, life under the ice, the effect of ice on the climate, the landscape, the water supply. The author, a geologist and geographer who knows his subject thoroughly, writes about it clearly and entertainingly and has enhanced the value of his book by fine photographs, a useful bibliography and a glossary.

AUBREY'S BRIEF LIVES, edited by Oliver Lawson Dick. The University of Michigan Press ($2.25). This Ann Arbor paperback makes available at a modest price a delightful and fascinating collection of biographical sketches of 16th- and 17th-century figures, from scholars and philosophers to soldiers and whores. In John Aubrey's collection of truths there are almost as many lies, but this makes not the slightest difference. The book is a treasure.

REFLECTIONS ON HUMAN NATURE, by Arthur O. Lovejoy. The Johns Hopkins Press ($4.75). A distinguished American historian of philosophy and ideas presents a group of lectures, originally delivered at Swarthmore College in 1941, that are mainly concerned with the developments and changes in the concept of human nature through the 17th and 18th centuries. Lovejoy is not only immensely learned and thoughtful but also quite incapable of being pedantic or dull. This book offers edification to any thoughtful reader.

OXFORD ILLUSTRATED DICTIONARY, edited by Jessie Coulson, C. T. Carr, Lucy Hutchinson and Dorothy Eagle. Oxford University Press ($12.50). This is the first Oxford illustrated dictionary. It contains some 1,700 text figures of plant and animal forms, machines, architectural details, geometric shapes and

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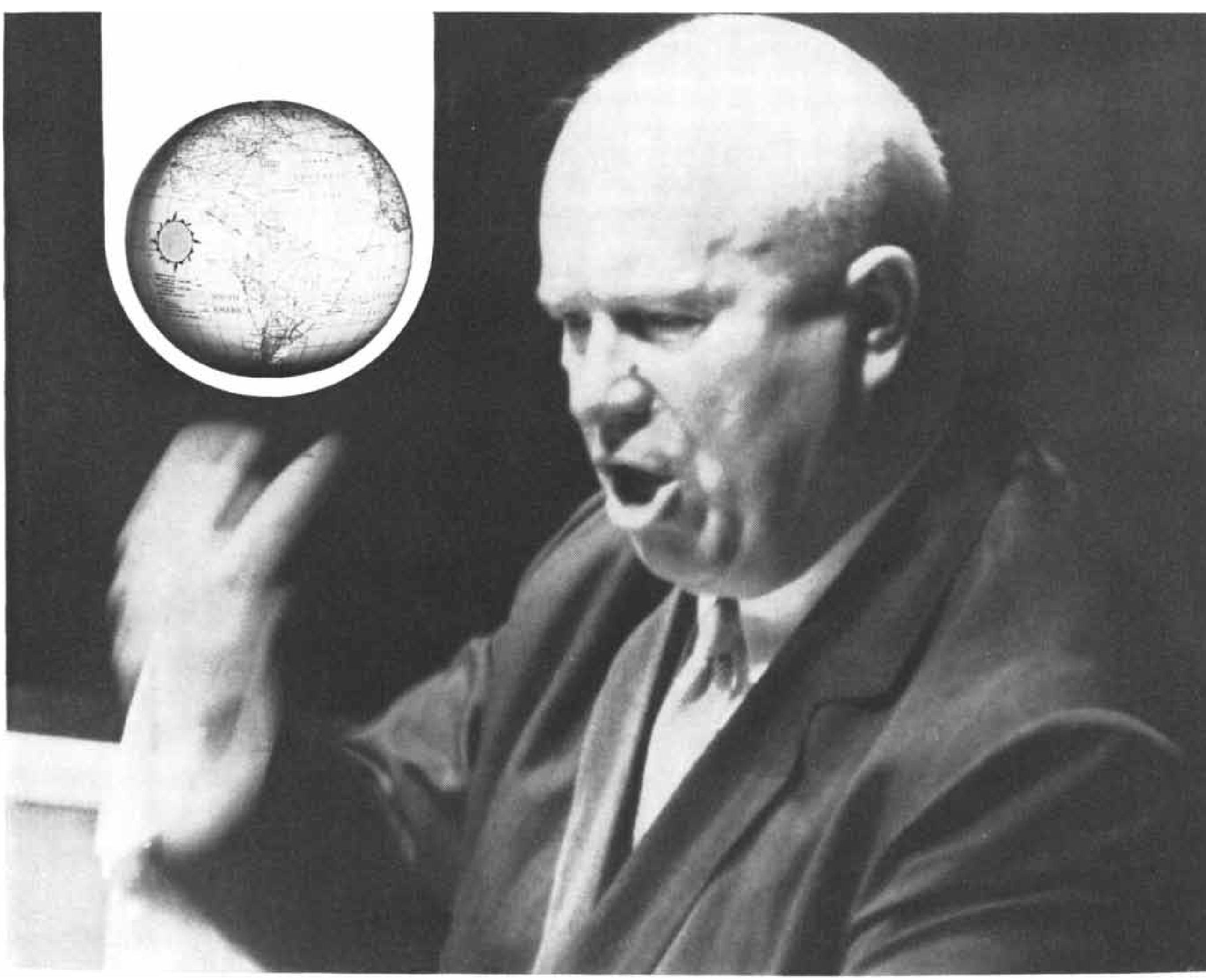

