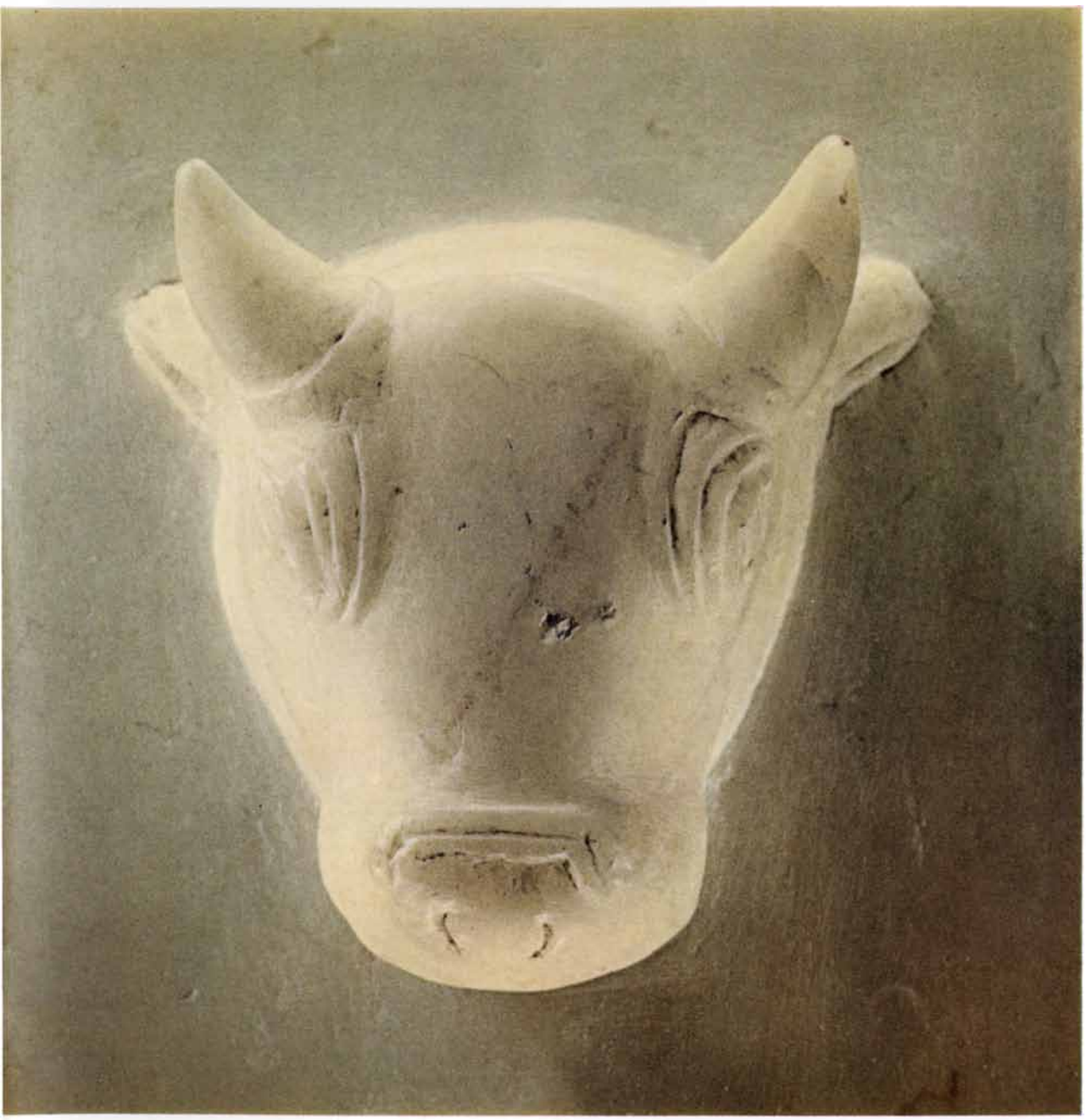
SCIENTIFIC AMERICAN



ANCIENT ARABIAN BULL

ONE DOLLAR

December 1969

from skyways to highways

UOP has a piece of the action in your life.

Take a seat in the sky.

Or the gasoline in the pump at the side of the highway.

Would you be surprised to learn that one company, UOP, has a lot to do with both comfort in the sky and efficient power for your everyday driving?

You shouldn't be surprised, really, because UOP is a surprising company doing many exciting things. It is a company held together by the common denominator of inexhaustible scientific curiosity.

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You've heard of Platforming®? That was an original by the scientists at UOP Process Division. Now widely used in formulating the most efficient gasolines, Platforming stands as one of the major breakthroughs in petroleum refining.

Universal Oil Products Company is also poking its nose for the new into such areas as fragrances, ground transportation equipment, pollution control, fabricated metals, petrochemical processes. All important to you.

No end in sight. Whoever you are, UOP has a piece of the action in your life.

A finger on the ocean's pulse.

Before a key research outpost can be established on Cobb Seamount in the Pacific Ocean, oceanographers must first find out exactly what kind of environment exists there. To collect precise answers to these questions meant devising a meter that must operate independently of any outside controls or maintenance for a minimum of nine months in a cold, deep water environment. To do the job, the Nereus Corporation, a young oceanographic firm located in the State of Washington, produced a unique instrument called the Surge Meter.

Man has been measuring waves scientifically since the time of Leonardo da Vinci. Today, modern instrumentation, using highly sophisticated impeller devices, can furnish precise and detailed profiles of wave and surge activity. But to determine the water forces existing at this undersea mountain meant coping with hydrological conditions so unusual that they were beyond the capabilities of impellers.

The Surge Meter has to be able to withstand the worst of the winter storms. This means holding its own against currents up to three knots. Then too, the water at Cobb Seamount has a strange characteristic: it oscillates back and forth over the pinnacle at a distance of one foot and a rate of once per second. To accommodate

these factors and anticipate still others, the Nereus engineers put the Surge Meter through six months of rigorous tests and made many modifications.

Ultimately, the principle used as the basis for the Meter was derived from observations made over one hundred years ago by Michael Faraday. Stated briefly, the principle says that the magnitude of a voltage appearing at the ends of a conductor moving through a magnetic field is proportional to the velocity of the conductor. In the case of the Surge Meter, the seawater acts as the conductor. It serves the same function as a copper wire, and moves at the unknown velocity. A sensor contains the coils through which the seawater passes to generate the magnetic field.

Unlike other such instrumentation, the Surge Meter uses no moving parts. Thus it can measure higher frequency portions of the wave spectrum than would be possible with mechanical sensors. Power in the Surge Meter is provided by storage batteries—all carefully sized to sustain operation over the nine-month period. To conserve power, the Meter has been programmed to record for ten minutes every twelve hours and at the rate of one "set" per second. At these intervals, the Meter measures and records, simultaneously, the water velocity and direction in the horizontal plane.

When the Surge Meter is retrieved in the Spring of 1970, the data collected by the Meter will be used to enable Project Sea Use II to perfect designs for the first manned seamount habitat in the Pacific. The work of this remarkable finger on the ocean's pulse will then be complete.

The State of Washington is a fertile field for the exciting new breakthrough industries of the future. In oceanography, aerospace, agriculture, fisheries, nuclear energy and many other areas, the smart money is betting on the State of Washington.

Daniel J. Evans
Governor

STATE OF WASHINGTON

For business location information, write: Daniel B. Ward, Director, Department of Commerce and Economic Development, Olympia, Washington 98501.

SCIENCE/SCOPE

Regulation of U.S. Army air traffic in combat zones or elsewhere will be possible with SAFOC (Semi-automatic Flight Operations Center). An advanced development model of the system was demonstrated by Hughes near Atlantic City, N.J., recently. It will provide a collision-avoidance capability, pinpoint the location of distressed or downed aircraft, identify friendly aircraft, provide ground-to-ground coordination of aircraft movement, and disseminate air-warning information to pilots.

A secure point-to-point communications link for ship-to-ship, ship-to-shore, and other industrial and military uses has been developed by Hughes. The new communicator uses a gallium arsenide pulsed laser beam as the carrier, transmits and receives either voice or digital information for distances up to six miles, and is virtually free of radio-frequency interference. It weighs only 5½ pounds and draws only 120 milliwatts while transmitting, 24 while receiving.

Better speeds for MOS devices are now possible with ion implantation, a technique perfected by Hughes research scientists after three years of development. The new technique is completely compatible with P-channel MOS processing, which the silicon-gate method is not. The IMOS (ion-implanted MOS) devices successfully fabricated by Hughes include a 64-bit shift register capable of 30 Mhz speeds and a 10-channel multiplexer that's about five times faster than today's best.

The U.S. Navy has responded to the need for improved submarine search and rescue operations by commissioning two giant catamarans which are designed to launch and recover submersible rescue vessels from centerline elevators located between the two hulls. Hughes designed the electronic installation and is installing and checking out the radar, sonar, communications, and navigation units.

Special opportunities for specialists: Hughes would like to hear from Radar Systems Engineers, Signal Processing Systems Analysts, Circuit Designers, High-Power Switching Engineers, and ThinFilm Process Engineers for Hybrid Microcircuitry. Requirements: B.S. degree, two years related experience, U.S. citizenship. Please write: Mr. J.C. Cox, Hughes Aircraft Company, P.O. Box 90515, Los Angeles 90005. Hughes is an equal opportunity employer.

When NASA's Mariners orbit Mars in 1971 scientists will survey approximately 70 percent of the planet's surface, recording significant data on its atmosphere and locating possible landing sites for instrument packages in 1973. Each Mariner will carry a two-channel infrared radiometer built by Santa Barbara Research Center, a Hughes subsidiary. The instruments will "take the temperature" of Mars during the Mariners' 240 orbits. These readings will subsequently be correlated with the photographs of the surface that will also be sent back to earth.

Established 1845 **SCIENTIFIC AMERICAN** December 1969 Volume 221 Number 6

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows, at slightly more than actual size, a bull's head carved from alabaster during the first millennium B.C. in Qataban, one of the ancient Semitic kingdoms of southern Arabia (see "The Rise and Fall of Arabia Felix," page 36). In the religion of the period the bull symbolized the moon god, one of the principal deities of the local pagan pantheon. The realistic rendering of the muzzle, the folds of skin above the eyes and the blunt horns are typical of the skill with which the sculptors of the civilization of Arabia Felix treated this religious theme.

THE ILLUSTRATIONS

Cover photograph by Victor E. Krantz, Smithsonian Institution

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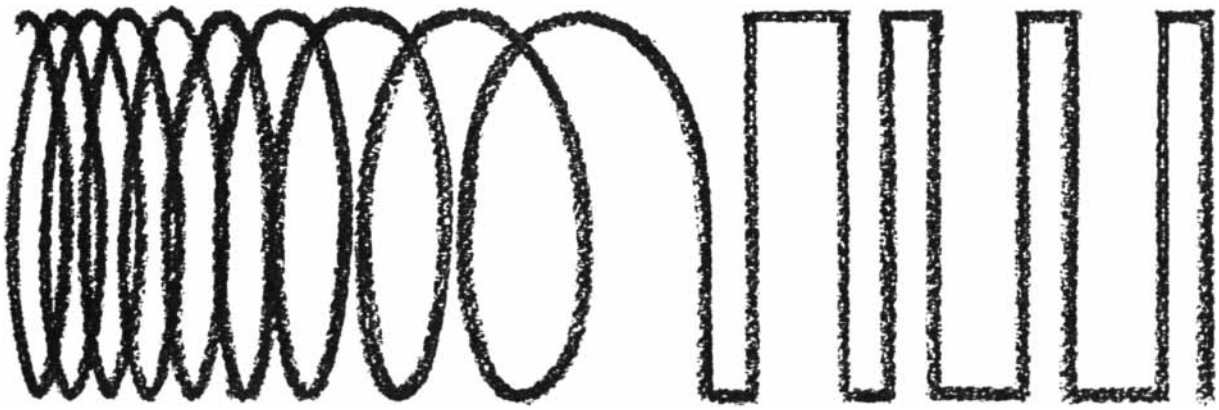


We uncoil the data transmitter

In data transmission, as in almost every other field of electronic engineering, the trend is towards micro-miniaturization. The objective is to produce cheaper, more reliable circuits. To transmit data signals on telephone channels, modulators and filters are required.

Unfortunately, when designers tried to miniaturize these circuits they met an apparently insoluble problem. Coils, which with capacitors determine the frequency response of a filter, are extremely difficult to reduce in size. So the designers examined ways of developing a filter without coils.

Dr. Leuthold of the ETH, Zurich, at that time working in our laboratories, evolved the theory of what is now known as the binary transversal filter. This consists of a resistor matrix connected to tappings on a flip-flop shift register. With a binary input signal it acts like a filter. Whilst not exactly equivalent to an LC filter, it can be made to act in a similar way in the desired frequency range. To do this, we make the shift frequency, which samples and shifts the input signal through the register, equal to a high multiple of the input bit frequency.

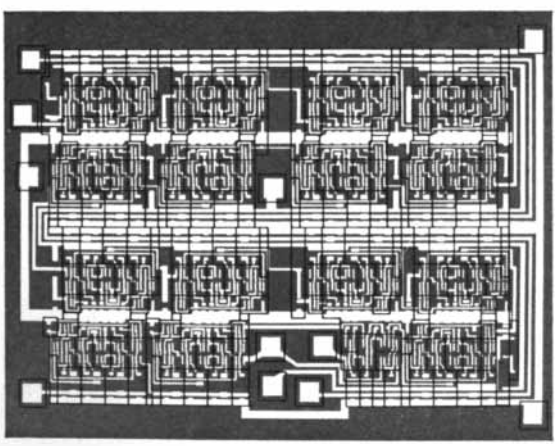
The new digital filter solved one problem but generated another - choosing a suitable method of modulation. To limit the spectrum of the modulated signal with a digital filter, the modulator output must take the form of a synchronous two level signal. This virtually ruled out conventional two-step (up and down) modulation, which would require analog filtering again.

The alternative, direct modulation on a carrier within the signal band, results in "fold-over" distortion. And, using square wave modulation, to other undesirable modulation products.

Nevertheless Mr. Van Gerwen, of our laboratories, decided to adopt the technique. He modulated the binary signals on a square wave carrier and got a mixture of the sidebands of all the odd carrier harmonics. Seemingly a complete mess. Yet, by making the carrier a multiple of half the bit frequency, both wanted and unwanted components occur at the same frequencies in the spectrum. Surprisingly, the unwanted components could be filtered out by adjusting the values of resistors in the filter matrix.

The new data transmitter, comprising flip-flops, logical AND-gates and resistors, worked and was, in principle, suitable for integration. Mr. Schmitz and Mr. Dijkmans of our laboratories, took up this challenge and concentrated all 203 transistors and 172 resistors on a single chip 6 mm², with resistance ratios accurate to within ± 1%. This chip can be used for 2400 bits per second in a 300 - 3400 Hz voice band channel. With a proportionately higher sampling frequency the same chip can also be applied to high speed data links. It operates at temperatures from -100°C to +100°C.

A similar technique can be used for an integrated data receiver. This needs an additional analog to digital encoder and consequently another chip.

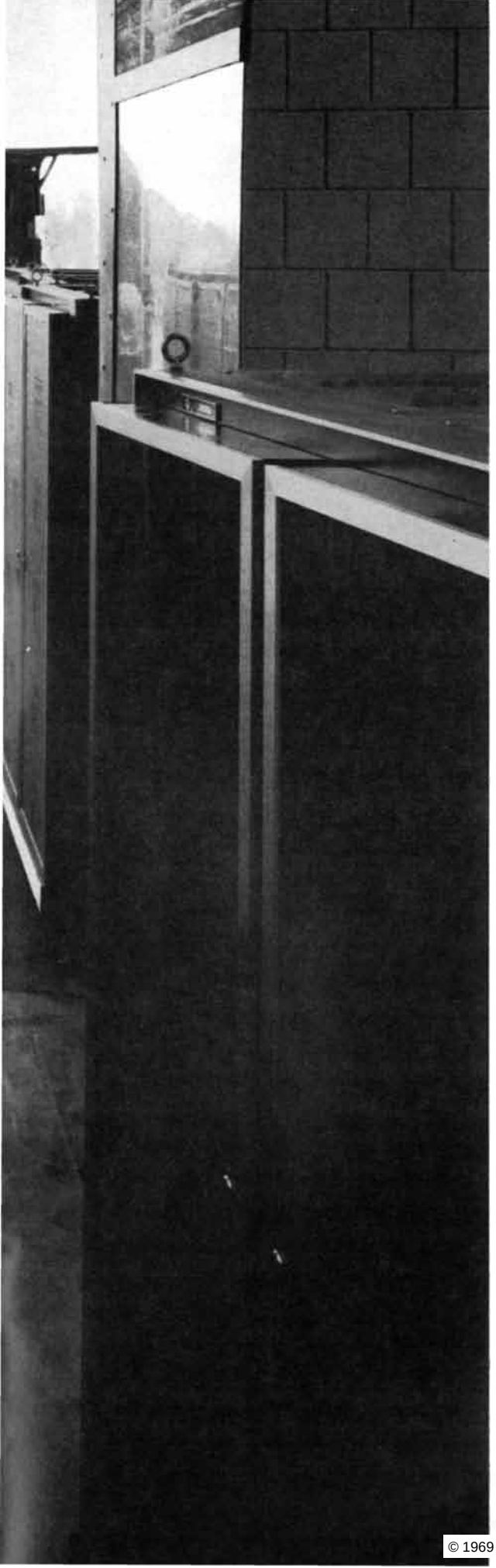


Fully integrated data transmitter - 203 transistors, 172 resistors on 6 mm² chip.

In the Research Laboratories of the Philips group of companies, scientists work together in many fields of science. Among these are: Acoustics, Cryogenics, Information Processing, Mechanics, Nuclear Physics, Perception, Solid State, Telecommunications and Television.

This work was carried out at the Philips Research Laboratories, Eindhoven, the Netherlands.

PHILIPS



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90-day delivery!

You don't have to play the waiting game when you order our HP 2000A Time-Share System. It's ready for you almost as soon as you're ready for it. In most cases, you can take delivery 90 days after we get your order.

But getting customers on the air fast is just one reason for our system's success. There are plenty of others.

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Simplicity is another reason for our system's popularity. HP BASIC is the easiest computer language around. That's why it's a favorite with scientists, engineers, educators, businessmen and other non-programmers. They can learn it in just a couple of hours, because it's almost like talking to the computer in English. Yet because the HP 2000A is so powerful, these users can put it to work on such sophisticated operations as matrixes, strings, and files.

The HP 2000A comes ready for your immediate use. All required software, control terminal and interfaces are included. And this system keeps on working and working and working. In fact, our customers have already logged over four million terminal-hours of successful, trouble-free operation.

With this kind of money-saving reliability, it's no wonder our time-sharing system is the most popular one around.

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HEWLETT hp PACKARD

DIGITAL COMPUTERS

LETTERS

Sirs:

I am writing in regard to the article "Porphyria and King George III," by Ida Macalpine and Richard Hunter, which appeared in your July issue. The article makes no mention of the fact that, following the publication of a paper by Dr. Macalpine and others in the *British Medical Journal* of January 6, 1968, which followed on a previous article in 1966 contending that many members of the British royal family from the time of Mary Queen of Scots onward had inherited porphyria, a series of letters was published disputing her claim. In Dr. Macalpine's first paper the "Royal Malady" was one type of porphyria, acute intermittent porphyria, and in her second paper she had changed the diagnosis to another disease, porphyria variegata.

An account of porphyria variegata in South Africa was published in *Scientific American* ["Pursuit of a Disease," by Geoffrey Dean; March, 1957]. Over the past 20 years I have seen many hundreds of people who have inherited this Mendelian dominant disorder, and I have shown that more than 8,000 white South Africans alive today inherited porphyria variegata from one ancestor who married at the Cape in 1688. I can, therefore, be excused for stating that I know a great deal about the symptoms caused by porphyria not only today but also in the past.

Dr. Macalpine maintains that not only did George III have porphyria variegata but also he inherited it through the royal line right back to Mary Queen of Scots. Only half of the children of a porphyric parent inherit the gene. Therefore the odds against the gene's persisting over so many generations in the royal line are very remote indeed.

One immigrant to South Africa who married at the Cape in 1688 now has more than 8,000 living descendants who have inherited porphyria variegata. We know that they suffer from no significant symptoms unless they take certain relatively recent drugs, such as barbiturates and sulfonamides. Those who inherited porphyria variegata had as large families on average as the rest of the early white settlers in South Africa and they lived on average as long as anyone else. There is nothing in the old records to suggest that they had suffered from symptoms of acute porphyria. Today the South Africans with porphyria variegata who avoid barbiturates and sulfonamides, and a few other seldom-used modern drugs, remain as well as those who have not inherited the disease, and they are accepted for life insurance. They may be troubled with a tendency for the exposed skin, say the skin on the back of the hands, to abrade easily.

If royal personages as far back as Mary Queen of Scots had inherited as a Mendelian dominant porphyria variegata, there should be hundreds of descendants alive today many of whom one would expect to have inherited the disorder. They had large families, legitimate and often illegitimate, that are well documented. Some of those descendants in recent years should have had typical acute porphyria attacks, say after receiving a thiopentone anesthetic. Nevertheless, in their article in the *British Medical Journal* only two very doubtful living cases are cited by the authors. The porphyria of Patient *A* is said to have been diagnosed by a distinguished physician who is not named. I have known many distinguished physicians to make a mistake in diagnosing porphyria. In Patient *B* the increase in porphyrin was very small and not at all diagnostic of the disorder.

In the case of James I, who is reported to have developed a pain in the left lumbar region and to have passed red urine after riding a horse, his doctor attributed the symptoms at the time to "gravel." I think His Majesty's doctor made a very sensible diagnosis, particularly because at autopsy James I had "two concretions" in his kidney. James I's eldest son, who was said in Dr. Macalpine's article to have died from acute porphyria, had an acute illness with diarrhea. I have never seen diarrhea in a patient with acute porphyria; constipation is the general rule. Mary Queen of Scots had an acute illness with a pain in her side made worse by breathing; quite likely she had pleurisy. Colic and diarrhea were much more likely caused by gastroenteritis, which must have been very common in those days.

There is no acceptable evidence that George III's attacks of mental illness that ended in a vacuous old age were caused by attacks of acute porphyria. The drugs that precipitate acute porphyria variegata did not exist in his day. There is no higher proportion of patients with porphyria variegata among the patients in mental hospitals than among the general population, and no special history of mental breakdown among the ancestors of present-day porphyrics in South Africa. Furthermore, porphyria variegata is very uncommon in Europe. Other causes of mental breakdown, sometimes of a physical nature, are much more common.

In conclusion, in my opinion the claim of Dr. Macalpine and Dr. Hunter that many members of the royal family from the time of Mary Queen of Scots, and including James I and George III, suffered from symptoms caused by acute porphyria variegata is quite unproved.

GEOFFREY DEAN, M.D., F.R.C.P.

Dublin, Ireland

Sirs:

The essence of Dr. Dean's argument is that severe attacks of porphyria occur exclusively as the result of the patient's having taken one of a variety of modern synthetic drugs known to precipitate attacks, since in South Africa he has never met them otherwise. Hence he generalizes that they could not have occurred in the past prior to the introduction of such compounds. This is not in keeping with our own experience nor with that of other physicians, and various contributors to the correspondence in the *British Medical Journal* also reported having seen severe attacks in the absence of

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NAME

NEW ADDRESS

OLD ADDRESS

drugs. Dean's experience of the symptomatology of the disorder equally does not conform to general experience when, for instance, he states that diarrhea never occurs (cf. Goldberg & Rimington, *Diseases of Porphyrin Metabolism,* 1962, page 79).

There is no gainsaying that thousands of porphyria cases may exist in this large, widely flung family. Dr. Dean should not confuse our aim—which was to strengthen our diagnosis of George III's illness by showing that this rare gene still exists in the family—with his own, which was to establish the prevalence of porphyria in South Africa. He himself traced thousands of present-day porphyrics to one supposedly porphyric immigrant in the 17th century, but he refuses to admit a similar possibility in the royal families because "only half of the children . . . inherit the gene. Therefore the odds against the gene's persisting over so many generations in the royal line are very remote indeed." Does he suggest heredity possibilities differ between South Africa and Europe?

Dr. Dean does not advance interest in this newly found disorder by such unsupported, unsupportable and irrelevant statements as that porphyria is not commoner in mental hospitals than outside. He must be aware that hundreds of thousands of mental hospital patients have never been screened for the disorder. Does he mean to differentiate himself also from universal experience that mental symptoms are common in acute attacks?

Other matters he raises do not relate to what we published in *Scientific American.* They have already been countered point by point in the *British Medical Journal.* He will find further details in *George III and the Mad-Business,* published by Allen Lane The Penguin Press, London, in 1969, and to be published by Pantheon Books, New York, in 1970.

IDA MACALPINE, M.D.

London

ERRATUM

In the article "The Cost of World Armaments" (SCIENTIFIC AMERICAN, October) the two curves in the chart on page 23 were incorrectly identified. Gross national product is represented by the colored curve and military expenditures by the black one.

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1919: "Sir Ernest Rutherford has recently conducted a series of experiments with nitrogen, the results of which indicate that this substance, which has always been considered an element, is in reality capable of a disintegration similar to that of radium. Rutherford found by experiment that if *alpha* radiation strikes the nucleus of a light atom such as that of hydrogen, the latter is moved for a certain distance in the direction of the movement of the radiation. But when the *alpha* radiation comes in collision with an atom of nitrogen, the effect is different—the radiation penetrates the atom before being reflected or repelled; certain particles are torn away and carried along in the direction of the radiation in the same way as were the atoms of hydrogen in the other experiment. But the curious thing about this is that these particles appear to be atoms of hydrogen. The conclusion seems inevitable that the hydrogen found has its origin in the nitrogen. To all appearance the *alpha* ray tears an atom of hydrogen away from the atom of nitrogen. Consequently Rutherford suggests that the atom of nitrogen, whose atomic weight is 14, consists of a central nucleus composed of three atoms of helium (each having an atomic weight of 4) and two atoms of hydrogen (whose atomic weight is 1)."

"Press dispatches from Stockholm announce that the Nobel prize for physics for 1918 has been awarded to Prof. Max Planck of Berlin University, the physics prize for 1919 to Prof. Johannes Stark of Griefswald University and the chemistry prize for 1918 to Prof. Fritz Haber of the Kaiser Wilhelm Institute. The chemistry prize for 1919 will be held over until next year."

"Only a few years ago it was the teaching that the atom was the smallest division of matter, and today scientists are discussing the possibility of learning how to use the force that would become available with the unlocking of the latent atomic power. Sir Oliver Lodge in a recent address spoke of the latent atomic power, which he considers so very great that it would be disastrous to have it become available to men before a moral plane high enough to prevent its abuse has been reached."