objects ranging from golf clubs to gondolas. As always in a work of this kind, it is not clear why certain words are illustrated and others not: for example, "mermaid" but not "derringer"; "submarine" but not "strawberry"; "wheel" and "well" but not "cylinder" or "cyclotron"; "the Prince of Wales Feathers" but not "linotype"; "griffin," "labarum," "guilloche" and "censer" but not "rocket," "gull," "die" (engraved stamp), "shrike," "football," "mitre" (joint), "flea," "Bunsen burner," "vacuum tube," "rhinoceros," "buffalo" or "llama." Still, this is a sturdy, attractive and useful book, up to the standards of the publishers of the great Oxford English Dictionary.

A Dictionary of Electronics, by S. Handel. Penguin Books ($1.65). The rapidity of advances in modern science and technology is epitomized by this dictionary. Its subject is only a few decades old; the word "electronics" itself is not to be found in any English dictionary published before 1940; of the 5,000 or so entries in this volume about a third did not exist before 1950. The definitions offered here are terse and many of them will convey little to the nontechnical reader. For those familiar with the language of the subject this inexpensive, illustrated and compact paperback should prove useful.

Notes

History of Science: Volume I, 1962, edited by A. C. Crombie and M. A. Hoskin. W. Heffer and Sons, Ltd. (30 shillings). This first volume of an annual review contains, among other things, a study of problems and sources of research in the physical sciences in the first half of the 19th century, a review of recent Newtonian research, a study of relations between science and technology during the 18th century, a survey of recent publications concerning the history of medicine and a number of essay book reviews.

Astronomical Techniques, edited by William A. Hiltner. The University of Chicago Press ($16.50). This second volume of *Stars and Stellar Systems*, a projected nine-volume compendium of astronomy and astrophysics, consists of 24 independent chapters that review such topics as modern photometrics, polarimeters, image converters and television apparatus now in use at astronomical observatories, as well as the more classical methods of measurement and reduction involving radial velocities, photographic and photoelectric photom-