"Dr. Einstein tells us that when velocities are attained which have but just now come within the range of our close investigation, extraordinary things happen—things quite irreconcilable with our present concepts of time and space and mass and dimension. We are tempted to laugh at him, to tell him that the phenomena he suggests are absurd because they contradict these concepts. Nothing could be more rash. When we consider the results which follow from physical velocities comparable with that of light, we must confess that here are conditions which have never before been carefully investigated. We must be quite as well prepared to have these conditions reveal some epoch-making fact as was Galileo when he turned the first telescope upon the skies. And if this fact requires that we discard present ideas of time and space and mass and dimension, we must be prepared to do so quite as thoroughly as our medieval fathers had to discard their notions of celestial 'perfection,' which demanded that there be but seven major heavenly bodies and that everything center about the earth as a common universal hub."

"Beginning with the first of January, 1920, the SCIENTIFIC AMERICAN SUPPLEMENT will be changed in form and in period of issue. The new journal, which will be published on the first of each month, will be known as the SCIENTIFIC AMERICAN MONTHLY. The SCIENTIFIC AMERICAN MONTHLY, although a separate journal, will be closely allied to the regular weekly SCIENTIFIC AMERICAN and will supplement the work in that journal. Many important topics which, owing to the limitations of space, can be referred to only briefly in the latter, will be published in full in the SCIENTIFIC AMERICAN MONTHLY, thus making the new journal a most important adjunct to the SCIENTIFIC AMERICAN."

SCIENTIFIC AMERICAN

DECEMBER, 1869: "The Darien canal project is reviving. The United States steamer *Nipsic,* attached to the South Atlantic squadron, is under orders to proceed to the Isthmus of Darien to make surveys and explorations, with a view to determining the best location for an inter-oceanic canal. A similar survey on the Pacific shore of the Isthmus will be made at a future day. It is asserted that President Grant will recommend the early construction of this Darien ship canal in his forthcoming message."

"Certainly those papers that have assumed to condemn the establishment of a chair of positive philosophy at Harvard and the publication of lectures of Professor John Fiske, the able expounder of 'positivism' in that institution, have greatly mistaken the spirit of the age. The thinkers of the period are struggling by every possible means to arrive at truth. They have disembarrassed themselves of all superstitious reverence for old doctrines and old beliefs, and have entered into their work with the determination to recognize nothing as true merely because it has long been accepted as such. They are obeying the injunction of St. Paul: 'Prove all things.' The clamor of bigots against free thought and free discussion avails no more to stem the current of thought than the howling of the wind below Niagara to stay the mighty cataract."

"Our predictions in regard to the effect of high-heeled shoes upon female health have been verified. A French physician states that this fashion 'has produced distinct diseases not only of the distorted foot but of the body. As the frame is thrown permanently into an unnatural position, it affects the spine, and as it is a question of balancing, nervous irritation sometimes occurs.' "

"The Austrian Government has introduced a novelty in postage, which might be introduced with great benefit in all countries. The object is to enable persons to send off, with the least possible trouble, messages of small importance, without the trouble of obtaining paper, pens and envelopes. Cards of a fixed size are sold at all the post offices for two kreutzers, one side being for the address and the other for the note, which may be written either with ink or with any kind of pencil. It is thrown into the box and delivered without envelope. A halfpenny post of this kind would certainly be very convenient, especially in large towns, and a man of business, carrying a few such cards in his pocketbook, would find them very useful."

In a world where everybody watches out for himself, it's comforting to have somebody watching out for you.

In this world, hardly anybody's interested in your problems. They have enough of their own.

So when you're alone in a strange town, you're really alone.

However, in every one of a thousand American cities and towns where there's a Hertz office, there's somebody who actually wants to help you.

We've been renting Fords and other good cars to more travelers for more years than anybody else. In that time, we've come to know about all the things that can mess up a business trip.

And we've learned how to do something about them.

The Hertz girl knows an awful lot about her town by just living there and what she didn't know already, we've taught her.

She can help you find a reasonably priced place to eat, an all-night drugstore, and an optician who takes credit cards. She also knows unusual things like where to find a stenographer or a locksmith.

Although this may be the first time you've ever had your problem, it's probably not the first time she's helped solve it.

Hertz

You don't just rent a car. You rent a company.

"You'd hardly know

Thus spake the mayor of Benicia.

His words are echoed by almost everybody else we spoke to in this breezy little city off the Carquinez Strait, near San Francisco.

Such words are music to the ears of Jersey's affiliate, Humble Oil & Refining Company. For Humble has spent an extra $10 million just to make their new Benicia refinery as unheard, unsmelled and unobtrusive as possible.

Conserve the air, the water, the beauty and the peace. These were Humble's main concerns as a newcomer to town. And, before a single bulldozer growled into action, they made studies of air currents, water, vegetation and sound levels to give themselves a benchmark against which to measure change.

Water. One way to keep it clean is to use as little as you can. There is less to get dirty and less to clean up. For each gallon of gasoline produced, many refineries use up to ten gallons of cooling water. Thanks to air-cooling and water recirculation, Benicia uses only one.

"How's the fishing off the refinery?" we asked. "Fine" said the mayor. "We hook sturgeon, bass and flounder. And sometimes we get a salmon."

the refinery was there."

Beauty. Nobody can hide a refinery. But, with subtle landscaping, you can stop it looking like a monstrous set of drums and clarinets.

At Benicia, embankments are covered with flowering iceplant. Tanks and towers are painted corn gold and moss green, the dominant colors of this Cézanne countryside. And it works.

Harold Gilliam, former consultant to the President's Council on Recreation and Natural Beauty, writes—"The refinery's impact on the landscape seems muted and moderate."

As for the air and the peace, our headline and picture surely say enough. But there's one effect of the refinery that every Benician notices. It has quintupled the city's tax base.

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THE AUTHORS

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R. P. LEVINE ("The Mechanism of Photosynthesis") is professor of biology at Harvard University. He was graduated from the University of California at Los Angeles in 1949 and received his Ph.D. there in 1951. At that time his research was concerned with the genetics and physiology of *Drosophila* from natural populations. Later he turned to the study of gene recombination in *Drosophila*. When he went to Harvard in 1953, he continued this work, but with the unicellular green alga *Chlamydomonas reinhardi*. It soon became apparent that this organism was particularly well suited for the study of the mechanism of photosynthesis and, in particular, its genetic control. In addition to his research Levine is involved in the teaching of one of the introductory courses in biology at Harvard; he contributes to the teaching of genetics. His teaching activity also includes an advanced course on photobiology for undergraduates and a seminar on photosynthesis for graduate students.

L. S. PENROSE ("Dermatoglyphics") is director of research at Harperbury Hospital near St. Albans in England; the hospital, which is part of the Kennedy-Galton Centre for Mental Retardation Research and Diagnosis, provides for the care of mentally retarded persons. Until 1965 Penrose was Galton Professor of Eugenics at University College London, and he is now emeritus professor of human genetics in the University of London. He has the degrees of M.A. and M.D. from the University of Cambridge and also studied medicine at St. Thomas's Hospital in London. From 1939 to 1945 Penrose directed psychiatric research for the Province of Ontario. He is a fellow of the Royal College of Physicians of London.

VICTOR VALI ("Measuring Earth Strains by Laser") is a research scientist at the Boeing Scientific Research Laboratories and a research professor at the University of Washington. He obtained his Ph.D. in physics from the University of Colorado in 1955. His research interests are all concerned with measurements of very high precision. Vali writes that he considers physics "a fascinating game where the rules are quite rigid and sometimes not known, and where the toys have become progressively more expensive."

JACK P. HAILMAN ("How an Instinct Is Learned") is associate professor of zoology at the University of Wisconsin. He was graduated from Harvard College in 1959 and received his Ph.D. from Duke University in 1964. While he was at Duke he spent a night in the Durham city jail, having been arrested for participating in one of the early civil rights demonstrations, a sit-in at a restaurant in Durham; the charge against him was later dismissed. From 1964 to 1966 he was at the Institute of Animal Behavior of Rutgers University, and from 1966 until this year he was assistant professor of zoology at the University of Maryland. In his study of sea gulls Hailman has traveled to many places, including Germany, Canada and the Galápagos Islands. In his leisure time he enjoys camping, hiking, mountain climbing and skin diving.

RALPH A. RAIMI ("The Peculiar Distribution of First Digits") is professor of mathematics at the University of Rochester, where he has been a member of the faculty since 1952 except for a year (1955–1956) as a postdoctoral fellow at Yale University. "I got my bachelor's degree in physics," he writes, "and even began graduate work in the physics department, but I discovered that I simply couldn't understand physics. I shifted to mathematics thinking that a year or two of math would clear up my troubles, but I got seduced and never returned to the physics department. All I know about physics now is what I read in *Scientific American*. P.S. Some of my best friends are physicists; I admire them from afar." Raimi took all his degrees through the Ph.D. at the University of Michigan between 1947 and 1954. He spent the year 1949–1950 in Paris as a Fulbright scholar and remarks that it "was more devoted to the exploration of the great vintages of 1945 and 1947 than it was to the works of Bourbaki." Raimi and his wife have two teenage daughters, of whom he says: "Neither shows the least interest in mathematics. Even though I myself am more literary than mathematical, I regret this fact. There is no education I know of (but I never studied Latin, one of the more useful things I lost to Deweyism) that yields a cleaner prose style than the study of mathematics."

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Marihuana

There is considerable evidence that the drug is a comparatively mild intoxicant. Its current notoriety raises interesting questions about the motivation of those who use it and those who seek to punish them

by Lester Grinspoon

The earliest record of man's use of marihuana is a description of the drug in a Chinese compendium of medicines, the herbal of Emperor Shen Nung, dated 2737 B.C. Marihuana was a subject of extravagant social controversy even in ancient times: there were those who warned that the hemp plant lined the road to Hades, and those who thought it led to paradise. Its use as an intoxicant spread from China to India, then to North Africa and from there, about A.D. 1800, to Europe, perhaps primarily through troops of Napoleon's army returning from the Egyptian campaign. In the Western Hemisphere marihuana has been known for centuries in South and Central America, but it did not begin to be used in the U.S. to any significant extent until about 1920. Since the hemp plant *Cannabis sativa*, the source of the drug in its various forms, is a common weed growing freely in many climates, there is no way of knowing precisely how extensive the world usage of the drug may be today. A United Nations survey in 1950 estimated that its users then numbered some 200 million people, principally in Asia and Africa.

Cannabis sativa has a long history of use as a source of fiber, as a drug in tribal religious ceremonies and as medicine, particularly in India. In the 19th century the drug was widely prescribed in the Western world for various ailments and discomforts, such as coughing, fatigue, rheumatism, asthma, delirium tremens, migraine headache and painful menstruation. Although its use was already declining somewhat because of the introduction of synthetic hypnotics and analgesics, it remained in the U.S. *Pharmacopoeia* until 1937. The difficulties imposed on its use by the Tax Act of 1937 completed its medical demise.

In any case, throughout history the principal interest in the hemp plant has been in its properties as an agent for achieving euphoria. The name marihuana is said to be a corruption of the Portuguese word *mariguango*, meaning intoxicant. The drug's ubiquity is evidenced in the multitude of vernacular terms by which it is known; in the U.S. it is variously called the weed, stuff, Indian hay, grass, pot, tea, maryjane and other names. In this country it is almost invariably smoked (usually as a cigarette called a reefer or a joint), but elsewhere the drug is often taken in the form of a drink or in foods such as sweetmeats.

Drug preparations from the hemp plant vary widely in quality and potency, depending on the climate, soil, cultivation and method of preparation. The drug is obtained almost exclusively from the female plant. When the cultivated plant is fully ripe, a sticky, golden yellow resin with a minty fragrance covers its flower clusters and top leaves. The plant's resin contains the active substances. Preparations of the drug come in three grades, identified by Indian names. The cheapest and least potent, called bhang, is derived from the cut tops of uncultivated plants and has a low resin content. Most of the marihuana smoked in the U.S. is of this grade. To the discriminating Hindu bhang is a crude substitute for ganja, a little like the difference between beer and fine Scotch, and it is scorned by all but the very poorest in India. Ganja is obtained from the flowering tops and leaves of carefully selected, cultivated plants, and it has a higher quality and quantity of resin. The third and highest grade of the drug, called charas in India, is made from the resin itself, carefully scraped from the tops of mature plants. Only this version of the drug is properly called hashish; the common supposition that hashish refers to all varieties of cannabis drugs is incorrect. Charas, or hashish, is five to eight times stronger in effect than the most potent marihuana regularly available in the U.S.

The chemistry of the cannabis drugs is extremely complex and not completely understood. In the 1940's it was determined that the active constituents are various isomers of tetrahydrocannabinol. Recently one of these isomers, called the delta-1 form, has been synthesized and is believed to be the primary active component of marihuana. The drug's effects, however, probably also involve other components and the

HEMP PLANT (*CANNABIS SATIVA*) is a common weed growing freely in many parts of the world, where it is used as a medicine, an intoxicant and a source of fiber. It is classified as a dioecious plant, that is, the male reproductive parts are on one individual (*left*) and the female parts are on another (*right*). Details of the two types of flower are shown at bottom. The active substances in the drug are contained in a sticky yellow resin that covers the flower clusters and top leaves of the female plant when it is ripe.

form in which it is taken. About 80 derivatives of cannabinol have been prepared, and some of these have been tested for effects in animals or in human volunteers.

The effects of cannabis (used here as a general term for the various forms of the psychoactive products of the plant) in animals are confined to the central nervous system. The drug does not noticeably affect the gross behavior of rats or mice or simple learning in rats; it does, however, calm mice that have been made aggressive by isolation, and in dogs it induces a dreamy, somnolent state reminiscent of the last stage of a human "high." In large doses cannabis produces in animals symptoms such as vomiting, diarrhea, fibrillary tremors and failure of muscular coordination. Lethal doses have been established for a few animals; given by mouth, the lethal dose for cats, for example, is three grams of charas, eight grams of ganja or 10 grams of bhang per kilogram of body weight. Huge doses have been given to dogs without causing death, and there has been no reported case of a fatality from the drug in man.

The psychic effects of the drug have been described in a very extensive literature. Hashish long ago acquired a lurid reputation through the writings of literary figures, notably the group of French writers (Baudelaire, Gautier, Dumas *père* and others) who formed Le Club des Hachichins (hashish smokers) in Paris in the 1850's. Their reports, written under the influence of large amounts of hashish, must be discounted as exaggerations that do not apply to moderate use of the drug. Hashish is supposed to have been responsible for Baudelaire's psychosis and death, but the story overlooks the fact that he had been an alcoholic and suffered from tertiary syphilis.

Bayard Taylor, the American writer, lecturer and traveler best known for his translation of Goethe's *Faust,* wrote one of the first accounts of a cannabis experience in terms that began to approach a clinical description. He tried the drug in a spirit of inquiry during a visit to Egypt in 1854 and related the effects as follows: "The sensations it then produced were ... physically of exquisite lightness and airiness—mentally of a wonderfully keen perception of the ludicrous in the most simple and familiar objects. During the half hour in which it lasted, I was at no time so far under its control that I could not, with the clearest perception, study the changes through which I passed. I noted with careful attention the fine sensations which spread throughout the whole tissue of my nervous fibers, each thrill helping to divest my frame of its earthly and material nature, till my substance appeared to me no grosser than the vapours of the atmosphere, and while sitting in the calm of the Egyptian twilight I expected to be lifted up and carried away by the first breeze that should ruffle the Nile. While this process was going on, the objects by which I was surrounded assumed a strange and whimsical expression.... I was provoked into a long fit of laughter. The Hallucination died away as gradually as it came, leaving me overcome with a soft and pleasant drowsiness, from which I sank into a deep, refreshing sleep."

Perhaps the most detailed clinical account is that of the noted New York psychiatrist Walter Bromberg, who in 1934 described the psychic effects on the basis of many observations and talks with people while they were under the influence of marihuana and of his own experience with the drug. "The intoxication," he wrote, "is initiated by a period of anxiety within 10 to 30 minutes after smoking, in which the user sometimes ... develops fears of death and anxieties of vague nature associated with restlessness and hyper-activity. Within a few minutes he begins to feel more calm and soon develops definite euphoria; he becomes talkative ... is elated, exhilarated ... begins to have ... an astounding feeling of lightness of the limbs and body ... laughs uncontrollably and explosively ... without at times the slightest provocation ... has the impression that his conversation is witty, brilliant.... The rapid flow of ideas gives the impression of brilliance of thought and observation [but] confusion appears on trying to remember what was thought ... he may begin to see visual hallucinations ... flashes of light or amorphous forms of vivid color which evolve and develop into geometric figures, shapes, human faces and pictures of great complexity.... After a longer or shorter time, lasting up to two hours, the smoker becomes drowsy, falls into a dreamless sleep and awakens with no physiologic after-effects and with a clear memory of what had happened during the intoxication."

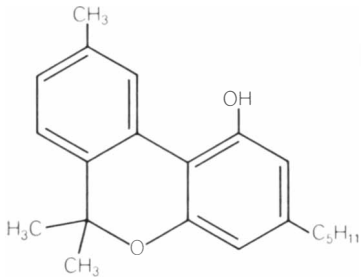
Most observers confirm Bromberg's account as a composite description of marihuana highs. They find that the effects from smoking marihuana last for two to four hours, and from ingestion of the drug, for five to 12 hours. For a new user the initial anxiety that sometimes occurs is alleviated if supportive friends are present; experienced users occasionally describe it as "happy anxiety." It is contended that the intoxication heightens sensitivity to external stimuli, reveals details that would ordinarily be overlooked, makes colors seem brighter and richer, brings out values in works of art that previously had little or no meaning to the viewer and enhances the appreciation of music. Many jazz musicians have said they perform better under the influence of marihuana, but this has not been objectively confirmed.

The sense of time is distorted: 10 minutes may seem like an hour. Curiously, there is often a splitting of consciousness, so that the smoker, while experiencing the high, is at the same time an objective observer of his own intoxication. He may, for example, be afflicted with paranoid thoughts yet at the same time be reasonably objective about them and even laugh or scoff at them and in a sense enjoy them. The ability to retain a degree of objectivity may explain the fact that many experienced users of marihuana manage to behave in a perfectly sober fashion in public even when they are highly intoxicated.

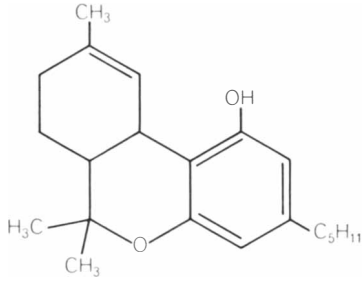
Marihuana is definitely distinguishable from other hallucinogenic drugs such as LSD, DMT, mescaline, peyote and psilocybin. Although it produces some of the same effects, it is far less potent than these other drugs. It does not alter consciousness to nearly so great an extent as they do nor does it lead to increasing tolerance to the drug dosage. Moreover, marihuana smokers can usually gauge the effects accurately and thus control the intake of the drug to the amount required to produce the desired degree of euphoria.

Let us consider now what has been learned from attempts to obtain objective measurements of the effects of the use of marihuana: psychological, physiological, psychic and social. There is a large literature on these studies, extending over a century or more and particularly voluminous in the 1960's. Although most of the studies leave much to be desired methodologically, many nonetheless add to the total of our knowledge about the drug.

An intensive investigation exploring various aspects of the marihuana problem was conducted in the 1930's by a committee appointed by Mayor Fiorello La Guardia of New York. In this inquiry Robert S. Morrow examined the effects of the drug on psychomotor functions and certain sensory abilities. He found that even in large doses marihuana did



CANNABINOL



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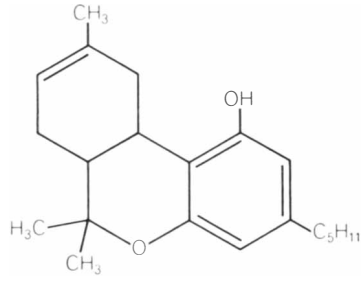

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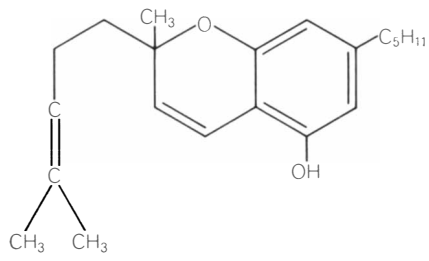
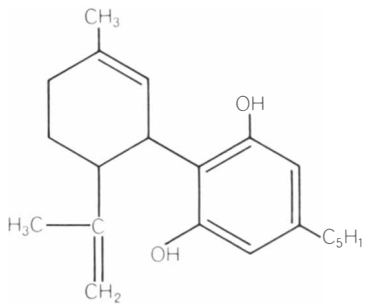


CANNABICHROMENE



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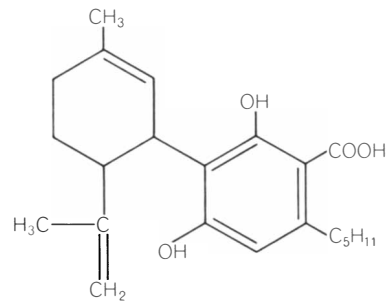


CANNABIDIOLIC ACID

**ACTIVE CONSTITUENTS of the cannabis drugs include various derivatives of cannabinol, only a few of which are represented by the molecular diagrams on these two pages. One of the isomers of tetrahydrocannabinol, called the delta-1 form (*second from left in*

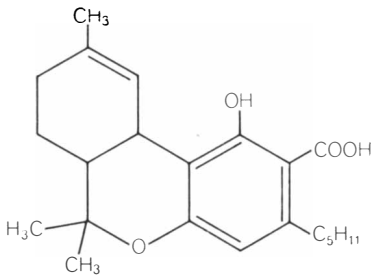
not affect performance on tests of the speed of tapping or the quickness of response to simple stimuli. Nor did it impair hearing acuity, musical ability or the ability to judge short time periods or short distances accurately. The drug did affect steadiness of the hand and body and the reaction time for complex stimuli.

More recently Lincoln D. Clark and Edwin N. Nakashima of the University of Utah College of Medicine used eight tests of perception, coordination and learning to examine subjects who received doses of marihuana by mouth. They found that performance on six of the eight tests was not impaired even by high doses of the drug. The two tasks on which performance was affected were reaction time and learning of a digit code; however, in the case of the former this conclusion was based on data from only two subjects and in the latter test it was based on data from five subjects, one of whom actually showed improvement while receiving the drug.

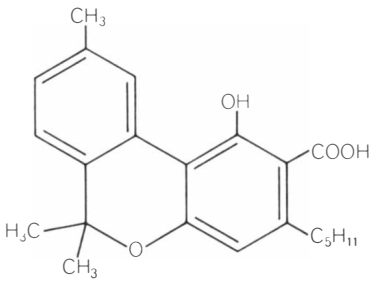
Andrew T. Weil, Norman E. Zinberg and Judith M. Nelsen of the Boston University School of Medicine recently applied other tests to two different groups of subjects, one group consisting of chronic users of marihuana, the other of persons experiencing the drug for the first time. In ability to maintain sustained attention (the "Continuous Performance Test") the performance of both groups was unaffected either by a low dose or by a high dose of the drug. In cognitive functioning (the "Digit Symbol Substitution Test") the drug-naïve group showed some impairment during the high, but the performance of experienced users of marihuana showed no significant impairment and in fact on the higher doses revealed a trend toward improvement. In muscular coordination and attention (the "Pursuit Rotor Test") the results were the same as in the DSST, but in this case the improvement in the chronic users' performance may have been due simply to practice at the task. Nine subjects receiving the drug for the first time were also tested for the effect on their time sense. Before taking the drug the subjects had shown that in the undrugged state they could come within two minutes of estimating a five-minute interval correctly. After receiving a placebo no subject changed his guess of a five-minute time span. While intoxicated on a low dose three subjects roughly doubled their estimate of a five-minute time span, and while on a high dose four increased their estimates.

In the La Guardia study Florence Halpern investigated marihuana's effects on intellectual functioning. She found that the subjects' scores on intelligence tests, particularly where number concepts were involved, tended to decline during the mature stages of a high. Their performance returned to normal afterward. In some tests of memory and of verbal facility the performances either were not impaired or actually were improved under the influence of low doses of the drug. She concluded that where intellectual performance was reduced the lowered scores were due to a loss of speed and accuracy during the intoxication.

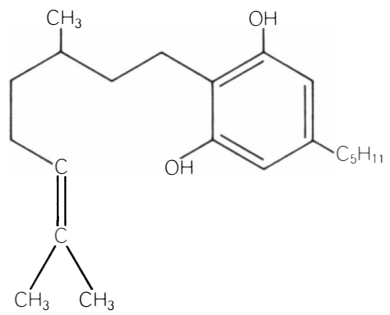
A number of investigators, including members of the La Guardia study, Weil's group and others, have examined the physical and physiological effects of marihuana intoxication. Occasionally there may be nausea, vomiting and diarrhea, particularly if the drug is taken by mouth. Usually, however, the bodily symptoms accompanying the high are slight. There is only very slight, if any, dilatation of the pupils accompanied by a sluggish pupillary response to light, slight tremors and a mild lack of coordination. A consistently observed physiological effect is increase in the pulse rate



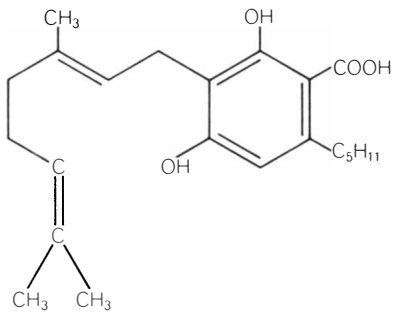
Δ¹-TRANS-TETRAHYDROCANNABINOLIC ACID



CANNABINOLIC ACID



CANNABIGEROL



CANNABIGEROLIC ACID

***top row*), has been synthesized and is believed to be the primary active component of marihuana. The drug's intoxicating effects, however, probably involve other components as well.**

[*see illustration on page 23*]; in addition there may be a slight rise in the blood pressure. Urination tends to increase in frequency and perhaps in amount. Often the mouth and throat feel dry, causing thirst. One of the most striking results of the intoxication is a sense of hunger. It generates a high appreciation of food, so that a person under the influence may approach an ordinary dish with the anticipation of a gourmet confronting a special treat. This effect suggests that the drug might be useful in the treatment of the pathological loss of appetite known as anorexia nervosa.

There is now an abundance of evidence that marihuana is not an addictive drug. Cessation of its use produces no withdrawal symptoms, nor does a user feel any need to increase the dosage as he becomes accustomed to the drug. Investigators have found that habituation to marihuana is not as strong as to tobacco or to alcohol. Bromberg concluded that marihuana is not habit-forming, and that it is used to serve "the hedonistic elements of the personality." It is certainly possible that in some people this desire may develop into a dependency on the drug for the experience of pleasure or respite from psychic pain. Can such a use be called abuse of the drug? The term "abuse" is difficult to define; its interpretation varies from culture to culture and from custom to custom. If abuse is measured in terms of the danger to the individual and society, then it must be pointed out that although the dangers of alcoholism and even of social drinking are well established, social drinking is not considered abuse in the U.S. The dangers of the use of marihuana, on the other hand, have not yet been clearly determined.

The prevailing public attitude toward marihuana in the U.S. is charged with a hyperemotional bias. In part this is the product of an "educational campaign" initiated in the 1930's by the Federal Bureau of Narcotics (since renamed the Bureau of Narcotics and Dangerous Drugs), a campaign that has disseminated much distortion and misinformation about the drug [*see illustration on next page*]. There are also cultural and social factors that contribute to the public apprehension about marihuana. The still powerful vestige of the Protestant ethic in this country condemns marihuana as an opiate used solely for the pursuit of pleasure (whereas alcohol is accepted because it lubricates the wheels of commerce and catalyzes social intercourse). Marihuana's effect in producing a state of introspection and bodily passivity is repellent to a cultural tradition that prizes activity, aggressiveness and achievement. And it may well be that social prejudices enter into the public alarm concerning the drug: prejudice on the part of the older generation, which sees marihuana as a symbol of the alienation of the young, and on the part of the white population, which, perhaps largely unconsciously, regards marihuana as a nonwhite drug that is rapidly invading the white community, because until fairly recently the smoking of marihuana took place mainly in the ghettos of Negroes, Puerto Ricans and people of Mexican origin. It is perhaps no accident that some of the Southern states have most severe laws against the distribution of marihuana, carrying penalties of life imprisonment or even death in some cases.

If we are to find a rational and effective approach to the problem of the increasing use of marihuana in the U.S., we obviously need to reduce the emotionalism surrounding the subject and replace myths with facts as far as they can be determined. Let us examine the current suppositions about the drug.

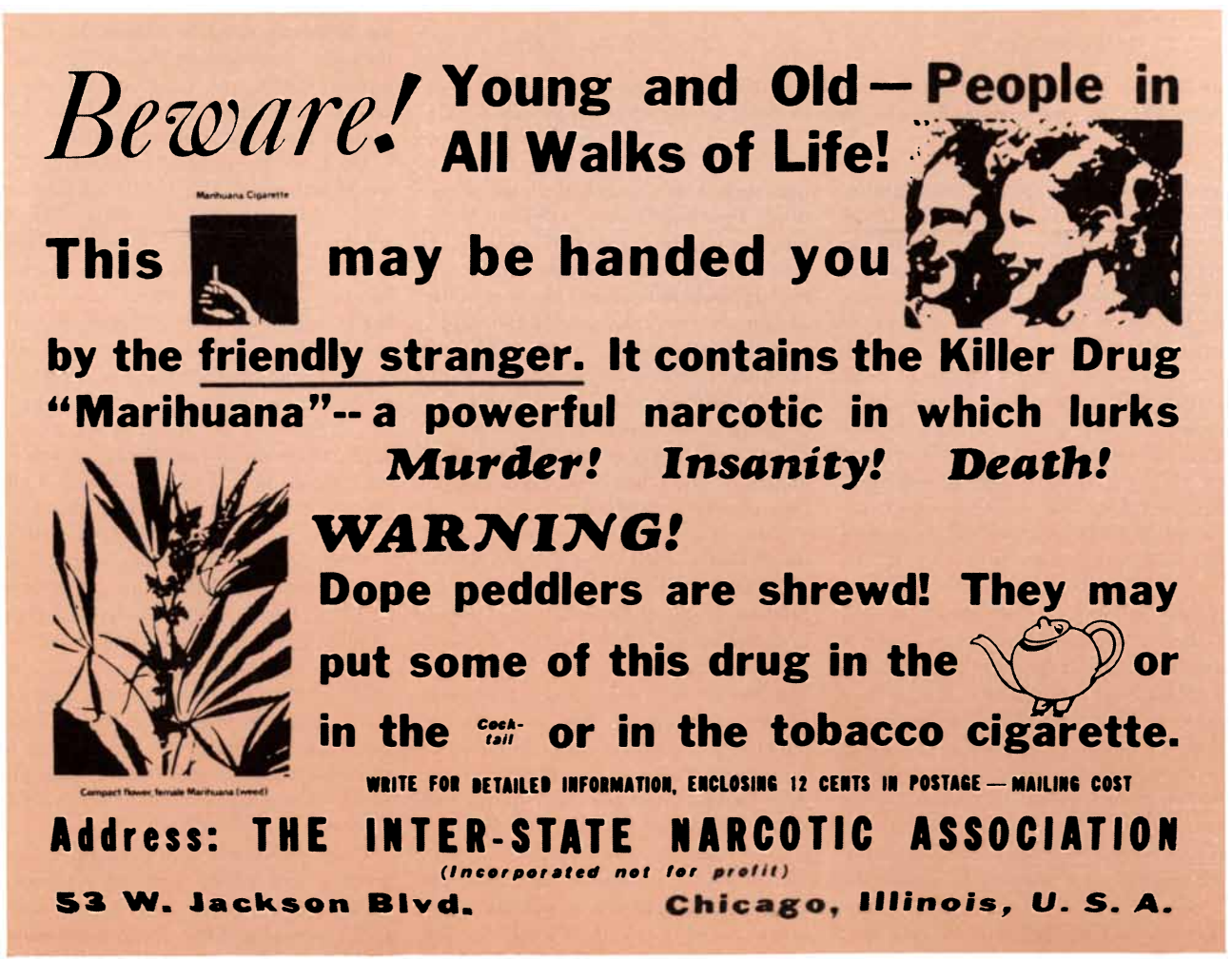
Does marihuana lead its users to the use of narcotics? The 1937 Federal law that made the cannabis drugs illegal led to a rise in price that provided an incentive to pushers of narcotics to also handle marihuana without any additional legal risk. The resulting potential for the exposure of users to both types of drugs might have been expected to lead to an increase in the use of narcotics that was significantly related to the increasing use of marihuana. No such relation has been found in several studies that have looked into this question, including the La Guardia study and a U.S. Presidential task force investigation of narcotics and drug abuse. It is true that the Federal study showed that among heroin users about 50 percent had had experience with marihuana; the study also found, however, that most of the heroin addicts had been users of alcohol and tobacco. There is no evidence that marihuana is more likely than alcohol or tobacco to lead to the use of narcotics.

Does marihuana incite people to aggression and violent criminal behavior, as some investigators have maintained? In an intensive study of the marihuana problem in Manhattan, Bromberg found no indication of such a relation. "No cases of murder or sexual crime due to

marihuana were established." Reviewing a case that had been cited by the Federal Bureau of Narcotics, of a man who was alleged to have confessed to murdering a friend while under the influence of marihuana, Bromberg found on examination of the individual that he was a psychopathic liar and that there was "no indication in the examination or history" that he had ever used marihuana or any other drug. A psychiatric investigator in Nigeria, T. Asuni, noted that an underprivileged community had a high incidence both of crime and of the use of hashish, but he concluded that these statistics were attributable to the frustrations of the people's lives rather than to a relation between the drug and crime. Indeed, two investigators of the use of the drug in India, R. N. Chopra and G. S. Chopra, have contended that instead of inciting criminal behavior cannabis tends to suppress it; the intoxication induces a lethargy that is not conducive to any physical activity, let alone the committing of crimes. The release of inhibitions results in verbal rather than behavioral expression. During the high the marihuana user may say things he would not ordinarily say, but he generally will not do things that are foreign to his nature. If he is not normally a criminal, he will not commit a crime under the influence of the drug.

Does marihuana induce sexual debauchery? This popular impression may owe its origin partly to the fantasies of dissolute writers and partly to the fact that in times past users in the Middle East laced the drug with aphrodisiacs. There is no evidence that cannabis stimulates sexual desire or power; this is conceded even by Ahmed Benabud, a Moroccan psychiatrist and investigator of the drug who condemns it severely on psychological grounds. There are those, on the other hand, who contend that marihuana weakens sexual desire—with equally little substantiation. Some marihuana users report that the high enhances the enjoyment of sexual intercourse. This may be true in the same sense that the enjoyment of art and music is apparently enhanced. It is questionable, however, that the intoxication breaks down moral barriers that are not already broken.

Does marihuana lead to physical and mental degeneracy? Reports from many investigators, particularly in Egypt and in parts of the Orient, indicate that long-term users of the potent versions of cannabis are indeed typically passive, nonproductive, slothful and totally lacking in ambition. It is possible that chronic use of the drug in its stronger forms may in fact have debilitating effects, as prolonged heavy drinking does. There is another possible explanation, however. Many of those who take up cannabis are people who are hungry, sick, hopeless or defeated, seeking through this inexpensive drug to soften the impact of an otherwise unbearable reality. In most situations one cannot be certain which came



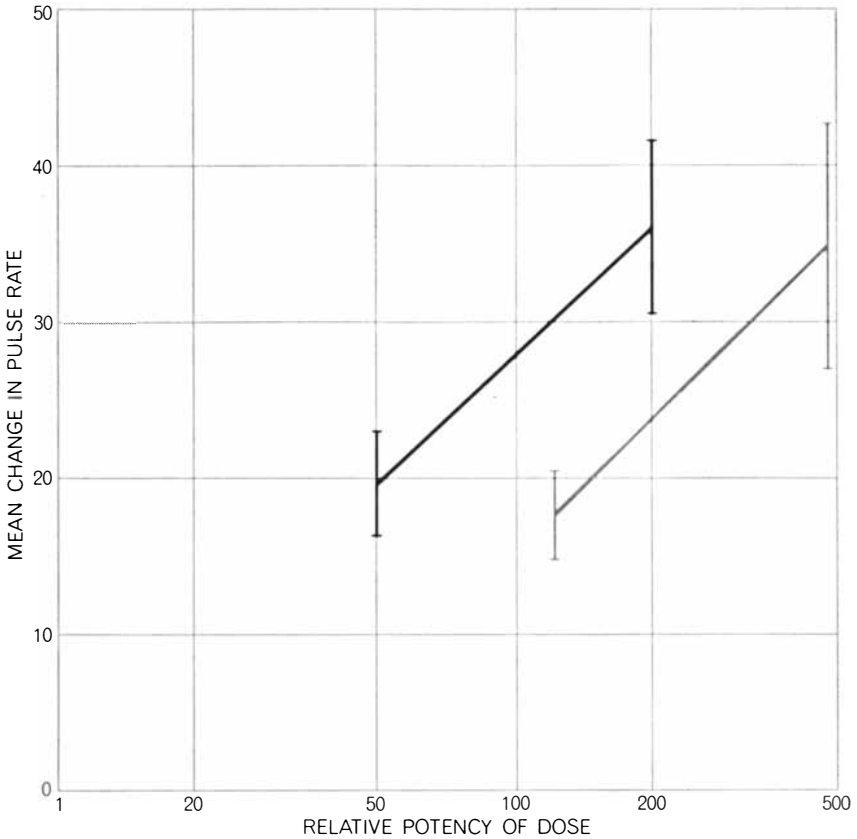
ANTIMARIHUANA POSTER is part of the "educational campaign describing the drug, its identification and evil effects" supported in the U.S. since the 1930's by the Federal Bureau of Narcotics (since renamed the Bureau of Narcotics and Dangerous Drugs).

first: the drug on the one hand or the depression or personality disorder on the other. This question applies to many of the "potheads" in the U.S. An intensive study of college students who had taken to marihuana showed that many of them had suffered serious conflicts or depression long before they began to use the drug.

There is a substantial body of evidence that moderate use of marihuana does not produce physical or mental deterioration. One of the earliest and most extensive studies of this question was an investigation conducted by the British Government in India in the 1890's. The real motive for the inquiry is suspected to have been to establish that cannabis was more dangerous than Scotch whisky, from whose sale the government could obtain a great deal more tax revenue. Nevertheless, the investigation was carried out with typical British impartiality and thoroughness. The investigating agency, called the Indian Hemp Drug Commission, interviewed some 800 persons, including cannabis users and dealers, physicians, superintendents of insane asylums, religious leaders and a variety of other authorities, and in 1894 published a report running to more than 3,000 pages. It concluded that there was no evidence that moderate use of the cannabis drugs produced any disease or mental or moral damage or that it had any more tendency to lead to excess than the moderate use of whisky did.

In the La Guardia study in New York City an examination of chronic users who had averaged about seven marihuana cigarettes a day (a comparatively high dosage) over a long period (the mean was eight years) showed that they had suffered no mental or physical decline as a result of their use of the drug. A similar study by H. L. Freedman and M. J. Rockmore, examining 310 Army men who had used marihuana for an average of seven years, produced the same finding.

In the effort to obtain a rational perspective on the marihuana problem one is inevitably drawn repeatedly to comparisons between this drug and alcohol and to the public attitudes toward the two drugs. The habit called social drinking is considered as American as apple pie, and it receives about as much public acceptance. Yet even this kind of drinking carries clearly demonstrated hazards and consequences of a most serious nature. Life insurance statistics show that social drinkers have considerably higher than average mortality rates from all the leading causes of death: diseases of the heart and circulatory system, cancer, diseases of the digestive system, homicides, suicides and motor-vehicle and other accidents. A majority of drivers killed in vehicle accidents are found to have been drinking. In contrast, there has been no evidence so far that marihuana contributes to the development of any organic disease, and in the only investigation to date of the effect on driving, a controlled study conducted recently by the Bureau of Motor Vehicles of the state of Washington, it was found that marihuana causes significantly less impairment of driving ability than alcohol does [*see illustration on page 25*].



INCREASE IN PULSE RATE is the most consistently reported physiological effect of marihuana intoxication. In this graph, based on the work of Harris Isbell and his colleagues at the University of Kentucky, the two lines show the pulse responses to varying doses of pure synthetic delta-1-tetrahydrocannabinol, taken both by smoking (*left*) and orally (*right*). In most cases the physiological effects of a marihuana "high" are slight.

Perhaps the weightiest charge made against cannabis is that it may lead to psychosis or at least to personality disorders. There is a vast literature on this subject, and it divides into all shades of opinion. Many psychiatrists in India, Egypt, Morocco and Nigeria have declared emphatically that the drug can produce insanity; others insist that it does not. One of the authorities most often quoted in support of the indictment is Benabud of Morocco. He believes that the drug produces a specific syndrome, called "cannabis psychosis." His description of the identifying symptoms is far from clear, however, and other investigators dispute the existence of such a psychosis. The symptoms said to be characteristic of this syndrome are also common to other acute toxic states including, particularly in Morocco, those associated with malnutrition and endemic infections. Benabud estimates that the number of kif (marihuana) smokers suffering from all types of psychosis is not more than five per 1,000; this rate, however, is lower than the estimated total incidence of all psychoses in populations of other countries. Thus one would have to assume either that there is a much lower prevalence of psychoses other than "cannabis psychosis" among kif smokers in Morocco or that there is no such thing as a "cannabis psychosis," and that the drug is contributing little or nothing to the prevalence rate for psychoses.

The American psychiatrist Bromberg,

in a report of one of his studies, listed 31 patients whose psychoses he attributed to the toxic effects of marihuana. Of these 31, however, seven patients were already predisposed to functional psychoses that were only precipitated by the drug, seven others were later found to be schizophrenics, one was later diagnosed as a manic-depressive and a number of others may have had an acute and temporary attack of psychosis (the "five-day schizophrenia") that could have been mistaken for a drug reaction.

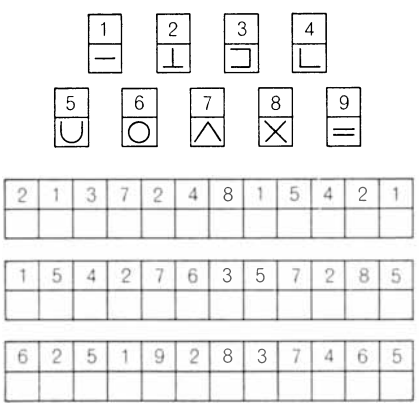
Bromberg found no psychotics among 67 imprisoned criminals who had been users of marihuana. Freedman and Rockmore found none among the 310 marihuana-smoking soldiers they studied, and similar findings have been reported in several other studies of sizable samples. The Chopras in India, in examinations of a total of 1,238 cannabis users, found only 13 to be psychotic, which is about the usual rate of incidence of psychosis in the total population in Western countries. In the La Guardia study nine out of 77 subjects who were studied intensively had a history of psychosis; this high rate could be attributed, however, to the fact that all the subjects were patients in hospitals or institutions. Samuel Allentuck and K. H. Bowman, the psychiatrists who examined this group, concluded that "marihuana will not produce psychosis *de novo* in a well-integrated, stable person."

This is not to say that the drug may not precipitate an acute anxiety state with paranoid thoughts or even a temporary psychosis in a susceptible person. A drug that alters the state of consciousness and distorts perception and the body image may well tip a delicately balanced ego, already overburdened with anxiety, into a schizophrenic reaction. In our clinical research program at the Massachusetts Mental Health Center in Boston we surveyed the cases of 41 patients who had been admitted in an acute state of schizophrenia. Six of the patients had used marihuana at one time or another, but in four cases the drug experience had occurred long before the schizophrenic breakdown. In the other two cases a careful study of the entire history failed to indicate definitely whether the drug had or had not precipitated the psychosis.

Very little research attention has been given to the possibility that marihuana might *protect* some people from psychosis. Among users of the drug the proportion of people with neuroses or personality disorders is usually higher than in the general population; one might therefore expect the incidence of psychoses also to be higher in this group. The fact that it is not suggests that for some mentally disturbed people the escape provided by the drug may serve to prevent a psychotic breakdown.

A century ago a French physician, Jacques Joseph Moreau de Tours, reported that he had successfully treated melancholia and other chronic mental illnesses with an extract of cannabis. Several other physicians in France, Germany and England tried the drug, with conflicting results. In the 1940's some interest developed in synhexyl, a synthetic tetrahydrocannabinol, as an apparently promising treatment for depressive psychoses; in the only controlled study, however, this particular drug was found to be no more effective than a placebo.

Tests of the use of cannabis to help



NAÏVE SUBJECTS	15 MINUTES			90 MINUTES		
	PLACEBO	LOW DOSE	HIGH DOSE	PLACEBO	LOW DOSE	HIGH DOSE
1	−3	—	+5	−7	+4	+8
2	+10	−8	−17	−1	−15	−5
3	−3	+6	−7	−10	+2	−1
4	+3	−4	−3		−7	
5	+4	+1	−7	+6		−8
6	−3	−1	−9	+3	−5	−12
7	+2	−4	−6	+3	−5	−4
8	−1	+3	+1	+4	+4	−3
9	−1	−4	−3	+6	−1	−10
MEAN	+0.9	−1.2	−5.1	+0.4	−2.6	−3.9
STANDARD ERROR	1.4	1.4	2.1	1.9	2.0	2.0

CHRONIC USERS	HIGH DOSE	HIGH DOSE
10	−4	−16
11	+1	+6
12	+11	+18
13	+3	+4
14	−2	−3
15	−6	+8
16	−4	
17	+3	
MEAN	+0.25	+2.8
STANDARD ERROR	1.9	4.7

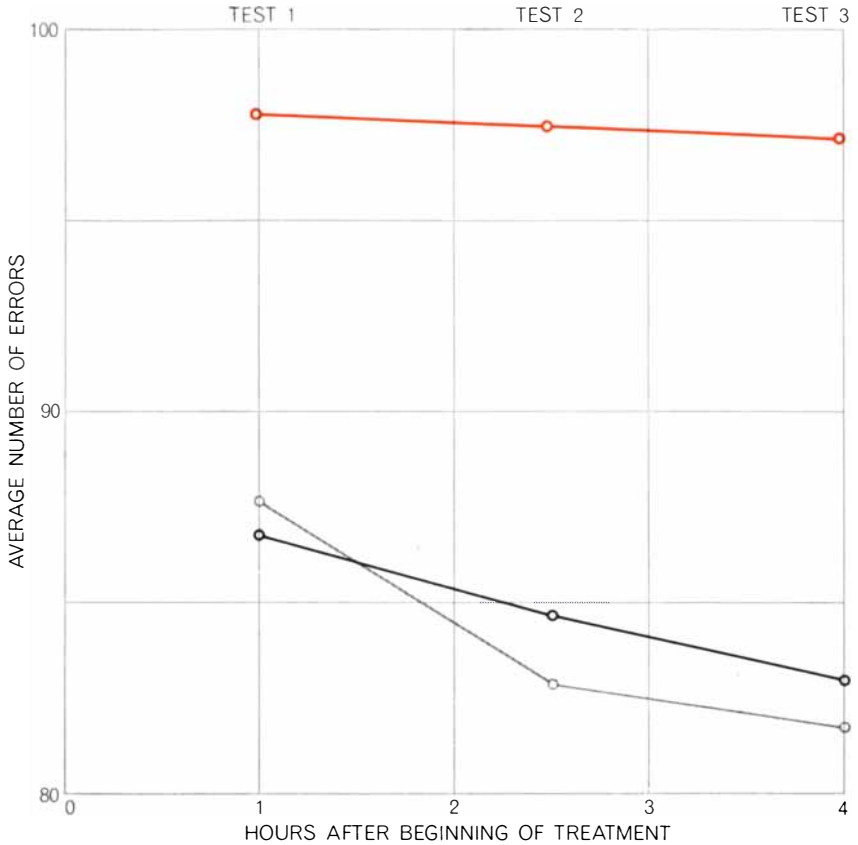
TEST OF COGNITIVE FUNCTIONING (called "Digit Symbol Substitution Test") was administered recently by Andrew T. Weil, Norman E. Zinberg and Judith M. Nelsen of the Boston University School of Medicine to two different groups of subjects, one group consisting of chronic users of marihuana, the other of persons experiencing the drug for the first time. A sample of the test is shown at left; the results of the study are summarized at right. On a signal from the examiner the subject was required to fill as many of the empty spaces as possible with the appropriate symbols. The code was always available to the subject during the 90-second administration of the test. The results were tabulated in terms of the change in scores from a base-line score (number correct before smoking marihuana) both 15 minutes and 90 minutes after the smoking session. On the average Weil and his colleagues found that the drug-naïve group showed some impairment during the high (*top right*), but the performance of experienced users of marihuana showed no significant impairment and in fact on the higher doses revealed a slight trend toward improvement (*bottom right*).

drug addicts withdraw from the use of narcotics have yielded more promising results. The first medical use for this purpose was reported in 1889 by an English physician, Edward Birch, who treated a chloral hydrate addict and an opium addict by replacing their drugs with cannabis and found they were then able to discontinue the cannabis without withdrawal symptoms. Similar successes were obtained more recently in two notable trials: one reported in 1942 by Allentuck and Bowman, who tapered off opiate addicts with a marihuana derivative, and another in 1953 by two North Carolina physicians, L. S. Thompson and R. C. Proctor, who withdrew patients from addiction to narcotics, barbiturates and alcohol by the use of pyrahexyl, a tetrahydrocannabinol.

Curiously, these encouraging results have not been followed up by large-scale clinical trials or basic research. It seems that research on the possible medical uses of marihuana is discouraged by the lingering common impression that it is addictive and by the fact that the drug is outlawed and difficult to obtain legally even for research purposes.

Indispensable to an understanding of marihuana's effects and of the present burgeoning spread of its use is the study in depth of people's motivations for using it. In India, where the use is not illegal and therefore not complicated by anxieties arising from that cause, cannabis serves the clear-cut purpose of simple relief from the dreariness and hardships of poverty. The Chopras note that during the harvest season the consumption of the drug increases by 50 percent among farmers in some areas. These authors observe: "A common practice amongst laborers engaged in building or excavation work is to have a few pulls at a ganja pipe or to drink a glass of bhang toward the evening. This produces a sense of well-being, relieves fatigue, stimulates the appetite and induces a feeling of mild stimulation which enables the worker to bear more cheerfully the strain of the daily routine of life."

This simple motivation goes far to explain the fact that in the U.S. marihuana first came into wide use in the ghettos. Several studies of population samples in the Army have shown that 87 percent or more of the marihuana users there were Negroes. Inquiring into the motivations of the 310 marihuana smokers they studied, Freedman and Rockmore found that the responses generally ran in this vein: the drug gave its users "a good feeling"; it was a substitute for whisky; "I feel bad all the time—weeds make me feel better"; "It makes me sleep and eases my pain"; "It makes me feel like I'm a man." For many the drug was evidently an escape from feelings of inadequacy, personal frustrations, anxiety and/or depression.



COMPARATIVE STUDY of the effects of marihuana and alcohol on simulated driving performance was conducted by the Bureau of Motor Vehicles of the state of Washington. The graph shows average number of errors on tests administered at three stages after treatment with alcohol (*color*), marihuana (*black*) and a placebo (*gray*). In general it was found that marihuana causes significantly less impairment of driving ability than alcohol does.

One must look beyond personal factors, however, to account for the current vogue of marihuana among large portions of the U.S. population. A study of 54 psychiatric patients who were white, middle-class college graduates, for example, elicited the responses that they took up marihuana out of curiosity, to go along with friends, for stimulation or for an unusual experience. Among the youth of this country marihuana has a powerful attraction for those who have a tendency to introspection and meditation or an urge to retire from involvement in society. For many the use of the illegal drug is an act of defiance of the "establishment."

As C. P. Snow has observed: "Uneasiness seems to be becoming part of the climate of our time." It is difficult to avoid the conclusion that the increasing use of marihuana is in part related to the fearful threats of overpopulation, racial conflict and nuclear war. Conversely, the same threats may indirectly be contributing to the emotional campaign against this drug. It is conceivable that some of the affect generated in the population by the violence and martial spirit of our time is being displaced onto issues such as marihuana. Regarded as essentially evil and dangerous, adopted by hippies, yippies and others who demonstrate and call attention to the aspects of reality and the threats of doom that most of us find too distressing to confront, marihuana is a natural target as a scapegoat.

In short, the anxiety and sense of helplessness generated by the dangers of our time may be focused in some degree on marihuana, driving some people to protective immersion in the drug and arousing others to a crusade against it. Although either of these responses may have some adaptive value for the individual psyche, neither contributes toward the development of a more secure world.

New Methods for Approaching Absolute Zero

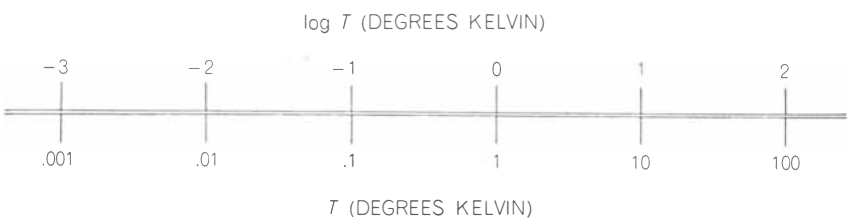
Low-temperature physicists have recently devised three different experimental procedures capable of lowering the temperature range accessible for research to within millidegrees of absolute zero

by O. V. Lounasmaa

The atoms and molecules that make up all the forms of matter are in constant thermal motion; the higher the temperature, the higher their average speed. In solids molecules have fixed lattice sites but their thermal motion causes them to vibrate around these equilibrium positions. In principle there is no upper limit of temperature; as thermal motion becomes increasingly violent a solid body first melts and then evaporates. Finally, as the temperature is increased still further, atoms lose some or all of their electrons, thereby forming a plasma, or cloud of charged particles. This situation exists inside stars, where the temperature is many millions of degrees Celsius.