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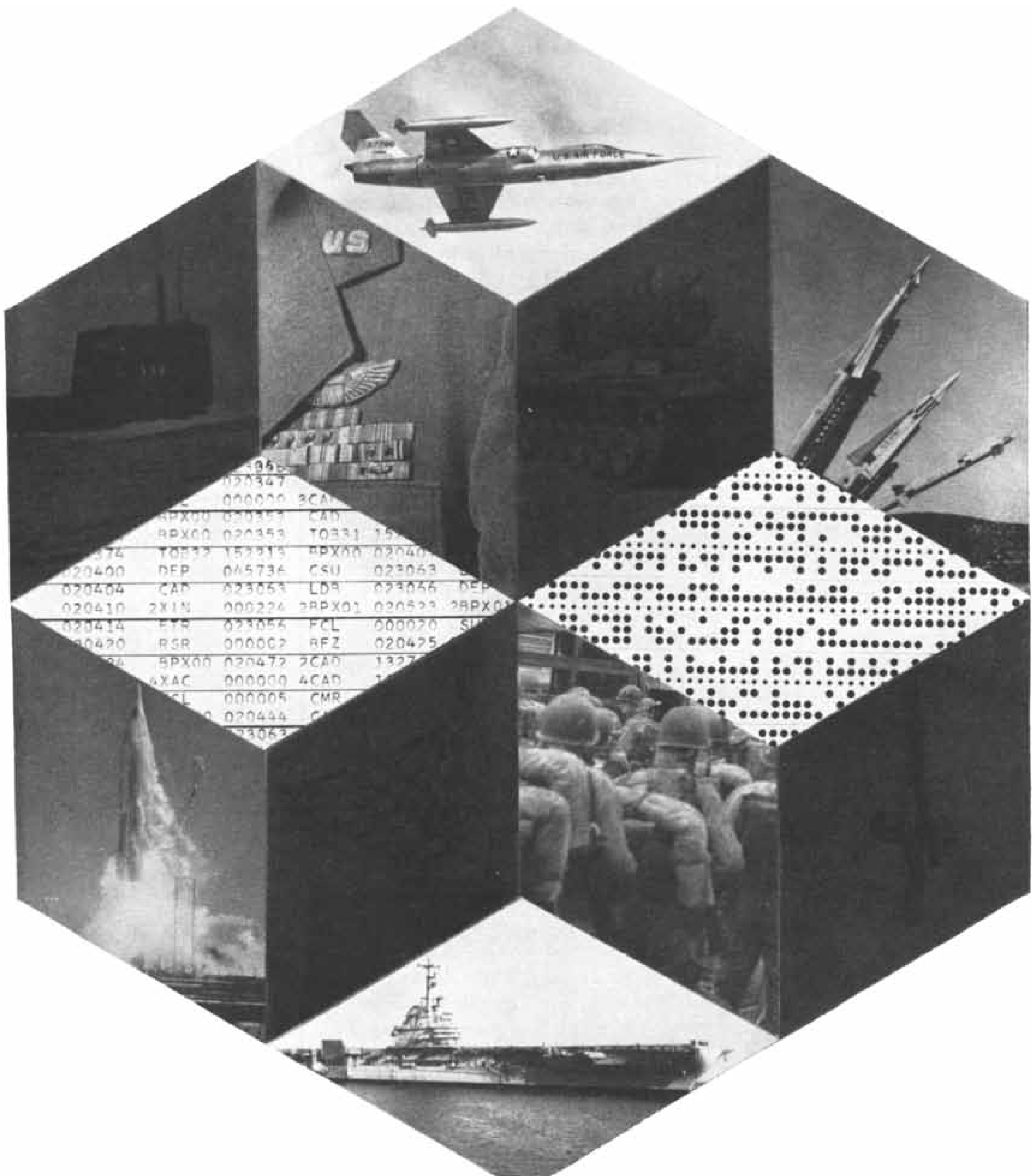

11-248

etry, techniques for visual measurement, measuring engines and so on.

Mathematical Logic, by Willard Van Orman Quine. Harper Torchbooks ($2.25). A reissue of Quine's survey (last revised in 1951), noted for its clarity. This is a desirable book for the serious student. A paperback.

Philosophy of Science, by Philipp Frank. Prentice-Hall, Inc. ($2.45). A reissue of an excellent book by a fine teacher. The main object is to exhibit the link between science and philosophy and to show that philosophy is still a living force, still growing, and has useful work to do in research and in the teaching of science and in deepening one's understanding of the world.

Manual of the Trees of North America, by Charles Sprague Sargent. Dover Publications, Inc. ($4). A two-volume paper-backed reprint of a monumental descriptive work based on 44 years of original research by this country's foremost dendrologist: the late Charles Sprague Sargent. It covers 185 genera and 717 species of trees found in the U.S., Canada and Alaska; there are 783 line drawings.

Principles of Stratigraphy, by Amadeus W. Grabau. Dover Publications, Inc. ($5). A two-volume soft-cover reprint of a major work of 20th-century geology that first appeared in 1913. In spite of advances in sedimentology since its publication, the treatise contains a mass of information about the surface of the earth that is, as the prefatory note by a contemporary geologist points out, as applicable today as when it was written.