In contrast, there is a definite stop at the other end of the temperature scale. Theoretically when thermal motion ceases, the coldest possible temperature—"absolute zero"—has been reached. This limiting temperature is −273.16 degrees C. (which is equal to −459.69 degrees on the Fahrenheit scale). A fundamental postulate of physics, the third law of thermodynamics, states that it is impossible to reach absolute zero. By suitable experimental procedures one can come closer and closer to this temperature, but ultimate success will remain elusive, no matter how hard one tries.

Low-temperature physicists customarily denote temperatures in degrees Kelvin. On this scale absolute zero is zero degrees K. and temperatures are measured upward using degrees that are equal in length to degrees on the Celsius, or centigrade, scale. The melting point of ice is thus 273.16 degrees K. The Kelvin temperature, represented by T, is often referred to as the absolute temperature. In nature the ratio of two absolute temperatures, T_1/T_2, is more important than their difference, $T_1 - T_2$. The ratio of 300 degrees K. to 100 degrees K. is equal to the ratio of three degrees K. to one degree K. From a fundamental point of view a temperature reduction from 300 degrees K. to 100 degrees is just as significant as cooling from three degrees K. to one degree. This fact can be graphically represented on a logarithmic scale where $\log T$, instead of T, is plotted on the temperature axis [*see illustration below*]. On this type of graph the unattainability of absolute zero becomes clear, the point $T =$ zero degrees K. being infinitely far to the left on the temperature axis. In practice a linear scale is normally used, but it is important to emphasize that the distance from 10 degrees K. to one degree is just as great as the distance from .001 degree K. to .0001 degree.



UNATTAINABILITY OF ABSOLUTE ZERO is graphically demonstrated by this illustration, in which the absolute temperature is plotted in degrees Kelvin on a logarithmic scale rather than on a normal linear scale. The logarithmic scale better represents the task confronted by low-temperature physicists, since in nature the ratio of two absolute temperatures, T_1/T_2, is more important than their difference, $T_1 - T_2$. Thus the distance from 10 degrees K. to one degree is just as great as the distance from .001 degree K. to .0001 degree. On the logarithmic scale the point at which $T =$ zero degrees K. is infinitely far to the left.

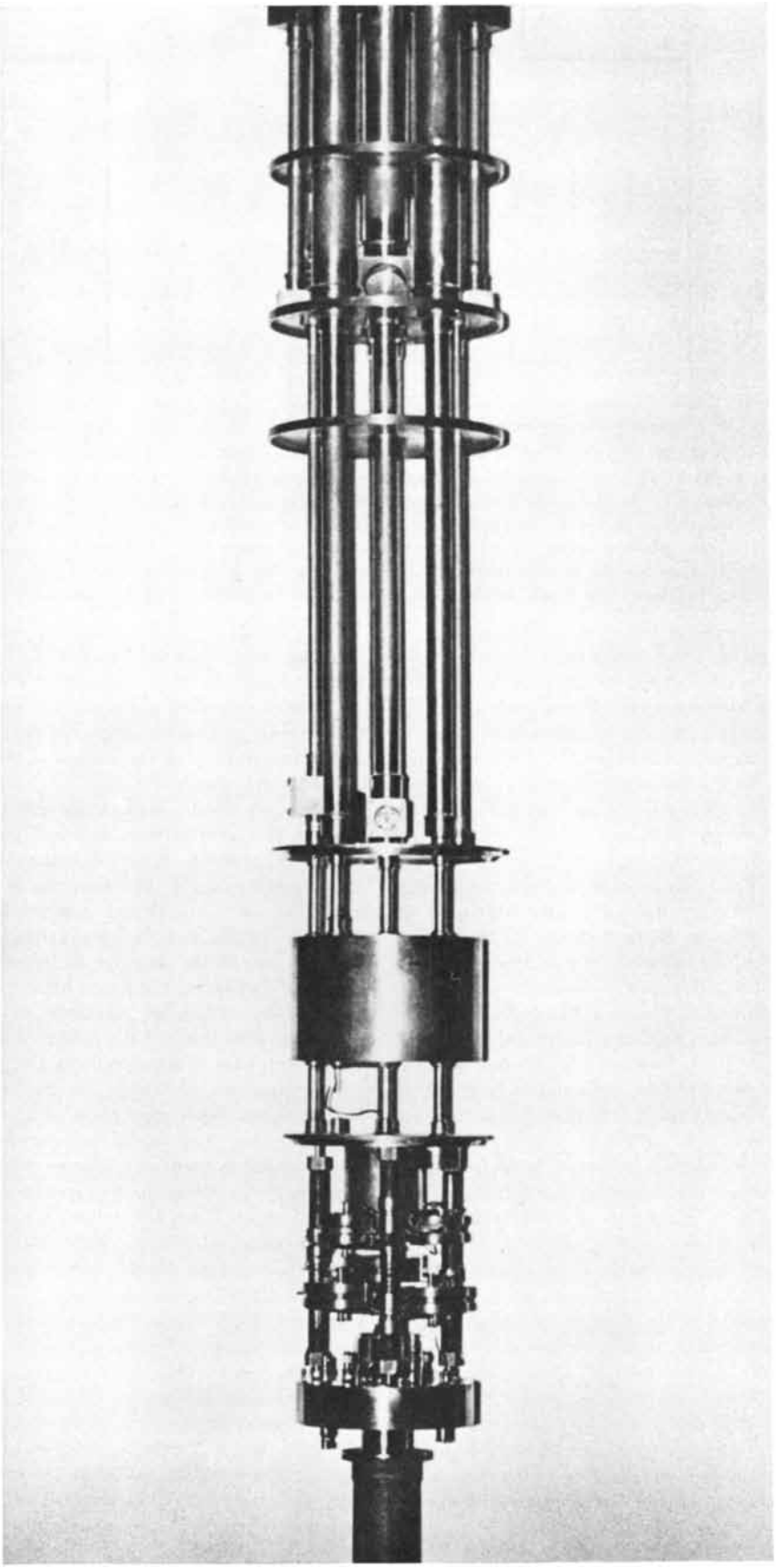
Low-temperature physicists constantly try to extend the temperature range accessible to experimental investigation closer and closer to absolute zero. There are at least two good reasons for this endeavor. First, certain fundamentally important properties of matter, such as superconductivity and superfluidity, occur only at such low temperatures. It is always possible that new, perhaps completely unsuspected and equally interesting properties will be found when it becomes possible to make measurements at still lower temperatures. The second reason for experiments near absolute zero is the desire to study matter under conditions at which thermal disorder is as small as possible. A typical example is the study of the angular distribution of gamma rays emitted from radioactive nuclei. A nucleus can be regarded as being either a sphere or an ellipsoid that has a definite magnetic axis with a north and a south pole. Normally these elementary nuclear magnets are randomly oriented because of their thermal motion. Even the highest magnetic fields available in the laboratory are not strong enough to align the nuclei unless the thermal motion has been reduced sufficiently by cooling the specimen to .01 degree K. or below. If this can be achieved, one should in principle be able to study the gamma ray emission from the aligned nuclei. Such experiments have actually been done, and it has been found that the intensity of the radiation is no longer isotropic (that is, nondirectional) in space. This result, made possible by advanced low-temperature techniques, was very important

for the development of nuclear theory. Sometimes temperatures in the vicinity of .001 degree K. or lower are required to bring order into a nuclear system.

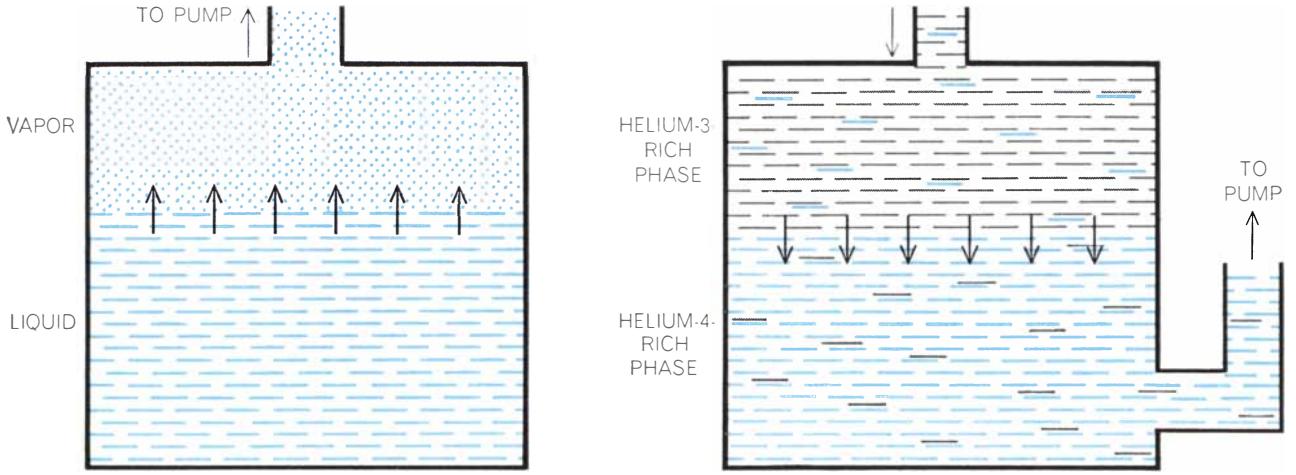
The simplest and most common method for making measurements at low temperatures is to immerse the specimen under study in a cold liquid. Nitrogen, which boils at 77 degrees K., and helium, which boils at 4.2 degrees, are the liquids normally used. The temperature of any liquid can be further reduced by pumping on it [*see illustration on next page*]. The pump removes molecules from the vapor phase. These are replaced by the fastest molecules from the liquid phase, thereby reducing the average thermal motion and hence cooling the liquid. Unfortunately, in every substance the number of molecules in the vapor per unit volume decreases rather rapidly with the absolute temperature. As a result a temperature is soon reached at which there are so few molecules in the vapor phase that further cooling becomes impossible. For ordinary liquid helium, which has a total of four nucleons (protons plus neutrons) in its nucleus, and hence is referred to as helium 4, this limit is approximately .9 degree K. For the rare helium isotope helium 3, which contains only three nucleons, the limit is .3 degree. For all other substances the limiting temperature is much higher.

A technique called magnetic cooling has for many years been the only practical way for reaching temperatures below .3 degree K. By using a suitable paramagnetic salt it is possible, under favorable conditions, to reduce the temperature to within .003 degree K. of absolute zero. I shall not describe this method in detail now since I must return to it later. It suffices to say here that the main drawback of magnetic cooling is that it is a "one shot" rather than a continuous method of refrigeration and that its cooling capacity is relatively small. There are many types of important experiment that cannot be performed in a cryostat that employs magnetic cooling. It is also important to be able to push the temperature range available for experimental investigations still further toward absolute zero.

Recently three new methods have become available for reaching temperatures in the millidegree (.001 degree K.) or submillidegree region. These are known as the helium-3/helium-4 dilution process, the Pomeranchuk method and nuclear cooling. A dilution refrigerator can maintain temperatures in the vicinity of 10 to 20 millidegrees continuously and in the presence of a relatively large heat leak. By the Pomeranchuk



NUCLEAR-DEMAGNETIZATION REFRIGERATOR is being built by the author and his co-workers at the Technical University of Helsinki. It is the most advanced type of ultralow-temperature cryostat and, when improved, should make possible many types of experiment in the submillidegree region. A schematic diagram of its operation appears on page 35.



OPERATING PRINCIPLES of an ordinary evaporation refrigerator (*left*) and a helium-3/helium-4 dilution refrigerator (*right*) are compared. In the evaporation refrigerator the liquid is cooled by pumping on its vapor, causing the fastest molecules or atoms in the liquid phase to move to the vapor phase (*upward arrows*), thereby reducing the average thermal motion and hence lowering the temperature of the liquid. In the dilution refrigerator the phase separation is between two helium-isotope mixtures, one of the phases (*top*) being rich in helium 3 (*black*) and the other (*bottom*) being rich in helium 4 (*color*). Cooling is produced when helium-3 atoms move from the helium-3-rich, or concentrated, phase to the helium-4-rich, or dilute, phase (*downward arrows*). Below .05 degree K. the concentrated phase is pure helium 3 and the dilute phase contains 6.4 percent of helium 3 dissolved in the helium 4.

method the temperature has been reduced to two millidegrees in a rather simple apparatus. By nuclear cooling .85 millidegree has been reached, and it is clear that a refrigerator of this last type, when improved, will make many types of experiment in the submillidegree region possible.

The principle of the dilution refrigerator was originally suggested in 1962 by Heinz London, G. R. Clarke and E. Mendoza of the Atomic Energy Research Establishment at Harwell in England. The first successful machines of this type were built in the U.S.S.R. by B. S. Neganov, N. Borisov and M. Liburg in late 1965 and in England by Henry E. Hall, P. J. Ford and K. Thompson in early 1966. Since then many cryostats of this new type have been constructed and successfully employed for a variety of measurements down to 10 millidegrees.

The operation of the dilution refrigerator is based on the peculiar properties exhibited by mixtures of helium 3 and helium 4 at low temperatures. Below about .8 degree K. a liquid mixture of these two isotopes spontaneously separates into two components, one of the phases being rich in helium 3 and the other rich in helium 4. Because of its lower density the helium-3-rich phase floats on top of the helium-4-rich phase [*see illustration above*]. As the temperature is lowered further, the concentrations of helium 3 and helium 4 in the two phases change; below about .05 degree K. the upper, or concentrated, phase is practically pure helium 3 and the lower, or dilute, phase has 6.4 percent of helium 3 dissolved in the helium 4. The 6.4 percent solubility of helium 3 in helium 4 even at absolute zero is of paramount importance for the success of the dilution refrigerator.

There is indeed a remarkable difference at low temperatures between the thermal properties of liquid helium 3 and liquid helium 4. The common isotope, helium 4, is almost completely inert, its specific heat being practically equal to zero below .3 degree K. In contrast, the specific heat of liquid helium 3 is very large at low temperatures. As a result one may think of the helium 4 in the dilute phase as acting only as a supporting medium, or "ether," for the helium-3 atoms. From this point of view an interesting and useful comparison can be made in terms of operating principles between the ordinary evaporation-type refrigerator and the helium-3/helium-4 dilution refrigerator. The concentrated phase in the dilution refrigerator, where helium-3 atoms are close to one another, corresponds to the liquid phase in the evaporation refrigerator; similarly, the dilute phase in the dilution refrigerator, with only 6.4 percent of the helium-3 atoms, corresponds to the vapor phase in the evaporation refrigerator. The positions of "liquid" and "vapor" have thus been interchanged in the two systems. When molecules move upward from the liquid into the vapor phase in the evaporation refrigerator, the temperature is lowered. Similarly, when helium-3 atoms move downward from the concentrated to the dilute phase in the dilution refrigerator, cooling results. That is how a dilution refrigerator operates.

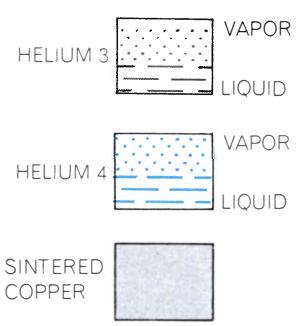
It is now easy to see the importance of the 6.4 percent solubility of helium 3 in helium 4 in the dilute phase. In an ordinary evaporation refrigerator the vapor phase becomes depleted of molecules rather soon, whereas in a dilution refrigerator the concentration of helium-3 atoms in the "vapor," or dilute, phase remains constant at 6.4 percent as the temperature is lowered. Thus the number of helium-3 atoms that cross the phase boundary per unit time is, in the latter case, independent of temperature. The reason it is impossible to reach absolute zero by the dilution method is that the amount of cold produced when one helium-3 atom crosses the phase boundary becomes smaller when the absolute temperature is reduced. For instance, the cooling power of a given dilution refrigerator at 10 millidegrees is four times smaller than it is at 20 millidegrees.

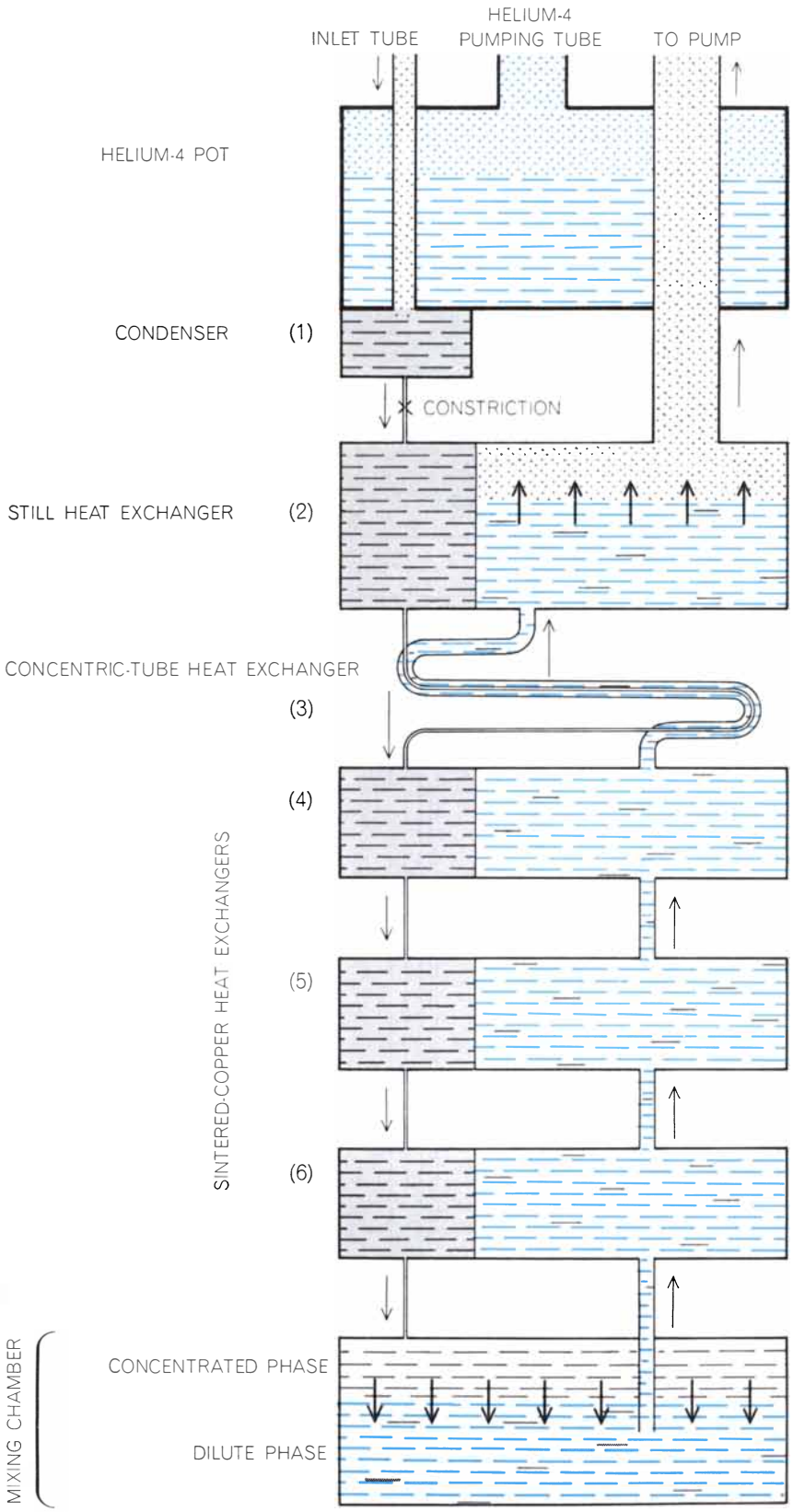
Having explained the principle of the dilution refrigerator, I shall next discuss how a machine of this type is designed for continuous operation [*see illustration on opposite page*]. Cooling is achieved in a container called the mixing chamber by causing helium-3 atoms from the upper phase to move across the phase-separation boundary to the lower phase. The process can be made continuous by circulating helium 3 in the system with a pump at room temperature. Incoming gas is first precooled and converted to liquid in the condenser, which is attached to the helium-4 pot at about

one degree K. The pressure of the helium 3 is kept high enough for condensation to occur by means of a flow-limiting constriction. The helium-3 liquid then enters a still heat exchanger at about .7 degree and passes through a concentric-tube heat exchanger and three sintered-copper heat exchangers before entering the mixing chamber. After crossing the phase boundary the helium-3 atoms, driven by an osmotic pressure gradient, proceed through the heat exchangers in reverse order to the still. Vapor is removed from the still by pumping. More than 90 percent of the outgoing gas is helium 3 because the vapor pressure of helium 4 at the still temperature is almost negligible. In this way it is possible to circulate mostly helium 3 in the system, as is required for an efficient dilution process. External heating of the still is necessary to keep its temperature high enough for maintaining a sufficient gas-circulation rate.

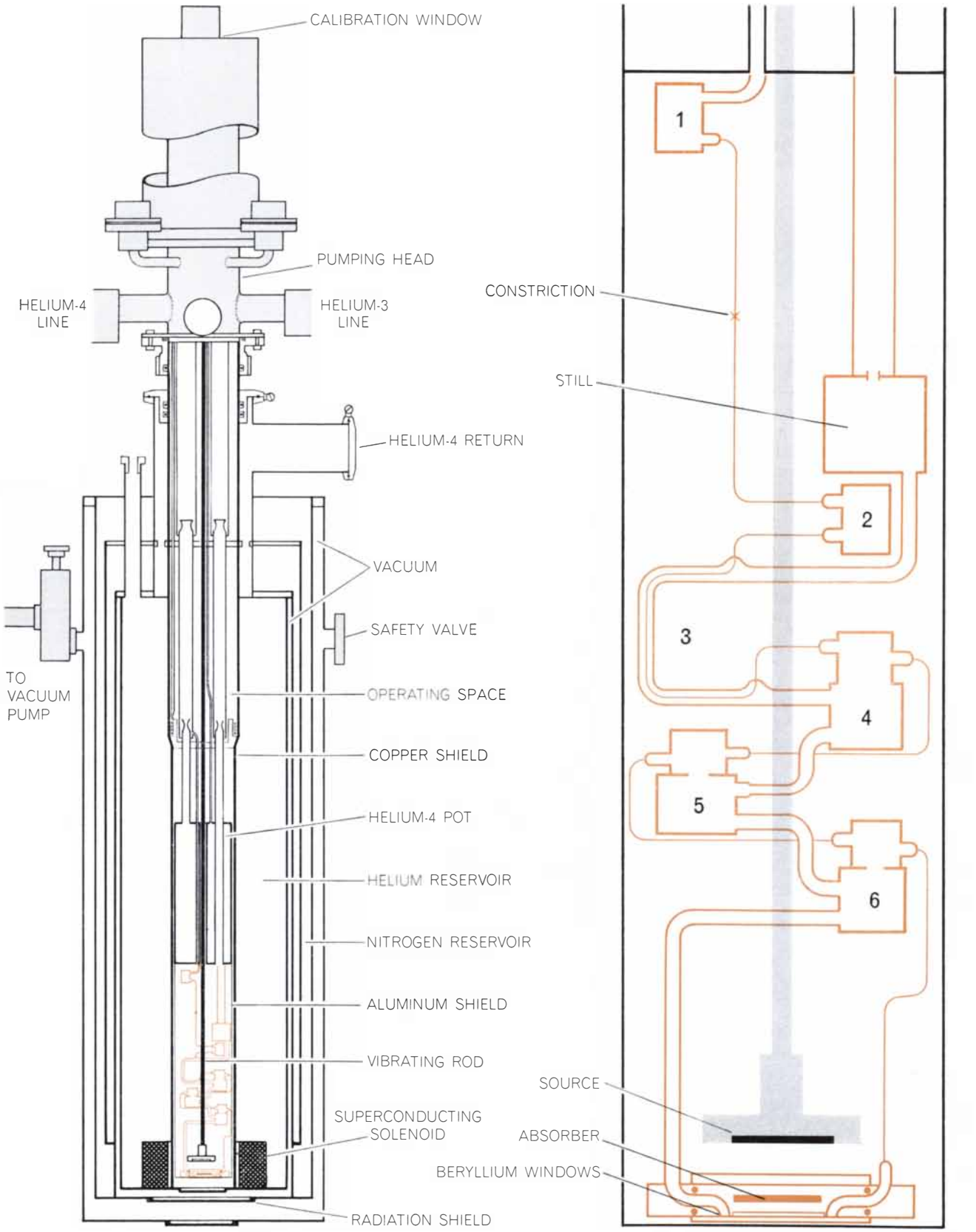
In every refrigerator it is important to conserve the cold that has been produced within the refrigerator. An essential part of the job is done by the heat exchangers, where the incoming helium-3 liquid is gradually cooled by the outgoing colder liquid. All but one of the heat exchangers in this system are of the sintered-copper type. The essential feature of their construction is that a large surface area, necessary particularly at the low-temperature end of the device, is achieved by filling the input and output sides with copper powder and then heating the device to about 1,100 degrees K. in order to sinter, or fuse, the particles to one another and to the copper walls. The one other heat exchanger in the system is made of two concentric tubes wound into a helix.

In the actual construction of a dilution





SCHEMATIC FLOW DIAGRAM shows how continuous operation is achieved in a helium-3/helium-4 dilution refrigerator. For simplicity it has been assumed that only helium 3 is circulated in the system; in actual refrigerators there is about 8 percent of helium 4 in the gas stream. The incoming gas is first precooled and converted to liquid in the condenser (*1*), which is attached to the helium-4 pot at a temperature of about one degree K. The pressure of the helium 3 is kept high enough for condensation to occur by means of a flow-limiting constriction. The helium-3 liquid then enters a still heat exchanger (*2*) at about .7 degree and passes through a concentric-tube heat exchanger (*3*) and three sintered-copper heat exchangers (*4, 5, 6*) before entering the mixing chamber. After crossing the phase boundary inside the mixing chamber the helium-3 atoms, driven by an osmotic pressure gradient, proceed through the various heat exchangers in reverse order to the still, from which vapor is removed by pumping. Key is at bottom left.



ACTUAL DESIGN of a dilution refrigerator built by the author's group for use in low-temperature nuclear research achieves thermal isolation from the outside by successive vacuum spaces and by progressively colder liquid mantles, which surround the inner parts (*color*). Heat flow from above is prevented by fabricating the connecting tubes out of materials with poor thermal conductivity. In the enlargement of the inner parts of the dilution-refrigeration system at right the numbers refer to the corresponding parts in the schematic diagram on the preceding page. Temperatures as low as 20 millidegrees (.02 degree K.) have been achieved in this system.

refrigerator for use in low-temperature nuclear research thermal isolation from the outside is achieved by successive vacuum spaces and by progressively colder liquid mantles, which surround the inner parts [*see illustration on opposite page*]. Heat flow from above is prevented by fabricating the connecting tubes out of materials with poor thermal conductivity such as stainless steel or a copper-nickel alloy.

In practice the operation of a dilution refrigerator proceeds as follows. After the cryostat has been cooled, first with liquid nitrogen to 77 degrees K. and then with liquid helium to 4.2 degrees, the helium-4 pot is filled. The temperature of the inner parts is then reduced to 1.2 degrees by pumping on the helium-4 pot, and condensation of the helium-3/helium-4 mixture begins. Next, helium 3 is circulated in the dilution refrigerator, reducing the temperature even further and causing the phase separation to occur in the mixing chamber. The dilution process then starts operating and the refrigerator reaches its lowest temperature in one to two hours.