Six Medieval Men and Women, by H. S. Bennett. Atheneum Publishers ($1.25). A reissue of a scholarly and entertaining book covering the lives of a few men and women of the 15th century for the purpose of enabling the modern reader to understand "something of what it meant to be a soldier, or a civil servant, or the wife of a country landowner at that time." A paperback.

A History of Greek Literature, by Moses Hadas. Columbia University Press ($1.95). A renowned classical scholar and teacher examines Greek literature from Homer to the novelist Lucian, including its poetry, its tragedies and comedies, its philosophical works, its orations and histories. A paper-backed reissue.

INDEX OF ADVERTISERS

FEBRUARY 1963

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Statue of Benjamin Franklin by James Earle Fraser in The Franklin Institute, Philadelphia

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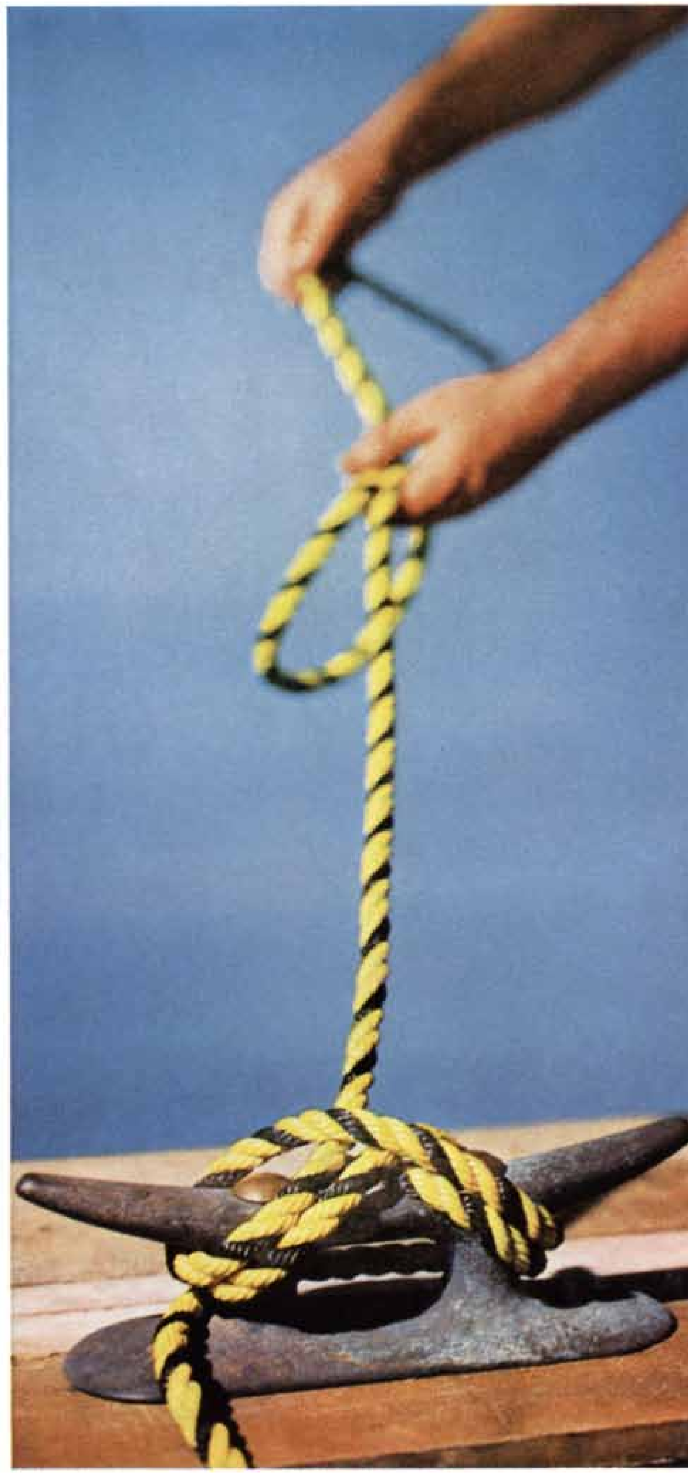

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