Although the dilution refrigerator is still young, it has already proved itself as a research tool in experiments that formerly could not be carried out at very low temperatures. Its main advantages are continuous refrigeration and large cooling power. Once the necessary "know-how" has been mastered it is perhaps easier to build and operate a dilution refrigerator than a cryostat employing magnetic cooling. A clear sign of the success of the dilution principle is that refrigerators of this type are now produced commercially.

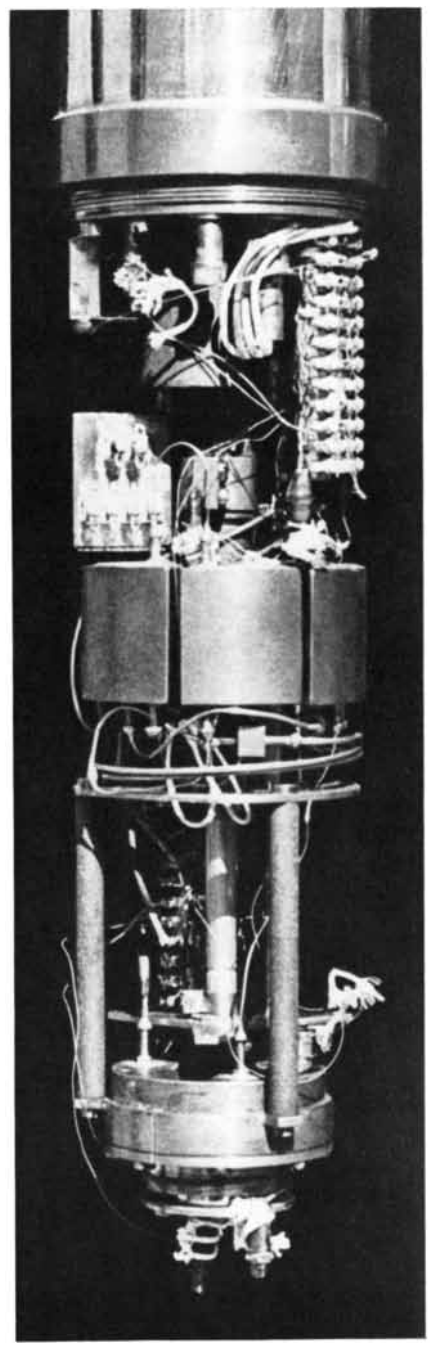
In 1950 the Russian physicist Isaak Y. Pomeranchuk proposed a new method of cooling that is based on the extraordinary properties of liquid and solid helium 3 at low temperatures. Partially successful experiments based on the Pomeranchuk effect for cooling were performed in 1965 by Yuri Anufriyev at the Institute for Physical Problems in Moscow, and by the beginning of 1969 R. T. Johnson, R. Rosenbaum, O. G. Symko and John C. Wheatley of the University of California at San Diego were able to reach two millidegrees by the Pomeranchuk method. Before I explain how this new method works, however, I must bring into the discussion the phase and entropy diagrams of helium 3.

A phase diagram shows, among other things, how the boundaries of the different states of aggregation of a substance depend on temperature and pressure. In the phase diagram of helium 3 [*see top illustration on next page*] the melting curve, which separates the solid and liquid phases, is unique in that it has a rather deep minimum, corresponding to a temperature of .318 degree K. and a pressure of 28.9 atmospheres. This minimum has an important consequence, which is the basis of Pomeranchuk cooling: If a mixture of solid and liquid helium 3, initially in equilibrium at one point (*A*) on the melting curve, is compressed, liquid will gradually be converted into solid and the system will cool to another point (*B*), also on the melting curve. Above .318 degree compression results in an increase of temperature, which is the normal behavior.

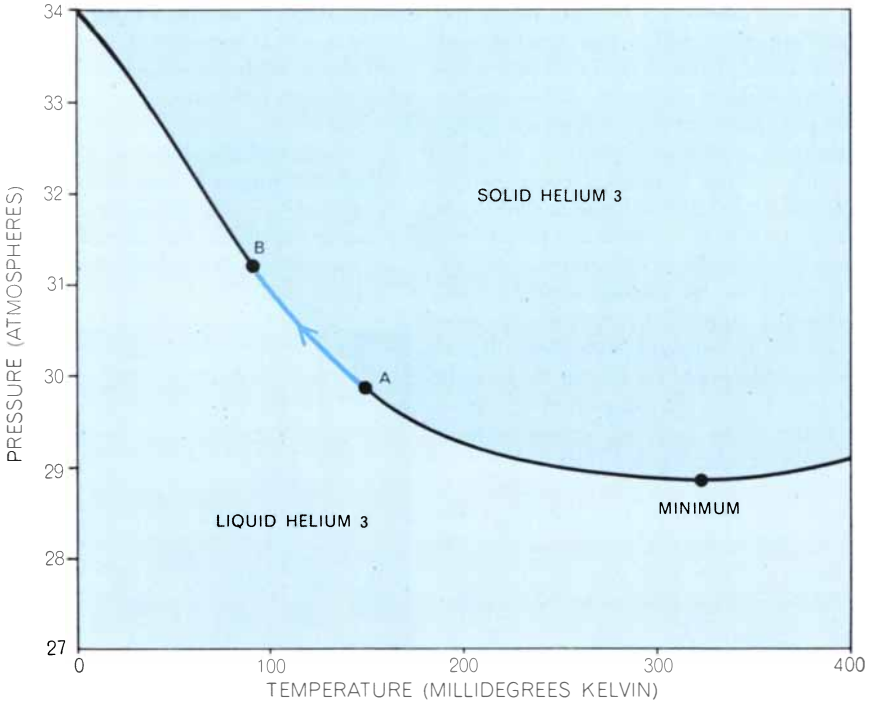
The entropy diagram of helium 3 is even more suitable for studying Pomeranchuk cooling. Entropy is a quantity that is the measure of disorder in a physical system; the more order, the smaller the entropy. For instance, as the temperature is increased thermal motion becomes more violent, the system becomes less ordered and consequently its entropy increases. In a solid atoms are arranged in a regular pattern whereas in a liquid there is no order; thus the entropy of a liquid is normally higher than the entropy of the corresponding solid at the same temperature. An entropy diagram is particularly suitable for quantitative studies of adiabatic processes, that is, processes in which the system under observation is thermally isolated from its surroundings. During an adiabatic process the entropy is constant.

The entropy diagram of solid and liquid helium 3 along the melting curve [*see bottom illustration on next page*] is, like the phase diagram of this substance, unique in the sense that below .318 degree K. the entropy of the solid is larger than the entropy of the liquid; the liquid phase is hence more ordered than the solid phase. The theoretical reasons for this peculiar situation cannot be discussed here but the explanation is connected with the orientation of the elementary magnets associated with the helium-3 nuclei. Pomeranchuk cooling proceeds on the entropy diagram as follows. At point *A*, close to the entropy curve of the liquid, there is very little solid helium 3 in the system under study. When pressure is applied adiabatically, liquid is gradually converted into solid and the point representing the system moves along a horizontal line (because entropy remains constant) to *B*. If compression is continued, the temperature is further reduced until at *C* there is only solid helium 3 in the system and the cooling capacity has been exhausted. It is fairly easy to calculate, using an entropy diagram, the percentage of solid in the system at any stage of compression and also to analyze the cooling power of the Pomeranchuk method.

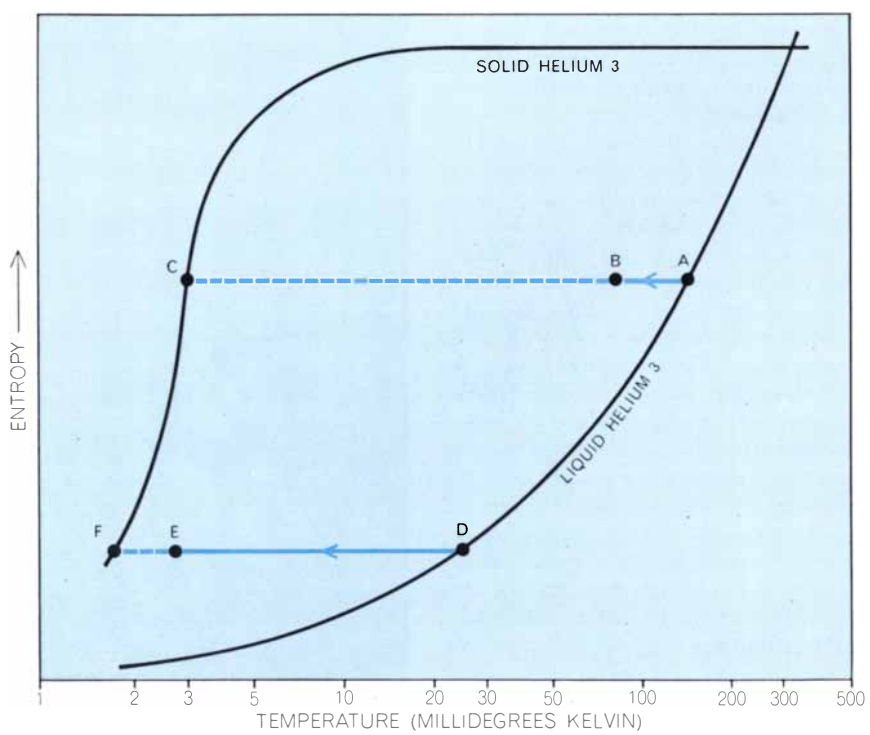
Although the soundness of Pomeranchuk's proposal was immediately recognized, certain difficulties, mainly connected with the question of how to compress helium 3 adiabatically (that is,



INNARDS of the dilution refrigerator depicted in the illustration on the opposite page can be seen in this closeup photograph. The various heat exchangers are arrayed at top. The mixing chamber is just below the bottom end of the central vibrating rod.



PHASE DIAGRAM OF HELIUM 3 at low temperatures and at pressures in the vicinity of the melting curve is useful for understanding the principle of the Pomeranchuk effect for cooling. The melting curve of helium 3 is unique in that it has a rather deep minimum corresponding to a temperature of .318 degree K. and a pressure of 28.9 atmospheres. If a mixture of solid and liquid helium 3, initially at *A* on the melting curve, is compressed, liquid will gradually be converted into solid and the system will cool to *B*, also on the melting curve. Above .318 degree compression always results in an increase in temperature.



ENTROPY DIAGRAM OF HELIUM 3 along the melting curve is, like the phase diagram of this substance, unique in the sense that below .318 degree K. the entropy (or degree of disorder) of the solid is larger than the entropy of the liquid. Pomeranchuk cooling proceeds from *A* to *B* as in the phase diagram at top; at *C* all the liquid would be converted into solid. In practice the system is usually precooled to a much lower temperature, between 20 and 30 millidegrees, before the helium 3 is pressurized (from *D* to *E* to *F*).

without frictional heating), prevented experimenters from even trying the method for many years. One reason for these experimental difficulties is that the minimum in the melting curve makes it awkward to increase the helium-3 pressure. A tube filled with helium 3 and passing from a temperature below the minimum to a temperature above the minimum will become blocked with solid helium 3 at .318 degree K., the temperature corresponding to the minimum, as soon as the pressure has been increased to 28.9 atmospheres. A cell containing helium 3 at a temperature below the minimum will thus be cut off from the outside helium-3 supply at this pressure. Further compression, therefore, cannot be obtained by admitting more helium 3 into the cell but must be achieved by other means, for example by "squeezing" the cell in some way.

The apparatus used by Wheatley and his co-workers for their Pomeranchuk experiments [*see illustration on opposite page*] contains essentially three concentric compartments. The outermost part is the mixing chamber of a helium-3/helium-4 dilution refrigerator used for precooling, the middle part is for liquid helium 4 employed for compressing the helium 3 after the plug has been formed in the helium-3 inlet tube, and the innermost part is the Pomeranchuk cell itself. The construction materials are epoxy resin and copper-nickel tubes. The upper, flexible-wall part of the helium-3 cell is made by rolling nearly flat one end of a copper-nickel tube. The salt pill of a cerium-magnesium-nitrate magnetic thermometer is placed at the bottom of the helium-3 cell for measuring the temperature.

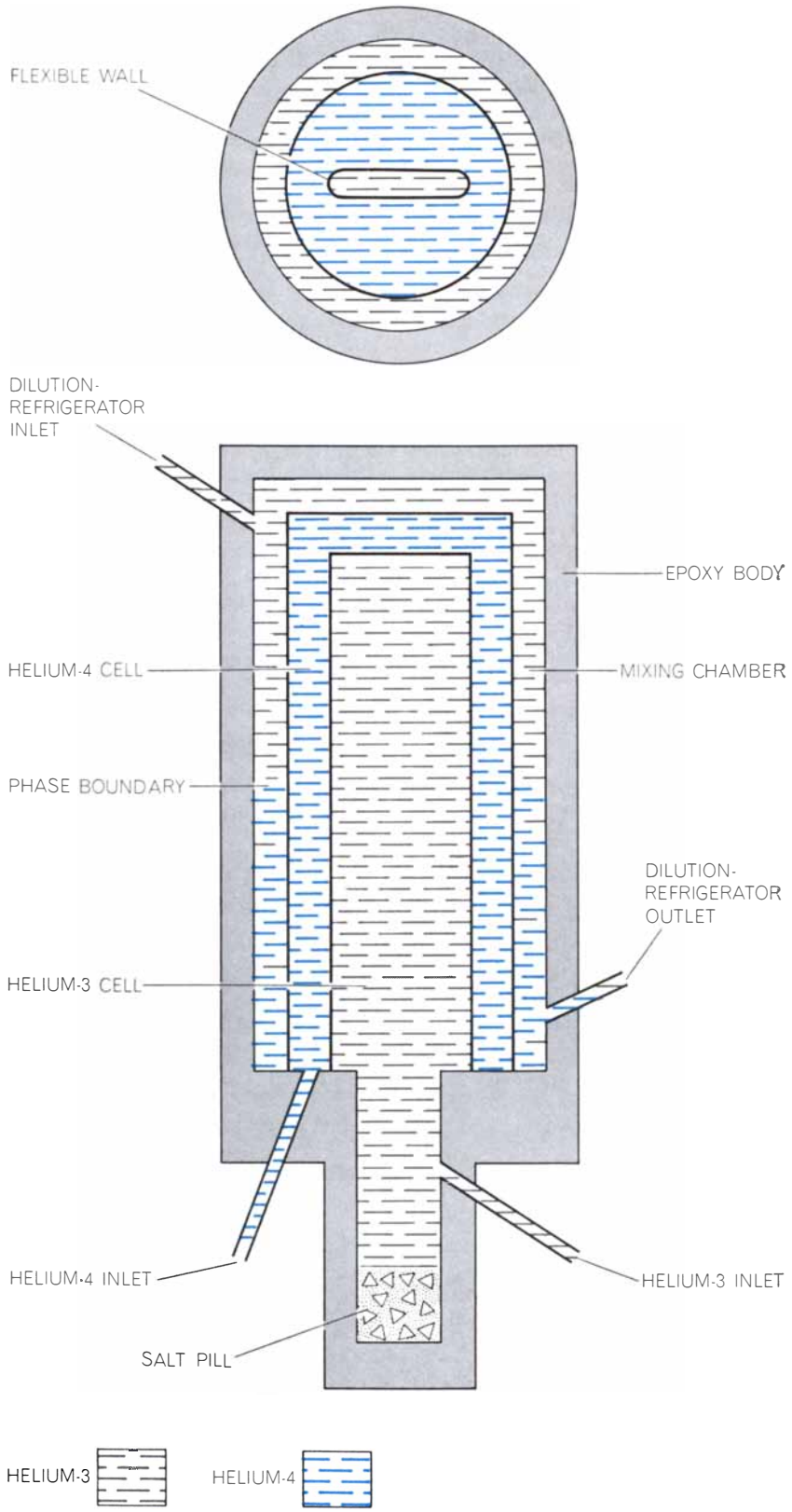
When the experiment is started, the assembly is first precooled to about .1 degree K. with the helium-3 pressure slightly below 28.9 atmospheres and with the helium-4 pressure at about .1 atmosphere. More liquid is then slowly admitted to the helium-3 cell until the pressure increases enough for the plug to form. Next, the assembly is cooled by means of the dilution refrigerator to about .025 degree. This phase of the experiment requires two or three days because of the very poor thermal contact between the mixing chamber and the helium-3 cell at low temperatures. Increasing the pressure of the helium 4 from an outside gas supply is then started at a rate of approximately .1 atmosphere per minute, causing the helium-3 cell to be "squeezed" and the pressure of the helium 3, initially at about 29 atmospheres, to begin to increase. As soon as the melting curve is reached at about

33 atmospheres the Pomeranchuk effect starts to operate. This point corresponds to *D* in the entropy diagram of helium 3 at the bottom of the opposite page. At first the temperature decreases almost linearly with increasing helium-4 pressure. Eventually the rate of cooling becomes slower because the entropy of the solid helium 3 is rapidly decreasing below .004 degree; finally the temperature stops going down. Owing to the poor thermal contact between the mixing chamber and the helium-3 cell there is no need for any heat switch between these two parts of the assembly.

From the entropy diagram of helium 3 one would get the impression that the ultimate temperature to be reached by Pomeranchuk cooling (represented by points *C* and *F*) does not depend much on the starting temperature. In practice this is not so. It turns out that once the fraction of solid in the helium-3 cell exceeds a certain limit (about 30 percent) cooling stops because of frictional heating caused by crushing of the solid. By starting at .15 degree K. (point *A* in the entropy diagram) 30 percent of the helium 3 is solid in the cell already at .08 degree (point *B*), whereas if the system is first precooled to .025 degree (point *D*), the solid concentration becomes 30 percent only below .003 degree (point *E*). A low starting temperature is thus essential for a successful application of the Pomeranchuk effect.

The use of helium 4 for transmitting pressure presents several practical advantages. The apparatus can be made relatively simple and frictional heating effects can be avoided. Helium 4 has, as was mentioned above, a negligible heat capacity at the temperatures of interest and therefore all heating effects due to warmer liquid being transferred to the helium-4 cell are absent. There are, of course, alternative methods for pressurizing the helium-3 cell; for example, different kinds of mechanical devices could be used. These would probably cause at least some frictional heating, and they would also make the apparatus distinctly more complicated, since moving parts would have to be introduced from the outside to the coldest sections of the cryostat.

It is too early to predict the impact the Pomeranchuk method will have on very-low-temperature refrigeration. A careful study of its potentialities is clearly warranted. The Pomeranchuk method has a good chance of becoming important between two and 10 millidegrees; its high cooling capacity in this temperature range, surpassing that of a dilution refrigerator by an order of magnitude, is



POMERANCHUK REFRIGERATOR assembled by John C. Wheatley and his associates at the University of California at San Diego consists essentially of three concentric compartments. The outermost part is the mixing chamber of a helium-3/helium-4 dilution refrigerator used for precooling, the middle part is for liquid helium 4 employed for compressing the helium 3 and the innermost part is the Pomeranchuk cell itself. The upper, flexible-wall part of this cell is made by rolling nearly flat one end of a copper-nickel tube. The cerium-magnesium-nitrate salt pill at the bottom is used in measuring the temperature.

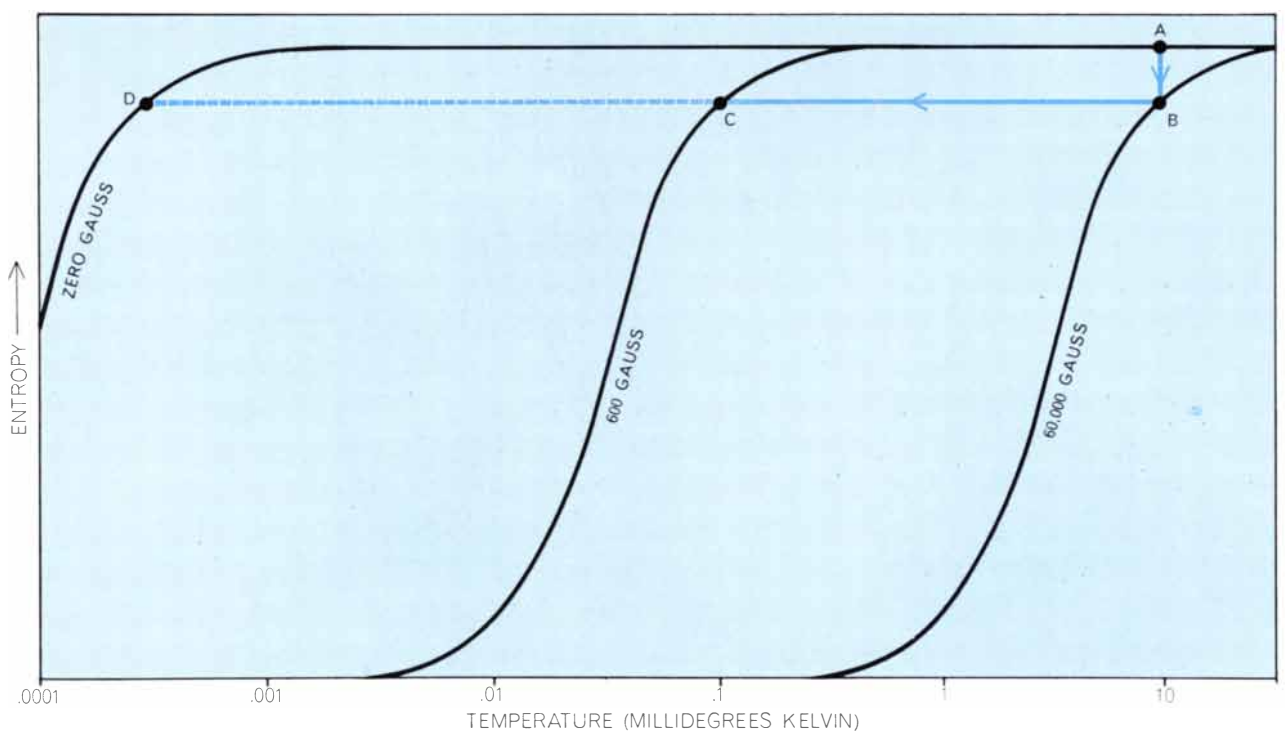
of particular practical importance. The Pomeranchuk effect is also interesting in its own right since, if compression of helium 3 is carried out in a large external magnetic field, the end result will be a solid with its nuclear elementary magnets highly oriented.

Nuclear cooling, or adiabatic demagnetization utilizing the nuclear instead of the electronic magnetic properties of matter, was first proposed in 1934 by Nicholas Kurti and Franz E. Simon of the University of Oxford and by Cornelius J. Gorter of the University of Leiden. The first practical realization of this method was not achieved until 1955. Since then considerable progress has been made only quite recently, notably by Edwin B. Osgood and John M. Goodkind of the University of California at San Diego and by Symko at Oxford. Nuclear cooling is on the verge of becoming a useful method for extending the temperature range available for experimental measurements into the submillidegree region.

Conventional magnetic cooling was briefly mentioned at the beginning of this article; the method utilizes the electronic elementary magnets of a suitable paramagnetic salt. The basic principle of both electronic and nuclear magnetic cooling is the same, but there are significant differences in practice. Because the nuclear elementary magnets are about 2,000 times smaller than the electronic magnets, the starting temperature for nuclear cooling must be much lower. Actual figures are about one degree K. for electronic cooling and about .01 degree for nuclear cooling. Considerably higher magnetic fields are also required in the latter case. The necessary starting conditions for nuclear-cooling experiments are thus difficult to achieve. There is an important compensation, however. The ultimate temperature that can be reached depends on the mutual interactions of the elementary magnets; it is impossible to cool to a temperature lower than that at which spontaneous ordering of the elementary magnets occurs. In the electronic case the limiting temperature is about .003 degree, whereas in the nuclear case it is approximately .0000005 degree!

The basic theory of nuclear and electronic magnetic cooling can best be explained with the help of an entropy diagram. In both cases the entropy depends on two external variables, the temperature and the magnetic field. It was mentioned above that an increase in temperature also increases the entropy. Remembering that the entropy is a measure of disorder in the system, it is easy to understand that in an external magnetic field, which aligns the elementary electronic or nuclear magnets and so brings order into the system, the entropy is reduced from the value it has at the same temperature but in zero magnetic field.

Before discussing the principle and the experimental arrangements for nuclear cooling I must briefly digress from the main topic to explain how a superconducting heat switch works. These devices, important in many low-temperature cryostats, are based on two observed facts: First, a metal (such as lead, tin or zinc) that becomes a superconductor of electricity at low temperatures is a much poorer conductor of heat in the superconducting state than it is in the normal state. Second, superconductivity can be destroyed by a modest magnetic field, thereby returning the metal to its normal state even though it is at a low temperature. A superconducting heat switch is made by placing a suitable conductor (for example a tin wire) inside a small coil. When a sufficiently high electric current flows in the coil, the magnetic field produced inside it is high enough to destroy superconductivity in



ENTROPY DIAGRAM OF COPPER as a function of temperature in an external magnetic field illustrates the principle of nuclear cooling. (When the external field is zero, the copper nuclei experience an internal field of three gauss, which spontaneously aligns the elementary nuclear magnets below .001 millidegree.) The arrow from A to B represents magnetization of the nuclei from zero to 60,000 gauss at an initial temperature (T_1) of 10 millidegrees. The arrow from B to C corresponds to adiabatic demagnetization (without frictional heating) from 60,000 to 600 gauss, whereby the temperature is lowered to .1 millidegree. By reducing the field to zero D would be reached at a limiting temperature (T_2) of .0005 millidegree, but the system would quickly warm back to T_1.

the tin wire; heat flows and the switch is thus in its "on" position. By cutting the current off the switch is turned into its superconducting or "off" position.

The principle of nuclear cooling can now be explained with reference to the entropy diagram on the opposite page and the schematic drawing of the experimental arrangement at the right. As the working substance a metal must be selected because it would otherwise take too long (weeks or months), to establish thermal equilibrium at the lowest temperatures; both copper and indium have been used. After the starting temperature T_1, near 10 millidegrees, has been reached by a dilution refrigerator or by electronic demagnetization, the nuclear stage is magnetized by increasing the external field from zero to 60,000 gauss in about 30 minutes. The temperature is kept constant at T_1 by conducting the heat of magnetization away to the precooling stage through a superconducting heat switch. In the entropy diagram on the opposite page the system thus moves from A to B.

The nuclear stage is then thermally isolated by turning the heat switch to its "off" position. Next, demagnetization is started by reducing the field in about 30 minutes from 60,000 gauss to 600 gauss. Since this is done adiabatically, the system moves along a horizontal line on the entropy diagram from B to C; the theoretical temperature T_2 that is reached in this way is about .1 millidegree. Still lower temperatures, in the microdegree range, could be obtained by reducing the magnetic field even further; this was actually done by Kurti and his co-workers in their pioneering experiments in 1955. A serious difficulty was encountered, however: the system warmed back to its starting temperature T_1 in about two minutes, which is too short a time for performing useful experiments.

By stopping the demagnetization at a modest external field, such as 600 gauss, temperatures in the submillidegree, if not in the microdegree, range can be reached and the system remains cold for a long enough time so that useful experiments can be performed. In this way Symko was able to cool to 1.7 millidegrees and he managed to keep his cryostat below 10 millidegrees for two and a half hours. Osgood and Goodkind achieved a temperature of .85 millidegree and it took seven hours before the nuclear stage had warmed back to one millidegree. Even though these experiments represent significant advances in the techniques of nuclear cooling, it is clear that we are far from the theoretical limiting temperature T_2.

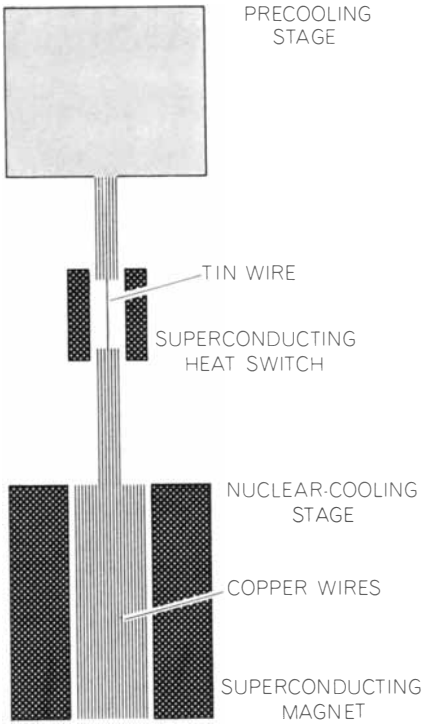
It should be emphasized that the main difficulty in these experiments is not how to reach very low temperatures but rather how to maintain cold, how to move cold from one place to another and how to measure the temperature. Much experimental work is required before these problems can be solved.

It has already been mentioned that in order to maintain cold the external magnetic field should not be reduced all the way to zero. Another requirement for preventing a rapid warming up is that the inevitable heat leak to the nuclear stage from its surroundings must be made very small indeed, less than one erg per minute. A heat leak of this size can be caused, for instance, by slight mechanical vibrations of the building in which the cryostat is located, by acoustical noise or by electric fields transmitted from radio or television stations. The cryostat must be carefully shielded against all these disturbances.

In order to investigate specimens other than those that can be employed as the working substance for nuclear cooling, it is necessary to be able to transfer heat from the specimen under study to the nuclear stage. This presents severe problems because the thermal resistance of most substances becomes high at very low temperatures.

The thermometers used for measuring temperatures in the millidegree region could easily be the topic of another article. Many of them, including the magnetic thermometer based on the electronic magnetic susceptibility of cerium-magnesium-nitrate salt, will not work at all in the submillidegree region. New ways of solving the thermometry problem have been proposed and some of the thermometers are being tested in experiments. It is too early to predict which of them will prove to be the best.

A cryostat currently under construction by the author and his co-workers [*see illustration on page 27*] will employ a helium-3/helium-4 dilution refrigerator and a nuclear-cooling stage in series in an effort to reach and maintain temperatures down to .2 millidegree. The cryostat is quite elaborate, employing all together seven stages of cooling: a liquid nitrogen bath at 77 degrees K.; a liquid helium bath at 4.2 degrees; a helium-4 pot at 1.2 degrees; a helium-3 pot at .3 degree; a dilution refrigerator; an auxiliary electronic magnetic cooling stage using cerium-magnesium-nitrate salt, and a nuclear stage made of thin copper wires. The apparatus is built on a large concrete block in a shielded room for reducing mechanical and electrical disturbances.



LAST TWO STAGES of a cryostat utilizing nuclear-demagnetization refrigeration are shown in this highly schematic diagram. The precooling stage, which must be capable of reaching a temperature near 10 millidegrees, is either the mixing chamber of a dilution refrigerator or a paramagnetic salt cooled by electronic adiabatic demagnetization. The nuclear stage is made of thin copper wires. It is surrounded by a superconducting magnet that produces a field of 60,000 gauss. A superconducting heat switch is located between the two cooling stages.

Of the three new methods of cooling described only the dilution refrigerator is truly operational at present. It will largely replace the conventional adiabatic demagnetization cryostat and even the simple helium-3 refrigerator. Many experiments that formerly would not have been feasible below .3 degree K. have already been done with dilution machines and much more work will be undertaken in the immediate future.

In the past the quest for lower and lower temperatures has been amply rewarded by new and fundamentally important discoveries; it is equally clear that much excitement lies ahead of us in the yet unexplored territory. Pomeranchuk cooling and nuclear demagnetization, even though they are not continuous modes of refrigeration, are the likely tools that will open this new territory for experiments. Only time will tell what is ahead on the never ending road toward absolute zero.

THE RISE AND FALL OF ARABIA FELIX

The Semitic kingdoms of southern Arabia waxed rich during the first millennium B.C. by controlling the trade in frankincense and myrrh. Why they waned a few centuries later is a question still under study

by Gus W. Van Beek

Among the ancient high cultures of the Near East none is so little known as the one that flourished in southern Arabia—the "Arabia Felix" of classical times—in the first millennium B.C. This is in part because southern Arabia lies very much on the periphery of the Fertile Crescent, the region where the mainstream of Near Eastern culture development flowed. The inhospitable conditions that prevail in Arabia—the hardships of travel, the difficulties of supplying expeditions, the hazards of tribal warfare and the inhabitants' general dislike of strangers—have also combined to keep Western knowledge of the region at a minimum.

The scientific exploration of southern Arabia began some three centuries ago when a Danish expedition, led by Carsten Niebuhr and including the naturalist Peter Forskål, arrived on the coast of Yemen in 1763. (An account of this tragic expedition, from which only Niebuhr returned, has recently been given by Thorkild Hansen in his book *Arabia Felix: The Danish Expedition of 1761–1767*.) The emphasis of the Danish expedition, and of several similar expeditions in the 19th century, was on copying early inscriptions and on recording various ancient monuments that chance had left exposed. The first archaeological excavations in southern Arabia were not undertaken until 1927, when Hermann von Wissmann and Carl Rathjens cleared a temple at Huqqa, near San'a. Ten years later Gertrude Caton Thompson, Elinor Gardner and Freya Stark, working at Hureidha in Wadi Hadhramaut, excavated a temple and several farm buildings and studied the area's pre-Islamic irrigation system.

No further work was done in Arabia Felix until 1950, when an expedition of the American Foundation for the Study of Man, under Wendell Phillips and William Foxwell Albright, began a series of excavations in Wadi Beihan. Several areas were unearthed in the ancient city of Timna, including a cemetery. In addition a small mound—Hajar Bin Humeid—was partially excavated, revealing some 20 successive levels of occupation that dated from the 11th or 10th century B.C. to the early centuries of the Christian era. The American Foundation group subsequently cleared part of the famous temple called Mahram Bilqis at Marib in Yemen, and excavated several sites along the southern and eastern coasts of Muscat and Oman. Since 1961 I have conducted systematic archaeological surveys in Wadi Hadhramaut, in Yemen and in southern Saudi Arabia in order to ascertain the boundaries, the environmental adaptations and the microcultural similarities and differences among the ancient states of southern Arabia.

Southern Arabia consists of four geographical and environmental zones. Fronting on the Red Sea and on the Gulf of Aden is a narrow coastal plain. The plain is interrupted in places where the mountains that lie inland jut into the sea, and it is sealed off from deep water by an almost continuous coral reef that severely restricts the establishment of ports and the development of shipping. Because of malaria, saline soil and excessive heat and humidity the plain does not support a large population today, and there is little evidence of ancient occupation.

The second zone consists of the mountain ranges that run parallel to the Red Sea coast and turn eastward to continue along the Gulf of Aden. Some of the ranges' peaks reach an altitude of more than 12,000 feet. Between the mountains are many fertile plains that, together with terraces on the neighboring slopes, provide agricultural support for a reasonably large population. A number of ancient sites, going back at least to the sixth century B.C., show that this zone was also occupied in antiquity.

The third zone consists of a rocky interior plateau and valleys that extend to the east and north of the mountains. Lying at elevations of 2,000 to 4,000 feet, the valleys and plains receive little rainfall but are watered by the considerable runoff from rain in the mountains. This zone has the greatest concentration of population today, and it is here that ancient sites are most abundant.

The fourth zone is the Rub' al-Khali (Arabic for "Empty Quarter"), a vast ocean of sand with dunes that reach a height of 500 feet. The zone is now sparsely populated by nomads and seems never to have supported a sedentary population.

Prehistoric man apparently first occupied southern Arabia during the equivalent of the Lower Paleolithic period in Europe; the initial occupiers had reached the Acheulean phase of cultural development. The remains of this culture are found in Africa, Europe and through the Near East and Middle East as far as India. The characteristic Acheu-

SMILING WOMAN of Arabia Felix shown on the opposite page was portrayed in alabaster during the first millennium B.C. and was unearthed at Timna, capital of the ancient kingdom of Qataban. The sculpture is nearly life-size; the hair is formed of plaster and the eyes are inlays of lapis lazuli and paste. The eyebrows were probably also once inlaid. Holes beside the jaw may have been made for the attachment of a gold necklace that was discovered near the sculpture.

GREAT DAM AT MARIB was the largest of the many irrigation works built in ancient Arabia Felix. Seen in the photograph is the masonry sluice at the south end of the dam; it diverted water from flash floods in the Wadi Dhana into a system of irrigation canals.

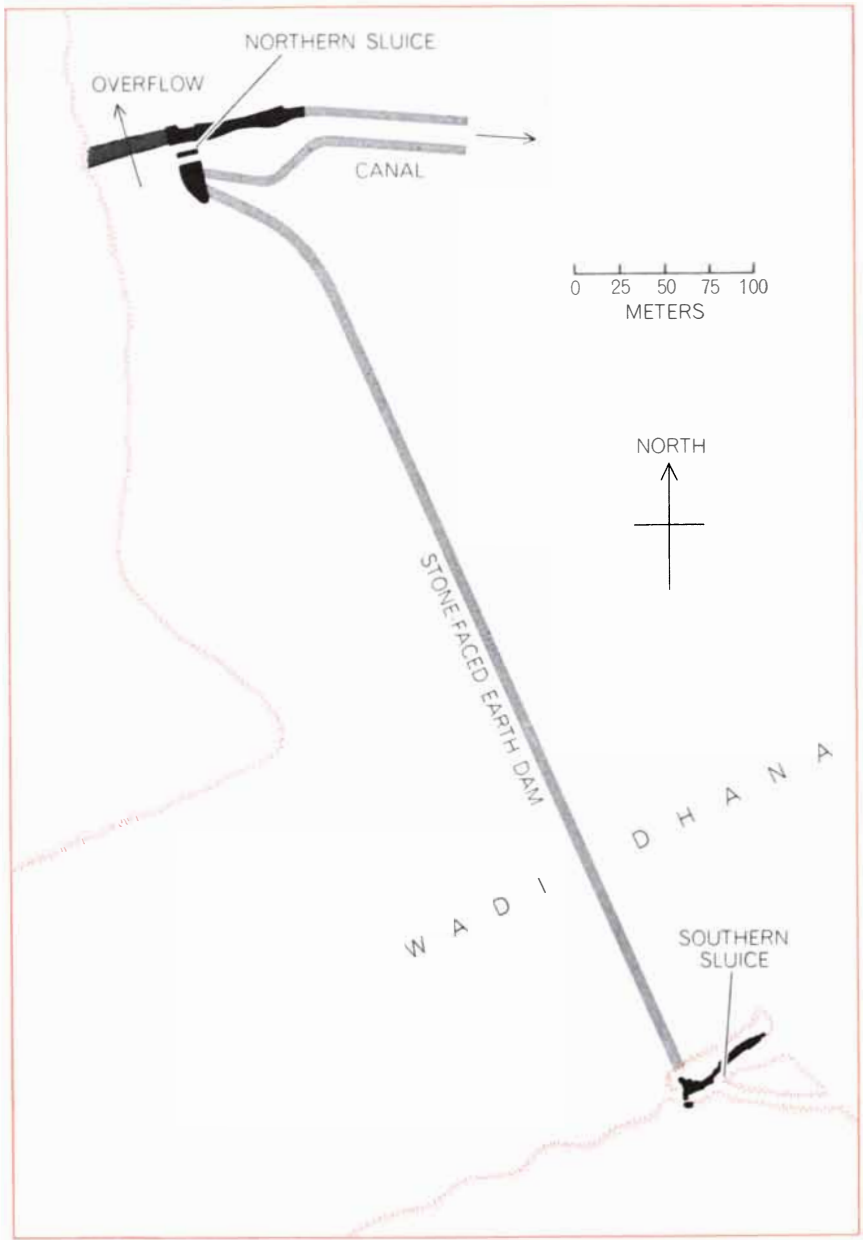
NORTH SLUICE of the Marib dam is seen from the west. The dam itself was built of earth that was faced with stone. It ran some 600 meters across the wadi floor between the two sluices. Runoff from mountain rains, diverted by the dam, irrigated 4,000 acres.

lean implement is the oval stone hand axe shaped by the detachment of flakes from both sides of a stone core. Several of these bifacially flaked tools have been found in the Empty Quarter and in the mountains near Nejran. Their scarcity, however, suggests that Arabia was a marginal hunting area in the Lower Paleolithic period.

Perhaps 75,000 years ago the Acheulean culture in southern Arabia was replaced by one that used tools made from flakes of flint rather than from cores; the flakes were formed by what is called the Levalloisian technique. The new culture was widespread throughout the region. During three and a half months in Wadi Hadhramaut in 1961–1962 Glen H. Cole of the Field Museum of Natural History recorded more than 100 Levalloisian sites in an approximately 60-mile stretch of the wadi; undoubtedly there are more. This period of prehistory in southern Arabia may correspond to the Middle Stone Age in Africa (the Middle Paleolithic in Europe). In Europe and Africa during that time man often sought the shelter of caves, but no cave deposits have yet been found in southern Arabia; all the sites are open-air camps.

Until this year it seemed unlikely that a culture possessing the complex blade-tool and flake-tool traditions associated with the Upper Paleolithic period in Europe and corresponding cultures in the Near East had ever existed in southern Arabia. Now, however, some tools have been found at sites in the Rub' al-Khali that are strangely reminiscent of the Solutrean culture of Europe. The new discovery may indicate a limited distribution of a similar culture in the region.

Next in the sequence of cultures in southern Arabia is one that is characterized by the small stone blade tools and arrow points commonly associated with Neolithic toolmaking. Artifacts of this kind have been found on the southern fringes of the Empty Quarter and in Wadi Hadhramaut. Unlike the Neolithic peoples farther north, who raised crops or tended animals, the population in southern Arabia subsisted by hunting and gathering alone. Charcoal from a hearth associated with Neolithic tools has yielded a carbon-14 date of about 3000 B.C., which indicates that the Neolithic persisted much longer in this region than elsewhere in the Near East.



PLAN OF MARIB DAM indicates its ambitious dimensions. Built in the first millennium B.C., the dam was destroyed in the sixth century A.D. This plan follows the one by Richard LeBaron Bowen, Jr., and Frank P. Albright in *Archaeological Discoveries in South Arabia*.

The first high culture to appear in southern Arabia did not evolve from its Neolithic predecessor. It came on the scene full-blown during the second half of the second millennium B.C., probably between 1300 and 1200 B.C. The culture appears to have been introduced by colonists from the Fertile Crescent or its fringes. The language of the newcomers was a form of Semitic that must have separated from the northern Semitic dialects before the 13th century B.C. This was a time when a number of northern Semitic consonants began to coalesce. South Arabic, however, preserves all 29 of the original consonants. Further evidence regarding the immigrants' place of origin is found in some of the earliest forms of their pottery and ceramic decorative motifs. These are suggestive of the pottery of northern Syria, western Mesopotamia and Palestine. At least at this stage in our investigations it appears that the newcomers' original homeland was the southern fringe of the Fertile Crescent, particularly the region of eastern Jordan and southern Iraq.

What force or forces gave rise to this migration? It is possible that pressures resulting from population movements in the Fertile Crescent forced the immigrants to look for a new home. This is a phenomenon well known in the ancient Near East and the Mediterranean world. It is perhaps more likely, however, that the immigrants were attracted to southern Arabia by the prospects of wealth to

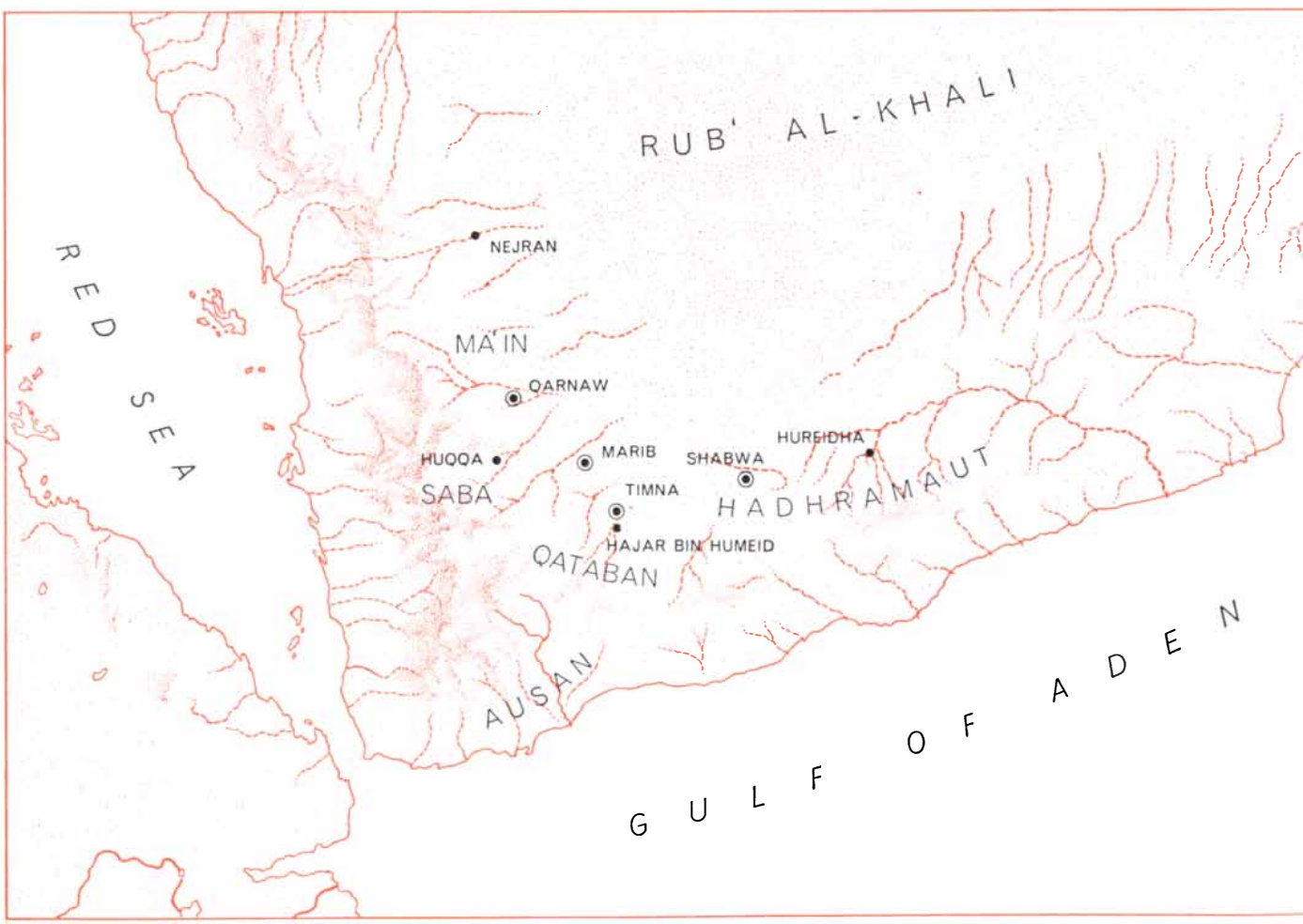
be gained through the production and distribution of two luxury commodities—frankincense and myrrh. Both are gum resins exuded by trees: frankincense comes from two species of the genus *Boswellia* (*B. Carterii* and *B. Frereana*) and myrrh from *Balsamodendron myrrha*. The trees are found only in southern Arabia and in Somalia across the Gulf of Aden; it is probable that their restricted range is determined by some unique combination of soil, elevation, temperature and rainfall.

In antiquity frankincense and myrrh had many uses. Frankincense was used primarily as incense in offerings to the gods. During Roman times, when cremation was widely practiced, it was also customary to burn frankincense in the funeral pyre. This too may have been to propitiate the gods, but Pliny the Elder suggests that it was intended to disguise the odor of the burning bodies. Pliny tells us that an entire year's production of Arabian frankincense was burned in the funeral pyre of Poppaea, the wife of the Emperor Nero.

Myrrh was used primarily in cosmetics and perfumes. The 18th-Dynasty Egyptian queen Hatshepsut, for example, is reported to have rubbed myrrh on her legs to make them fragrant. Theophrastus and Pliny inform us that myrrh was one of the chief ingredients in three famous cosmetic preparations of classical times: Egyptian perfume, Mendesian ointment and a substance named Magaleion. Both frankincense and myrrh were also among the classical *materia medica;* they were prescribed to promote menstruation and for such ailments as paralysis of the limbs, "broken head" and dropsy.

Because of the many uses for the resins the rising demand could not be met by the limited supply. As a result the price was driven up, and in Biblical times frankincense and myrrh ranked with gold as gifts suitable for the Christ child. Pliny states that in Alexandria, where frankincense was processed, workmen were required to strip for inspection before being allowed to leave the factory. Thus the same motive that drives men to seek their fortune in gold, uranium or oil may have caused the northern Semites to move to southern Arabia.

The time of the migration and the start of a major trade in frankincense and myrrh coincided with a significant development in ancient transportation: the effective domestication of the camel. It was the domesticated camel that made possible travel and cargo-carrying over vast stretches of arid lands. Moreover, the animal's anatomical limitations largely dictated the line the trade routes took. Because the camel is exceptionally top-heavy when loaded and has feet that are not suited to rocky surfaces, it is not a good beast of burden for mountainous regions. This means that the best camel routes follow relatively level ground that



FIVE ANCIENT KINGDOMS arose in Arabia Felix; their capital cities are indicated by circled dots. All lie within the most populous zone in southern Arabia today, an area of plains and valleys that is watered by the runoff of rainfall in the mountains to the west and south. People also live in the mountains and did so in ancient times, as the presence of a number of early ruins shows. The

offers a footing of soil or sand. The caravans laden with frankincense and myrrh therefore moved across the plateau and through the valleys to the east of the high mountain ranges of southern Arabia. Pliny tells us that the journey from Timna in southern Arabia to Gaza in Palestine required 65 stages, which presumably meant 65 nights on the road.

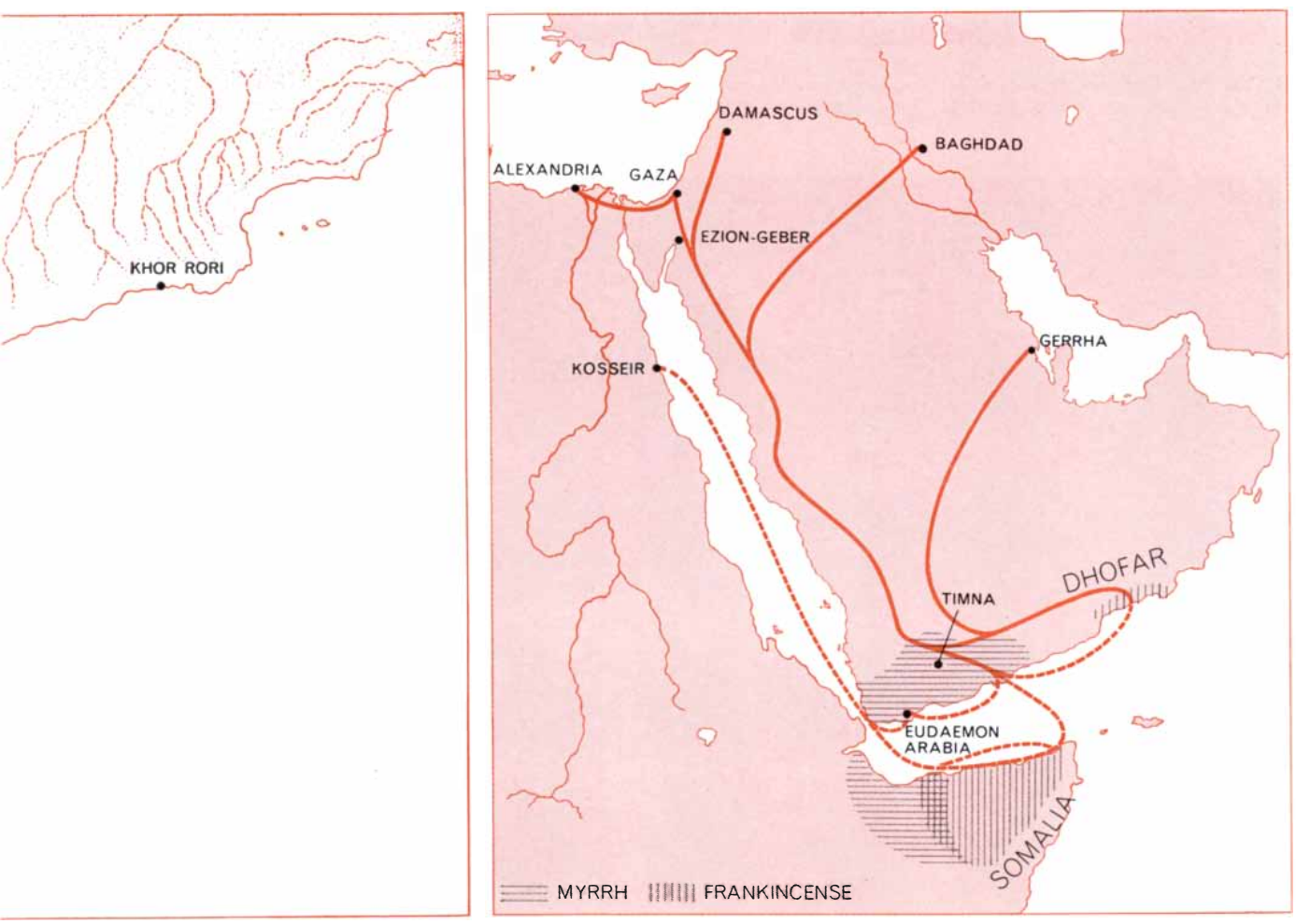
Frankincense and myrrh were also transported by sea. In the 10th century B.C. King Solomon's fleet, which operated from Ezion-geber under Phoenician management, probably carried frankincense and myrrh to markets in the Fertile Crescent. Taking advantage of the alternating direction of the seasonal monsoon winds, Arab vessels carried frankincense and myrrh westward to the Persian Gulf and also up the Red Sea to Egypt throughout the first millennium B.C. During the first century of the Christian era Greek ship captains discovered the secret of the monsoon winds and they too engaged in the lively trade.

During the first millennium B.C. several kingdoms flourished in southern Arabia. They included Saba (Biblical Sheba), with its capital at Marib; Qataban, with its capital at Timna; Hadhramaut, with its capital at Shabwa; Ma'in, with its capital at Qarnaw, and Ausan, which was situated in the mountains between Qataban and modern Aden. Saba, Qataban and Hadhramaut were the earliest states; Ma'in and Ausan appeared about the middle of the first millennium B.C. Not all prospered simultaneously. The period of ascendancy of the western kingdoms—Saba, Qataban and Ma'in—tended to be successive. Hadhramaut, farther to the east, seems to have enjoyed periods of importance coinciding with those of some of the western kingdoms.

The earliest states were at first governed by rulers bearing the title *Mukkarib,* probably meaning "priest-king." Later this title was dropped and a word meaning only "king" was used. Although we know the names of most of the rulers in southern Arabia through the first millennium B.C. until the sixth century A.D., we know little more about the states. There is a dearth of historical texts among the region's inscriptions.

Only a few wars between states are recorded, suggesting that southern Arabia enjoyed comparative peace. This may be because the region was isolated from the great nations of the north (Egypt, Israel, Assyria, Babylonia, Persia and Greece), which were continually involved in military actions. Another fact suggesting that there was little warfare between the states of southern Arabia is that most of the region's ancient towns and cities were unfortified.

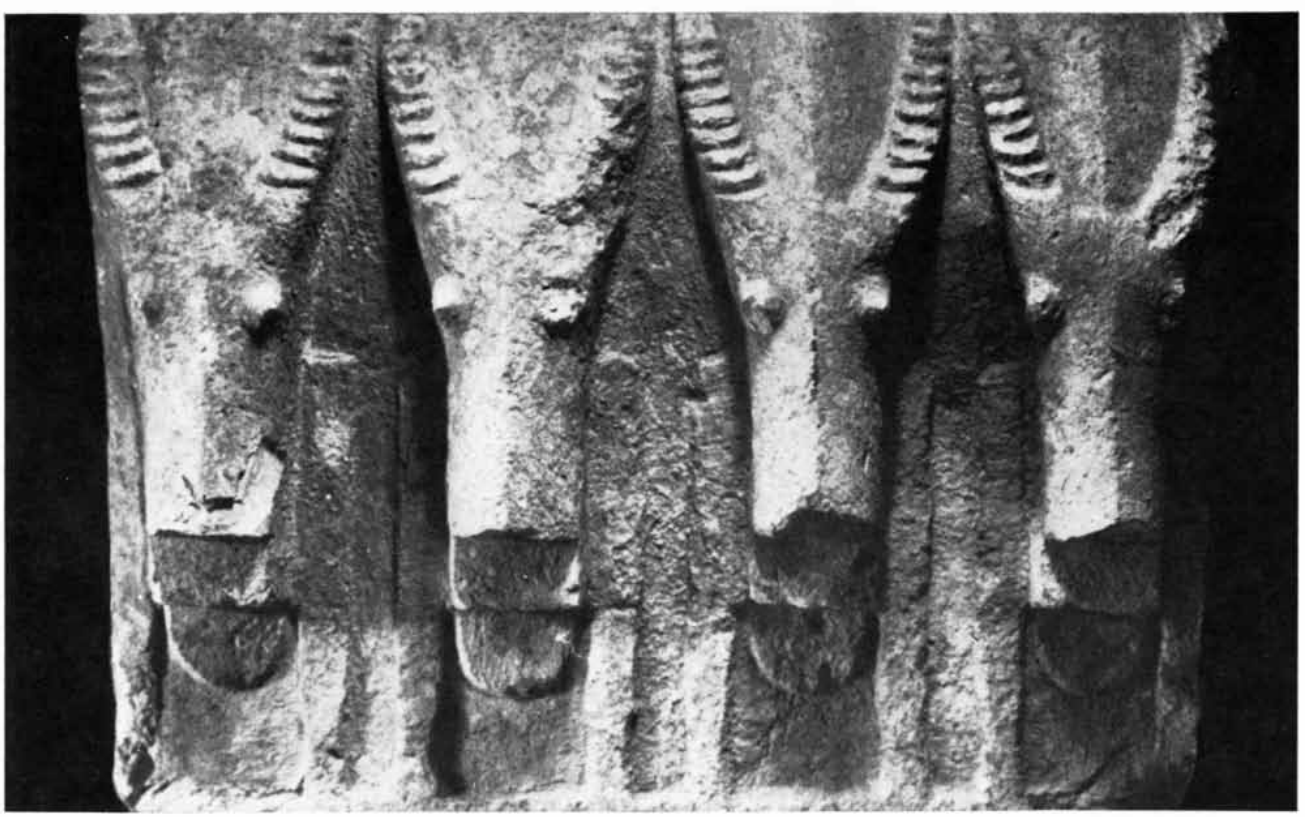
Although the states shared a common culture, each was distinguished from the other by microcultural differences. All the states used South Arabic as their language, for example, but there were distinctive dialect differences be-



hot coastal plain was and is only lightly settled, however, and then as now only a few nomads entered the bleak Rub' al-Khali.

TRADE ROUTES from the parts of southern Arabia and Somalia that produced frankincense and myrrh went overland to the Persian Gulf, Mesopotamia and the Mediterranean and by sea to Kosseir. Expansion of the trade coincided with the domestication of the camel.

ENTRANCE HALL of the pagan temple at Marib contains examples of the ancient masons' skill. What appear to be recessed windows of latticework, surmounted by louvers, are in fact false; the details were chiseled into the solid stone blocks of the temple wall.



STYLIZED IBEXES exemplify the less naturalistic tradition in southern Arabian sculpture. Horns, eyes and muzzles are shown in the round but the animals' beards are only squarish planes, the chests are semicircular planes and the forelegs are narrow ribbons.

tween states, reflected in both vocabulary and grammar. Similarly, although the pottery of the several states was identical in many features of forming technique, shape and style, certain additives for tempering, certain specific shapes and certain decorative styles characterized the pottery of each kingdom.

The culture common to all the states was imported into the region with its major characteristics fully formed. These included a tradition of urban living, a knowledge of the techniques of irrigation agriculture, a language written in an alphabetic script, a knowledge of ceramics and metallurgy, a complex religion and a developed art. The settlements ranged from small towns built chiefly of sun-dried mud brick to large cities possessing buildings with stone masonry of varying quality and style. Many of the stone structures featured architectural designs of singular beauty, such as walls with recessed panels and lattice windows associated with a series of rectangular projections and false louvers [*see top illustration on opposite page*]. One particular style of masonry, in which the face of the hewn stone block was dressed so that its borders were left smooth and its center was roughened by pecking, has a long history in southern Arabia. The style originated in Phoenicia, whence it spread to Mesopotamia, southern Arabia and Greece. It later passed from the Greeks to the Romans and thence to other parts of the Western world.

A key feature of the high culture in southern Arabia was its sophisticated irrigation system. The system was not based on the exploitation of perennial rivers, as in Mesopotamia and Egypt, but instead capitalized on the runoff water from the region's infrequent rains. The major installations were of two kinds. The most ambitious consisted of dams built across stream beds that were usually dry. When rain fell and a flash flood filled the stream bed, the dam backed up the water to a height sufficient to make it flow through masonry sluices at one end or both ends of the dam, feeding the floodwaters into canals. From these canals the flow of water was diverted by means of other sluices into secondary and tertiary canals that finally distributed the water over the cultivated area. In the second kind of installation the runoff from mountain rainfall was first collected in wide earthen canals and was then distributed to adjoining fields as it was by the other system.

It is important to note that the dams of southern Arabia never retained water in a reservoir system but served only to deflect the runoff from the occasional rains into irrigation canals. The largest and most famous dam was located at Marib, and sections of it, its canals and its sluices can still be seen today. The Marib system irrigated some 4,000 acres. Remains of stone-built sluices and traces of dams and canals can be found in every arable valley on the inland side of the southern Arabian watershed. The runoff irrigation system was supplemented by the use of well water for irrigation in those valleys where the water table was no more than 60 to 75 feet below the surface.

Statements by authors of the classical period indicate that the region's agricultural production was sufficient to meet the food needs of its population. In a well-known mariner's handbook of the first century A.D. (*The Periplus of the Erythraean Sea*), for example, the anonymous Greek author notes that luxury goods but not agricultural produce were in demand at ports in southern Arabia. This nutritional self-sufficiency was made possible only by the inhabitants' ingenious use of flash-flood water in their irrigation system.

The ancient language of southern Arabia belongs to a subgroup known as South Semitic. The forms of its letters are among the most symmetrical and graceful found in any Semitic script. Several thousand inscriptions are now available to scholars; the vast majority are graffiti that consist mainly of personal names. Among the more formal texts are burial inscriptions that provide the name of the deceased, building inscriptions that often contain information useful for dating the structure, and dedicatory texts. Only a few inscriptions are annalistic or historical documents that can be used in attempting to reconstruct the history of the region.

As is true of most Semitic religions, the principal deities of southern Arabia's ancient faith were identified with the moon, the sun and the planets. The temples in which they were worshiped are generally among the largest and most impressive examples of architecture found in the region. The temple walls were covered with dedicatory and votive inscriptions, cut in stone or cast in metal, and every temple contained a water installation, either a well or a series of channels cut in the floor and leading to a tank. There is evidence in some places that the worshiper had to walk through water in order to enter the temple itself, and the temple installations indicate in general that some kind of ritual ablution was practiced by the worshipers.

The immigrants to southern Arabia were probably adept at metallurgy when they first settled the region, because by 1200 B.C. the technology of bronze alloying had been known for 1,000 years in the Near East and iron was coming into widespread use in the Fertile Crescent. Artifacts found in the lowest stratum at Hajar Bin Humeid, which is dated between the 11th and 10th centuries B.C., include iron bands and rivets used to repair stone bowls. Other objects made of iron, such as knife blades and spear points, are found at sites dating from the 10th century to the end of the first millennium B.C. Bronze technology was also highly advanced in southern Arabia. The lost-wax process of casting was widely used to produce sculptures and plaques with designs and inscriptions in relief, in addition to more utilitarian objects. There is also evidence that drawn copper wire was used to make bracelets and other pieces of jewelry. In the first century B.C. objects made from brass appear. Some were certainly imported but others were probably made locally.

Pottery making, on the other hand, lagged appreciably behind the ceramic technology of neighboring lands. The potter's wheel, which came into general use as a mass-production technique elsewhere in the Near East by about 1800 B.C., was not used in southern Arabia in pre-Islamic times. All the region's pottery was laboriously shaped by hand from clay lumps, coils or tubular sections. Pot surfaces were commonly finished with a red slip—a mixture of fine clay and water with the consistency of thick cream—that was burnished before firing. Common decorative techniques included incision, painting and the application of ornaments. Applied ornaments and designs were characteristic of the early period, from the late 11th and 10th centuries to about the seventh century B.C. Painting—limited to dots, lattice patterns, barbs of feather and other simple geometric designs—was popular chiefly during the eighth century B.C. Incision, including the use of engraved lines, designs and inscriptions, was the most common decorative device; examples are found in all periods.

The sculptural art of southern Arabia ranges in form from almost realistic portraiture to the highly stylized and primitive. There is no evidence of evolution; examples of each form appear

BRONZE PLAQUE bears a votive inscription in the distinctive alphabetical script of the South Arabic language. At bottom a forearm and hand hold out a plate for offerings.

contemporaneously. Most of the sculptures served as votive offerings that were placed in temples and cemeteries. Sculptures of the human head, commonly made of alabaster, portray individuals who are recognizably different (although there is an archaic stylization of certain features, particularly the nose and mouth). The most beautiful alabaster head found so far in southern Arabia is a nearly life-size portrait of a woman. Her hair is rendered in plaster that overlies the stone. Her eyes are inlaid with lapis lazuli and paste. Her eyebrows and cautery marks high on her cheeks presumably were also once filled with some inlaying material. Her ears are pierced for earrings, and the holes at each side of her neck may have been intended for the attachment of a gold necklace that was found in the same tomb.

Full figures received only cursory treatment in southern Arabian sculpture. In one representation of a woman, for example, the facial features are rendered in considerable detail. Except for the breasts, however, the woman's body is largely formless even though such details as the neckline and sleeve length of her dress are included. The people of southern Arabia apparently considered the face and head to be the distinctive part of the individual and were not strongly conscious of the body.

The symbol of the moon god in southern Arabia was a bull's head, and the local sculptors equaled or excelled all ancient peoples in their rendering of the subject. A bull's head unearthed at the Timna cemetery offers an excellent example of one sculptor's realistic portrayal of the animal's muzzle, the folds above its eyes and the shape of its short horns [*see illustration on the cover of this issue*]. In contrast to this example much southern Arabian sculpture was highly stylized. Crude plaques, for instance, show stylized human faces in low relief. Such plaques are contemporary with far more refined work. Perhaps they served as memorial stones for people who could not afford better craftsmanship.

The ibex is another subject that was rendered with stylized features and the use of a minimum of planes. A typical ibex frieze probably once adorned the cornice of a building [*see bottom illustration on page 42*]. Here the animals are shown from the front; horns, eyes and muzzle are easy to recognize but the beards are only squarish planes below the muzzles, the chests are flat, semicircular planes below the beards and the legs appear as long bands that extend

from just below the animals' eyes to the bottom of the frieze.

Through their trade the people of southern Arabia came into contact with many parts of the ancient world. Inevitably they acquired articles abroad, including works of art. In some instances the foreign imports were so popular that both the technique and the motif of the piece were then imitated locally. The most spectacular imported works of art found so far in southern Arabia are classical bronzes; the finest examples are two lions being ridden by male infants [*see illustration below*]. The pieces are Hellenistic in style and execution and probably were either made in some Hellenistic bronze-casting center such as Alexandria or cast locally with imported molds. They date from about 75 B.C. The lions are thought to reflect Hellenistic religious ideas, symbolizing the subjugation of the sun (represented as the lion) by the moon (represented as the infant rider).

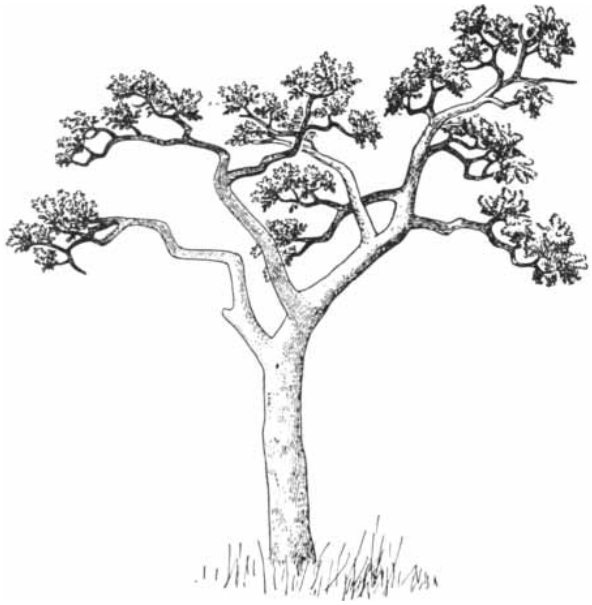
Quite apart from their artistic merit, the bronzes helped to solve a knotty historical problem. They were found in 1950 at Timna in an excavation at the base of the building to which they had once been attached. From other evidence we know that Timna was destroyed about A.D. 15 and was never reoccupied. For many decades a debate had raged among specialists in southern Arabian inscriptions regarding the chronological relations between the various ancient states. One group argued in favor of a "high" chronology, in which the kings of Qataban were assumed to have ruled as early as the ninth or eighth century B.C. Others favored a "low" chronology that placed the Qatabanian kings in the closing centuries of the first millennium B.C.

An inscription on the base of the lion bronzes states that two men, Thuwybum and Aqrabum of the family Muhasniyum, were responsible for decorating a house named Yafash. A second inscription, carved on one of the stone blocks that form the wall of the building where the lion bronzes were found, states that the same two men refurbished the house Yafash during the reign of the Qatabanian king Shahr Yagil Yuhargib. Thus a link is established between the Hellenistic bronzes and the reign of a Qatabanian monarch. The bronzes prove that the low chronology, which places the Qatabanian kings in the latter half of the first millennium B.C., is the correct one.

A number of other Greek bronzes have come to light in southern Arabia. They include statues of Herakles and of the Thracian deity Sabazios, a statue of a Greek woman making an offering of a pellet of incense, and a small composite capital surmounting a fluted column that probably supported a table. From Khor Rori, a site on the Arabian Sea just south of the frankincense forests of Dhofar, comes evidence of trade with India: a third-century-A.D. Indian statuette of a Salabhanjika, or tree nymph [*see illustration below*]. Portraying a girl caught in the movement of a dance, it is alive with vivacity. This is the oldest import from India discovered in southern Arabia so far.

In addition to bronzes, the peoples of southern Arabia also imported quantities of pottery from abroad, much as we now import china from England, earthenware from Bavaria and porcelain from Japan. Thus far finds include fragments of a Greek *lekythos,* decorated with a net pattern and probably made during the fourth century B.C., lead-glazed cups, or *skyphoi,* of the first century B.C. (from northern Syria, Asia Minor or possibly from southern Russia) and a number of fragments of ware from Italy and the Near East. These are obviously only samples of the variety of imports that

IMPORTED TREASURES attest to the extent of the trade networks linking Arabia Felix with the rest of the ancient world. A lion with an infant rider (*left*) is one of a pair of bronzes found at Timna. Hellenistic in style, it bears a South Arabic inscription on its base. The lion bronzes may have been made abroad or perhaps were cast locally, using imported molds. They date from about 75 B.C. The dancer (*right*) was found on the Dhofar coast. The oldest-known find from India, it dates from the third century A.D.



WEALTH OF ARABIA FELIX came from frankincense and myrrh, the aromatic resins of two plant genera that grow only in southern Arabia and Somalia. Frankincense trees have stiff, low branches and red flowers; the species illustrated (*left*) is *Boswellia Carterii*. The myrrh tree resembles a low, spreading cedar; the species illustrated (*right*) is *Balsamodendron myrrha*. During classical times myrrh resin was a major ingredient in cosmetics and frankincense was used in burnt offerings and in funeral pyres.

flowed into southern Arabia in the days when the region enjoyed its greatest prosperity.

Starting in the fourth century A.D. and continuing until the seventh century, the civilization of Arabia Felix began a slow and steady decline. The many factors that led to this decline are interwoven in such complex relationships that in most instances it is difficult, if not impossible, to determine order or distinguish cause from effect.

Perhaps the most important reason for the decline was the economic loss suffered when the frankincense market collapsed. With the triumph of Christianity in A.D. 323, the year Constantine the Great proclaimed it the state religion of the Roman Empire, a number of changes in traditional Roman customs occurred. One change was the replacement of cremation by simple burial. The elimination of funeral pyres cut heavily into the demand for frankincense. There was still a small market for it as church incense and as a medicinal substance, but the quantity required was insignificant compared with the amount formerly consumed in cremations. The sharply reduced market must have been accompanied by a sudden decline in the flow of wealth into southern Arabia, with grave consequences for the region's economy.

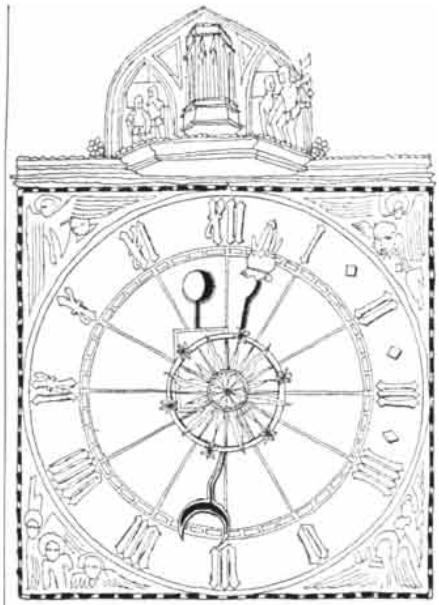
The reduced demand must also have led to an increased isolation of southern Arabia. Once frankincense ceased to be a major commodity the region no longer played a significant role in world commerce; located far from the center of political, economic and cultural activity in the Mediterranean basin, southern Arabia was deprived of the stimulus that flows from contact with and involvement in the milieu of current ideas and trends. It is not impossible that southern Arabian culture began to turn inward on itself as a result of its reduced contact with other cultures.

Within four years of Constantine's proclamation Ethiopia was also converted to Christianity, and Ethiopian missionaries soon entered southern Arabia. By the latter part of the fourth century much of the region was ruled by Ethiopian Christians. There were also many Jews in southern Arabia; indeed, a Jewish dynasty eventually rose to power in the old Sabaean kingdom. After persecuting the Christians of Nejran the last Jewish monarch was driven out of Saba and was finally killed by Ethiopian Christians who were angered over the persecution of their coreligionists. The period of Ethiopian rule that followed was succeeded by a Persian occupation under the Sassanids, during which the Sassanid state religion, Zoroastrianism, must have been introduced. Finally, Persian rule gave way to the Islamic conquest of the region in the seventh century.

Thus in the brief span of 300 years the people of southern Arabia were exposed in rapid succession to three alien religious systems, all possessed of much vitality and zeal. The old paganism must have slipped badly under the buffeting of these new ideologies. In all probability the earlier system of values was discredited, and the frequent changes in the prevailing faith left the people without any body of ideas or definable frame of reference.

It seems likely that a kind of fatigue overtook the culture, leaving it no longer able to respond to the demands and trends of the changing times. There are earlier parallels for this phenomenon in the ancient Near East, but surely there are no better examples than southern Arabia. By the time Islam burst on the scene there was little of the old worth saving. As when Roman culture faced the dynamic faith of Christianity, there was no longer a viable cultural style capable of resisting the new integration brought by Islam.

The decline of Arabia Felix, then, resulted from a combination of factors, political, economic and cultural. Perhaps other causes such as disease—causes we shall one day learn—also played a role. We have hardly scratched the surface in our efforts to resurrect the stuff of which the little-known culture of Arabia Felix was made. This is a continuing task.



The Nobel Prizes

The Nobel prizes in science for 1969 have been awarded for pioneering studies of bacterial viruses, for insights into the nature of fundamental particles and for novel concepts of molecular structure. In addition a Nobel prize was given for the first time in economics; it was awarded for the development of mathematical models of economic activity.

The prize for physiology and medicine was shared by Max Delbrück, Alfred D. Hershey and Salvador E. Luria "for their discoveries concerning the replication mechanism and genetic structure of viruses." The prize for physics was given to Murray Gell-Mann "for his contributions and discoveries concerning the classification of elementary particles and their interactions." The prize for chemistry was shared by Odd Hassel and Derek H. R. Barton "for their work to develop and apply the concept of conformation in chemistry." The new prize in economics was shared by Ragnar Frisch and Jan Tinbergen "for having developed and applied dynamic models for the analysis of economic processes."

Delbrück received a Ph.D. in theoretical physics from the University of Göttingen in 1930 and later studied under Niels Bohr in Copenhagen. He was profoundly influenced by Bohr's prediction that biologists would ultimately encounter something akin to the uncertainty principle of quantum mechanics as they learned more about the fundamental processes of living matter. Challenged by this prospect, Delbrück decided to become a biologist.

In 1937 he obtained a Rockefeller Foundation fellowship to study biology at the California Institute of Technology, where genetics was dominated by the "fruit-fly school" of Thomas Hunt Morgan. The substance of the gene was still unknown but it was thought to be protein. Following the physicist's tradition of working with the simplest possible system, Delbrück took up the study of bacteriophages, the viruses that infect bacteria, and soon he developed the plaque technique for observing their growth. In this technique a dilute suspension of viruses is spread on a sheet of bacterial cells growing on a nutrient medium in a glass dish. A virus enters a bacterial cell, takes over the cell's chemical machinery and makes numerous copies of itself. The cell bursts and releases the new viruses, which then infect nearby cells and eventually leave a plaque, or clear area, in the bacterial culture. Delbrück determined that a bacteriophage requires only about 20 minutes to make about 100 copies of itself.

Luria, born in Italy and trained in medicine, met Delbrück in 1940, and for a period both worked at Vanderbilt University. In 1943 they published an important paper showing that when bacteria exhibit a resistance to certain viruses, the resistant forms arise by mutation and natural selection. Previously it had been argued that the original bacterial strain somehow "developed" a resistance to the virus. A year earlier Luria and Thomas F. Anderson had succeeded in making the first electron micrograph of a bacterial virus; the particle, one of the now well-known *T* family, was seen to consist of a roundish head and a short straight tail (see "The T2 Mystery," by Salvador E. Luria; SCIENTIFIC AMERICAN, April, 1955). Since 1947 Delbrück has worked at the California Institute of Technology; Luria has been at the Massachusetts Institute of Technology since 1959.

Hershey became a member of what has been called the American phage group in the early 1940's. In 1946 he and Delbrück independently demonstrated that virus mutants will recombine with one another to form new viruses (see "Bacterial Viruses and Sex," by Max and Mary Bruce Delbrück; SCIENTIFIC AMERICAN, November, 1948). Previously recombination had been thought to occur only in higher organisms. The new

finding pointed the way to refined experiments in which the genetic structure of viruses was mapped in great detail. At the time, however, no one knew whether the genes of the virus consisted of protein or nucleic acid, or some combination of the two. In 1952, working with Martha Chase at the Carnegie Institution of Washington's laboratory in Cold Spring Harbor, N.Y., Hershey proved conclusively that only the nucleic acid of the virus enters the bacterial cell; its protein jacket remains outside. The nucleic acid was deoxyribonucleic acid—the DNA that James D. Watson and Francis H. C. Crick proposed, a few months later, to have the form of a double-strand helix.

Gell-Mann made his first major contribution to theoretical physics 16 years ago at the age of 24, only two years after receiving his Ph.D. from M.I.T. In 1953 the new high-energy accelerators were producing a baffling multiplicity of new subnuclear particles. Gell-Mann perceived that by assigning appropriate small numbers (−2, −1, 0, +1, +2) to each particle he could predict which particles would interact to form new particles and which reactions were forbidden. By using the term "strangeness" to describe these new quantum numbers he introduced physicists to a lively new idiom (see "Elementary Particles," by Murray Gell-Mann and E. P. Rosenbaum; SCIENTIFIC AMERICAN, July, 1957).

As the particles continued to proliferate, Gell-Mann recognized (early in 1961) that they might be grouped into supermultiplets in much the same way that the neutron and proton, for example, form a simple multiplet. Because the new grouping involves eight quantum numbers, Gell-Mann referred to it as the "eightfold way," a term suggested to him by Buddha's eight rules for avoiding pain. The eightfold way predicted the existence of, among others, the omega-minus particle, which was soon found at the Brookhaven National Laboratory. The concept of supermultiplets was worked out independently by Yuval Ne'eman, an Israeli engineer turned physicist.

Most recently Gell-Mann has put forward the idea that the "elementary" particles are each composed of three particles more elementary still, which

he calls quarks. The quarks would be unique among particles in possessing fractional electric charges: $+2/3$, $+1/3$, $-2/3$ and $-1/3$. The neutron, for example, would consist of two quarks of $-1/3$ charge and one quark of $+2/3$ charge. Physicists have been hunting the quark for several years; possible examples have recently turned up in cloud-chamber photographs of high-energy cosmic rays. Many physicists, including Gell-Mann, remain skeptical, however, that the quark has been captured.

Hassel was professor of physical chemistry at the University of Oslo until his retirement five years ago. Barton is professor of organic chemistry at the Imperial College of Science and Technology in London. In the late 1930's Hassel began using physical methods to study the chemical structure of simple organic molecules, including cyclohexane, a molecule with the same six-member ring as benzene but with six more hydrogen atoms. In the textbooks of that day such rings were presented as flat structures. Hassel's data showed that the ring in cyclohexane could be bent into either a "boat" form or a "chair" form. In the boat form two opposite pairs of carbon atoms lie in a plane and the two remaining carbon atoms are raised like the bow and stern of a boat. In the chair conformation one end of the boat is flipped down. In actuality the ends can flip back and forth, ending up either on the same side of the central plane or on opposite sides. Such different arrangements are known as conformational isomers. Barton extended Hassel's ideas to structures with more than one ring, and he showed in a series of papers how different conformational isomers have distinctive properties and form different compounds.

The new Alfred Nobel Memorial Prize in Economic Science was created last year by the Sveriges Riksbank, the national bank of Sweden, to commemorate its 300th anniversary. The economics award carries the same cash prize as the other Nobel awards: $73,000. Frisch and Tinbergen, the first winners, are respectively Norwegian and Dutch. Frisch was professor of social economy and statistics at the University of Oslo from 1931 until his retirement four years ago. Tinbergen has been a professor at the Netherlands School of Economics since 1933.

For many years chief editor of the journal *Econometrica*, Frisch has served as an economic adviser to Norway as well as to several underdeveloped countries, including India and the United Arab Republic. His specialty has been the development of mathematical methods for analyzing market conditions, economic growth and business cycles. In these studies he has pioneered the concept of "multicolinearity," which refers to the tendency of many statistical indicators to move in concert.

Tinbergen was economic adviser to the League of Nations in the late 1930's. While there he completed a major mathematical analysis of the U.S. economy from 1919 to the financial collapse in 1932. From this study he derived important theories of the business cycle and methods for stabilizing it. As director of the Central Planning Bureau of the Netherlands he has developed an econometric model for the nation that lends itself both to short-range forecasts and to longer-range political and economic planning.

Food and People

In 1968 the food production of the developing nations increased at a faster rate than their population, states the Food and Agriculture Organization of the United Nations in a preliminary annual report. For all developing countries together food production rose about 3 percent, whereas the average growth of population in those nations was 2.6 percent. In a foreword to the report Addeke H. Boerma, the director-general of the FAO, writes: "Several elements in the current situation . . . continue to justify the hope that a growing number of developing countries can now increase their [food] production a good deal faster than in the past, provided—and this is crucial—that appropriate policies are pursued. . . . Unless governments continue to strengthen the emphasis on agriculture in all the relevant fields of policy—including investments, institutions, foreign exchange allocation and helpful price policies—the potential implicit in the new techniques simply will not be realized at the required speed."

Performance varied widely between regions. In the Far East, exclusive of mainland China (for which the FAO lacked reliable information), food production rose 5 percent. In the Near East and Africa the gain was about 2 percent, and in Latin America there was a decline of about 2 percent, attributable mainly to widespread drought.

In terms of commodities the largest increases were recorded in the production of cereal grains. Wheat production rose by 14 percent to a record world total of 308 million metric tons. The increase was particularly large, almost 20 percent, in the developing countries, no-

tably India and Pakistan and the nations of North Africa. The only major cereal to show a decline was corn, mainly because of a deliberate cut in production in the U. S.

The report explores the matter of how much the gain in the Far East was due to conscious efforts to accelerate the growth of output, "in particular through the more widespread use of the high-yielding cereal varieties and the other inputs associated with them." The conclusion is that "the greater use of the new techniques in the Far East was indeed a factor," first because the nations of that region have adopted the new cereal varieties at a much faster rate than other developing regions and also because "in the developing Far East at least seven countries—China (Taiwan), Ceylon, India, Republic of Korea, Malaysia, Pakistan and the Philippines—representing some 70 percent of the area's total cereal output, have moved well beyond the experimental stage in the use of the new techniques." It is probably no coincidence, the report says, that the most rapid adoption of new technology "has taken place in the Far East, where the food situation has been particularly precarious in recent years and where food imports have been greatest." Hence it seems that "the most important single reason for the shift to the new technology in these countries has been a strong government commitment, triggered by the urgency of the food shortage and made possible by the genetic successes achieved at this point in time."

Tokamak

Between 10 and 30 trillion particles per cubic centimeter at approximately 10 million degrees Celsius for 20 thousandths of a second—these three numbers represent the best combination of experimental conditions achieved so far in the 20-year-old international quest for controlled thermonuclear power. They respectively denote the density, temperature and confinement time of a doughnut-shaped plasma, or gas of charged particles, generated inside the device called Tokamak 3 at the I. V. Kurchatov Institute of Atomic Energy in Moscow. The numbers were made public recently in a widely anticipated report in *Nature* by members of a joint Russian-British research team that had just completed a series of sophisticated laser measurements of the Tokamak's performance.

The new Tokamak results agree with those obtained by other techniques and announced earlier this year by the Rus-

sians. The preliminary announcement of the results was greeted with some skepticism outside the U.S.S.R., since the early measurements could be interpreted in two different ways, one indicating much more of a forward step than the other. The laser measurement technique has been utilized for several years at thermonuclear-research laboratories in both Britain and the U.S. Last year, in order to speed up the resolution of the questions concerning the Tokamak results, a group from the British Atomic Energy Authority's Culham Laboratory was invited by the head of the Kurchatov Institute, Lev A. Artsimovich, to use the laser technique on Tokamak 3. This unusual collaboration resulted in the recent *Nature* report, which was signed by N. J. Peacock, D. C. Robinson, M. J. Forrest and P. D. Wilcock of the Culham Laboratory and V. V. Sannikov of the Kurchatov Institute.

The new machine is the largest in the Tokamak series of plasma containers built by the Russians. It is toroidal in shape, with a major diameter of two meters and a minor diameter of .4 meter. The plasma stream is prevented from touching the walls of the chamber by means of a helical magnetic field that is actually a composite of two separate fields. One field is formed by an electric current flowing through coils wrapped around the outside of the plasma chamber; the other is formed at right angles to the first by a current induced to flow within the plasma. It is not yet understood why this configuration has resulted in significantly better results than those obtained from roughly similar machines in the U.S., although the symmetry of the Tokamak design and the resulting uniformity of its magnetic field are thought to be important.

The U.S. Atomic Energy Commission has already provided funds for two machines of the Tokamak type in this country. One, named Ormac, is expected to be ready to go into operation at the Oak Ridge National Laboratory by next summer. The other will result from the conversion of the Model C Stellarator at the Princeton Plasma Physics Laboratory; it is expected to be finished by next spring. In the meantime the Russians are constructing several machines of modest size, each of which is to investigate a specific problem; for example, one will explore the use of radio-frequency heating to make the plasma still hotter. Their second-generation machine, Tokamak 10, is already designed but not yet under construction. It is estimated that the performance of Tokamak 3 needs to be improved only by a factor of 200 to reach the level at which fusion reactions between hydrogen nuclei in the plasma can release more energy than is needed to operate the device.

Mars Is Like Itself

The nine-man group responsible for the recent Mariner television pictures of Mars introduces its preliminary analysis of the results in *Science* with the following epitome: "Before the space era, Mars was thought to be like the earth; after Mariner 4, Mars seemed to be like the moon; Mariners 6 and 7 have shown Mars to have its own distinctive features, unknown elsewhere in the solar system." *Mariner 6* flew past Mars on July 31, *Mariner 7* on August 5. The television survey team was headed by Robert B. Leighton of the California Institute of Technology.

In all the two spacecraft produced 143 far-encounter pictures, 59 near-encounter pictures and 1,177 pictures at various distances containing limited but still useful information. The most distant pictures were taken from more than a million miles away; the near-encounter pictures were taken at distances ranging from 5,700 miles down to 2,200 miles. "The classical martian features stand out clearly in the far-encounter pictures," the Leighton team reports, "and, as the image grows, these features transform into areas having recognizable relationships to the numerous craters which mark the surface." For example, two of the most famous "canals" on Mars, Cantabras and Gehon, coincide with a near-linear alignment of craters with unusually dark floors.

Some of the major findings are: Photographs of the planet's limb reveal that particles in the atmosphere produce clearly stratified scattering layers with a total thickness of about six miles. The atmosphere also seems to support processes that alter the brightness of surface features at different times of the day. On the other hand, the atmosphere contains no sign of the "waves, billows or cirriform streaks" characteristic of clouds.

The surface exhibits three distinctive kinds of terrain: cratered regions (almost devoid of young moonlike craters), featureless regions (some larger and smoother than any known on the moon) and "chaotic" terrain (consisting of a virtually uncratered irregular network of short ridges and depressions). "Marked erosion, blanketing, and other surface processes must have been operating almost up to the present in the areas of featureless and chaotic terrains; only this could account for the absence of even

small craters there.... The chaotic terrain gives a general impression of collapse structures, suggesting the possibility...of permafrost some kilometers thick, and of its localized withdrawal."

The pictures reveal nothing like the mountains or other topographic features produced on the earth by tectonic processes, which suggests that "the crust of Mars has not been subjected to the kinds of internal forces that have modified, and continue to modify, the surface of the earth." The cratered regions of Mars appear to have undergone little erosion, by water or anything else, and thus seem to be very ancient.

Nowhere, in fact, do the investigators see any "strong indication" of the action of liquid water, water vapor or ice. (They conclude that the polar caps are almost certainly carbon dioxide snow.) "The results thus reinforce the conclusion...that scarcity of water is the most serious limiting factor for life on Mars. No terrestrial species known to us could live in the dry martian environment.... While one cannot rule out, on the basis of the TV data, the possibility that a... brief, aqueous epoch occurred during the early history of the planet, it must be said that the effect of the TV results so far is to diminish the a priori likelihood of finding life on Mars. However, it should be noted that if Mars is to be a testing ground for our notions about the origin of life, we must avoid using these same notions to disprove in advance the possibility of life on that planet."

Another Messenger

On the basis of experiments with bacterial cells, which have no clearly defined nucleus, there is abundant evidence that genetic information coded in linear molecules of DNA is transcribed first into linear molecules of messenger RNA, or mRNA. These molecules then serve as an information-bearing tape that is "read" by the particles called ribosomes, which travel along it. The mRNA with its associated ribosomes is called a polyribosome; it provides the mechanism for translating the genetic message carried by mRNA into the amino acid sequence of protein molecules.

It has not been demonstrated, however, that the flow of genetic information from DNA to protein is this straightforward in higher organisms, whose cells have a distinct nucleus surrounded by cytoplasm. Although mRNA is abundantly present in the cytoplasm, where protein is manufactured, its origin has not been directly traced to the DNA in the nucleus. If mRNA is indeed formed

in the nucleus, no one has been able to demonstrate how it passes from the nucleus into the cytoplasm.

The answer to this mystery may now be supplied by Eugene Bell of the Massachusetts Institute of Technology. In a recent issue of *Nature* he reports discovering in the cytoplasm of animal cells a class of DNA molecules that he calls informational DNA, or *I*-DNA. The *I*-DNA in the cytoplasm is found in combination with protein in small particles that Bell names *I*-somes. The *I*-DNA is also found in association with polyribosomes, which carry out the actual synthesis of protein.

Bell therefore proposes a new model for the flow of genetic information in nucleated cells. He suggests that DNA in the nucleus is transcribed first not into mRNA but into short pieces of messenger DNA, or *I*-DNA. The *I*-DNA passes into the cytoplasm, where it combines with protein to form *I*-somes. In the cytoplasm *I*-DNA may or may not be replicated. In any case, *I*-DNA is ultimately transcribed into mRNA in the cytoplasm, perhaps at the same time that the mRNA is being translated into protein.

Trial by Voiceprint

A panel of the Acoustical Society of America has expressed serious doubt about the accuracy of a new police identification technique, the use of sound spectrograms to match an unknown voice, recorded during surveillance, with the voice of a suspect repeating the same words. Reporting in *Science,* the six-man panel points out that the assumed analogy between fingerprints and voiceprints is false: finding a similarity between fingerprints involves the objective study of anatomical evidence but finding a similarity between voiceprints is a matter of subjective judgment on the observer's part. The similarities between two sound spectrograms are often more a product of the word spoken than of the voice speaking it. Conversely, the same individual speaking the same word may produce two completely different voiceprints.

The panel notes that voiceprint identifications have played a part in a number of recent court cases. In the aftermath of the Watts rioting, for example, the Los Angeles police recorded the voice of a man who admitted to arson during an off-camera television interview. The recording was later matched with the voiceprint of a suspect, who was then tried and convicted. In a case involving obscene telephone calls a suspect was identified by matching his voiceprint with excerpts from recordings of tapped calls, and a conviction was obtained. The panel observes that in a lengthy series of experiments the rate of mistaken identification of voiceprints ranged from zero to as much as 63 percent; among other factors affecting the number of false identifications was the observer's degree of training.

The panel consisted of Richard H. Bolt, Franklin S. Cooper, Edward E. David, Jr., Peter B. Denes, James M. Pickett and Kenneth N. Stevens. They conclude that the available results are inadequate to establish the reliability of voice identification by means of sound spectrogram.

Neutronium

The existence of an unstable "atom" consisting of a neutron bound to an electron is inferred from an experiment in which a refrigerated crystal of lithium fluoride containing trapped electrons is irradiated with neutrons. The neutrons are retained at least 40 seconds after capture. The experiment is reported in a communication to *Physical Review Letters* by T. J. Grant and J. W. Cobble of Purdue University.

It had been known from theory and scattering experiments that electrons and neutrons interact with a potential of some 3,800 electron volts, but it had not been shown that an electron and a neutron could form a bound species. In their experiment Grant and Cobble used as a source of electrons a crystal of lithium fluoride that had been heavily irradiated with gamma rays, a process that produces about 10^{17} trapped electrons per cubic centimeter. The crystal was chilled to the temperature of liquid helium, 4 degrees Kelvin, and was bombarded for a minute with neutrons at the rate of two million neutrons per square centimeter per second. The crystal was then quickly transferred to a chamber where it was allowed to warm up, and where any neutrons released could be counted as they escaped from the crystal. The average yield of neutrons presumably captured by electrons and subsequently released from the bound state was two per individual run. When the experiment was repeated with the crystal at room temperature, there was no statistical evidence for neutron capture. When trapped electrons were removed from the crystal by heating and the crystal was again irradiated with neutrons at 4 degrees K., the number of neutrons apparently captured was reduced by a factor of four. An analysis of these results indicates that the neutron-electron

species has a half-life of about 30 seconds at 4 degrees K.

Blood of the Pharaohs

A problem in Egyptian history of the 14th century B.C. is whether two of the successors to the pharaoh Ikhnaton were brothers. Using a new microserological technique, investigators in England and Egypt have cast additional light on the question. R. G. Harrison and R. C. Connolly of the University of Liverpool and A. Abdalla of the University of Cairo report in *Nature* that their blood-type analysis strengthens the case for those who believe the two were brothers (although it does not fatally weaken the case for those who believe they were not).

Ikhnaton is famous as a religious reformer whose campaign to substitute a kind of monotheism for the bizarre polytheism of his time collapsed after his death. Neither of his immediate successors would be remembered by nonspecialists today except that the tomb of one —Tutankhamen—astonished the world by its riches when it was opened in 1922. The mummy of "King Tut" is in the custody of the United Arab Republic's Department of Antiquities; another of the department's treasures, until recently believed to be the mummy of the great Ikhnaton himself, has now been shown to be more probably that of his immediate successor, one Smenkhkare.

Tutankhamen and Smenkhkare had one bond in common: each was married to a daughter of Ikhnaton. The three investigators thought that knowledge of the two successors' blood type might settle the question of whether they were also brothers. Because the usual serological analysis requires quantities of tissue that were not available from either mummy, they developed a refined method that needed only a few milligrams of tissue dust. Both mummies proved to belong to the A_2 blood group and also to harbor the serum antigen MN.

It does not follow that because the pharaohs had two blood fractions in common they were brothers. If A_2 and MN were the only fractions existing within the Egyptian population of the second millennium B.C., for example, the two pharaohs need not even have been relatives. Other investigators, however, have established the existence of other blood fractions among Egyptians of that period. Harrison, Connolly and Abdalla therefore conclude that, because their findings are not negative, the probability that the two pharaohs were close relatives is correspondingly increased.

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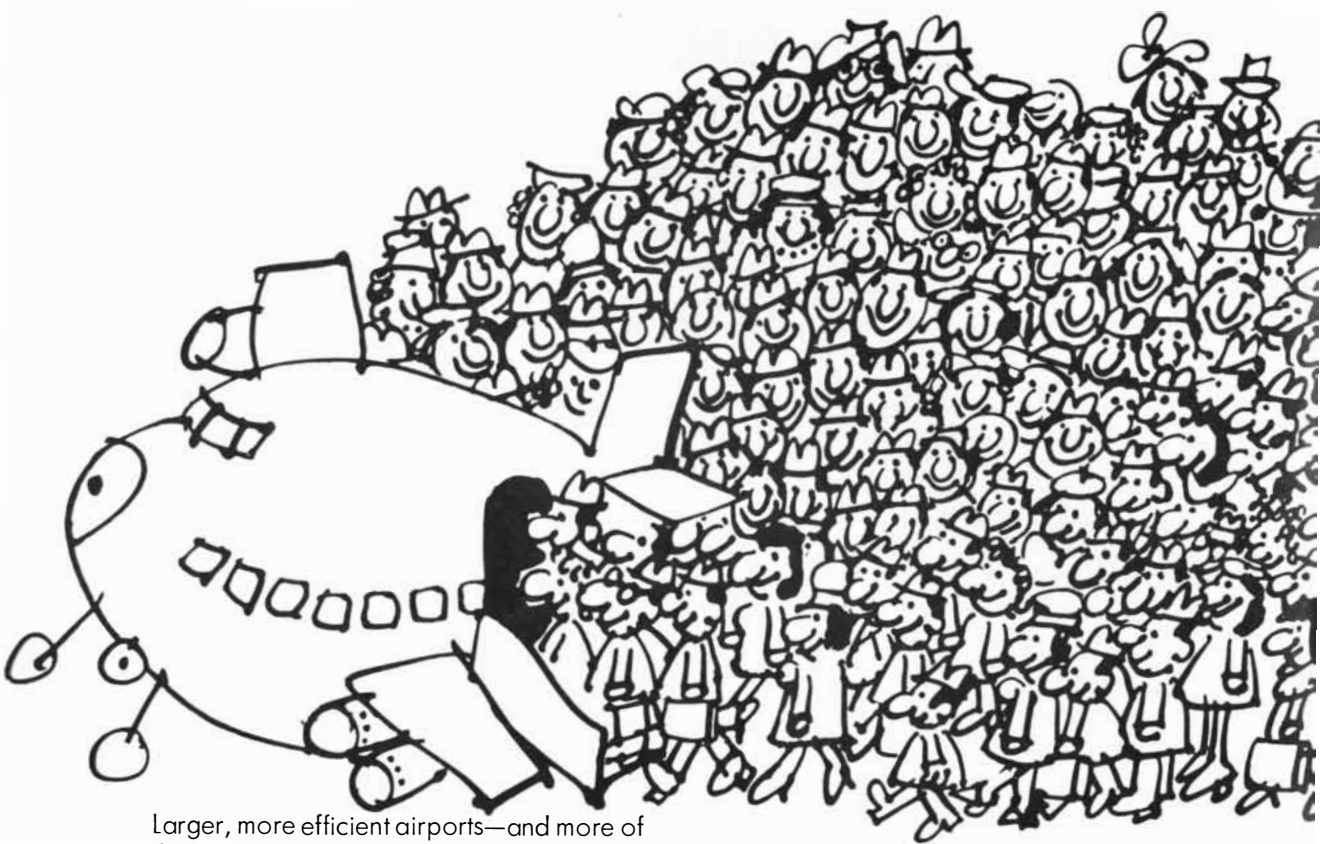

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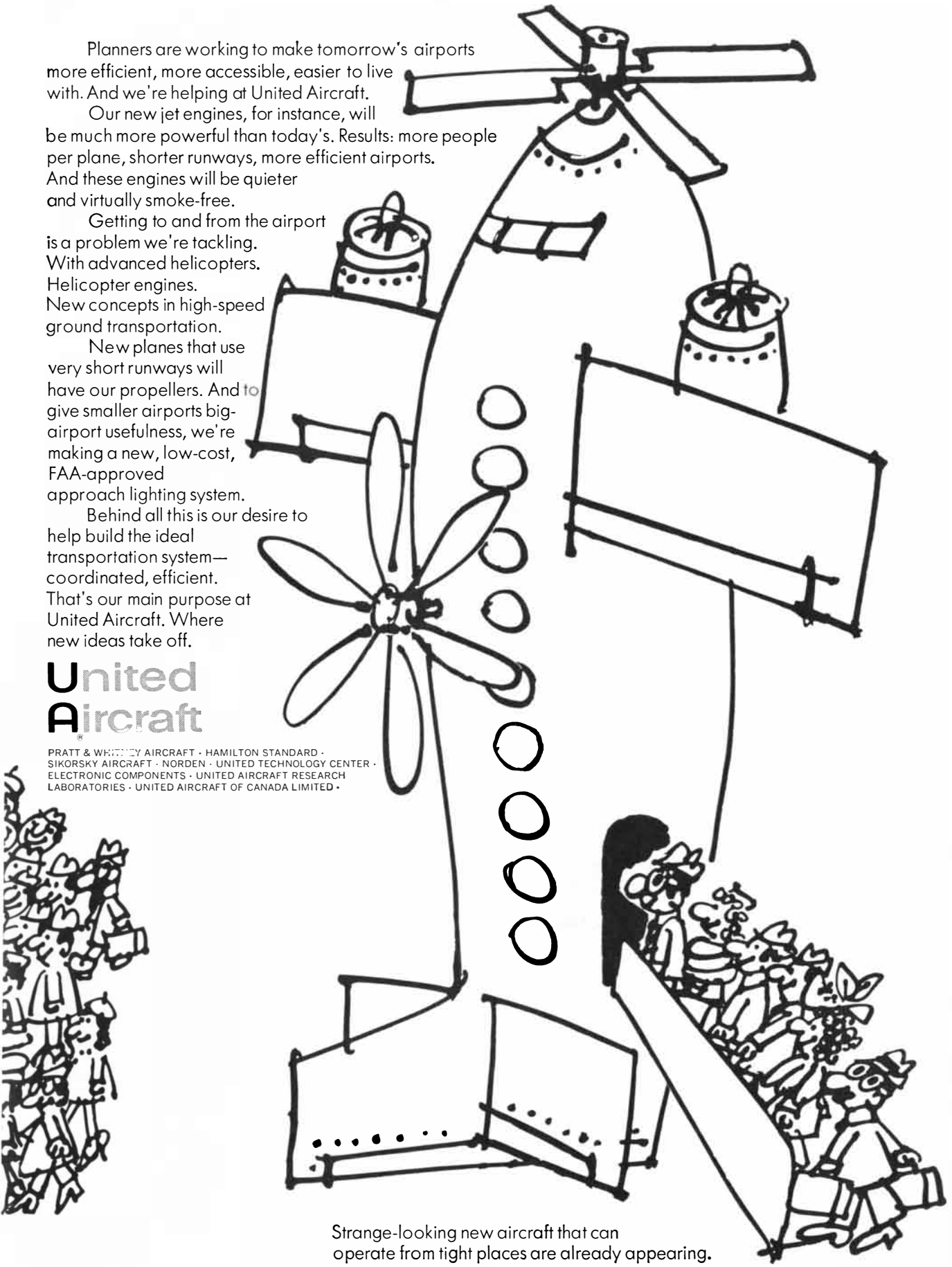


Strange-looking new aircraft that can operate from tight places are already appearing.

The Mechanism of Photosynthesis

Light of two wavelengths is required to activate two photochemical systems. Together they provide the electrons, protons and energy-rich molecules needed to convert carbon dioxide and water into food

by R. P. Levine

Light interacts with living organisms in such processes as vision, bioluminescence and photosynthesis, but it is apparently only during photosynthesis that light energy is converted into useful forms of chemical energy. That energy, in turn, is used to build up complex molecules—notably carbohydrates—that animals require as food. Photosynthetic organisms also provide most of the oxygen in the atmosphere, and the evolution of animals was certainly dependent on the existence of oxygen-evolving microorganisms in the primitive seas.

The study of photosynthesis spans the disciplines of photophysics, photochemistry, biochemistry and physiology. In recent decades such studies have revealed many remarkable aspects of the photosynthetic process. The simple equation that summarizes the process has been known since the 19th century: water (H_2O) plus carbon dioxide (CO_2) yields some form of carbohydrate (represented by CH_2O) and oxygen (O_2). The reaction is driven by light energy. Photons are first absorbed by chlorophyll and other photosynthetic pigments. The red and blue-green algae, for example, contain pigments called phycobilins in addition to chlorophyll [*see illustration on page 60*].

Once the light energy is absorbed, it is used for two purposes. First, it is used to generate what a chemist calls "reducing power." Reduction involves the addition of electrons or the removal of protons, or both. Molecules that are rich in reducing power can transfer electrons to more oxidized molecules. The reducing agent produced by photosynthesis is NADPH, the reduced form of nicotinamide adenine dinucleotide diphosphate (NADP). Second, the light energy becomes converted into the energy-rich phosphate compound adenosine triphosphate (ATP). ATP and NADPH have certain structural elements in common [*see illustrations on page 61*]. Both are needed to reduce CO_2, a relatively oxidized molecule, into carbohydrate. The overall balance sheet for photosynthesis shows that three molecules of ATP and two molecules of NADPH are required for each molecule of CO_2 reduced.

In most algae and in higher plants photosynthesis occurs in the intricate, membrane-filled structure known as the chloroplast [*see illustration on opposite page*]. Within the chloroplast light energy is trapped and the rapid photophysical and photochemical reactions take place that generate the ATP and NADPH to be used in the more leisurely biochemical process of reducing carbon dioxide to carbohydrate. Once ATP and NADPH have been formed they are released into the nonmembranous, or soluble, phase of the chloroplast; there the fixation of carbon dioxide can proceed in the absence of light with the assistance of a number of soluble enzymes.

The Absorption of Light Energy

When chlorophyll or one of the other photosynthetic pigments absorbs photons, the pigment passes from its lowest energy state, or ground state, to a higher energy state. The excited state is not stable, and the pigment can return to the ground state within 10^{-9} second. If in that brief period the energy is not used for the generation of ATP or NADPH, it can be dissipated as fluorescent light. Since 100 percent efficiency is never achieved in biological systems, fluorescence is always observed during photosynthesis; the fluorescence is at a longer —hence less energetic—wavelength than the wavelength originally absorbed. As we shall see, fluorescence has been useful to the investigator of photosynthesis.

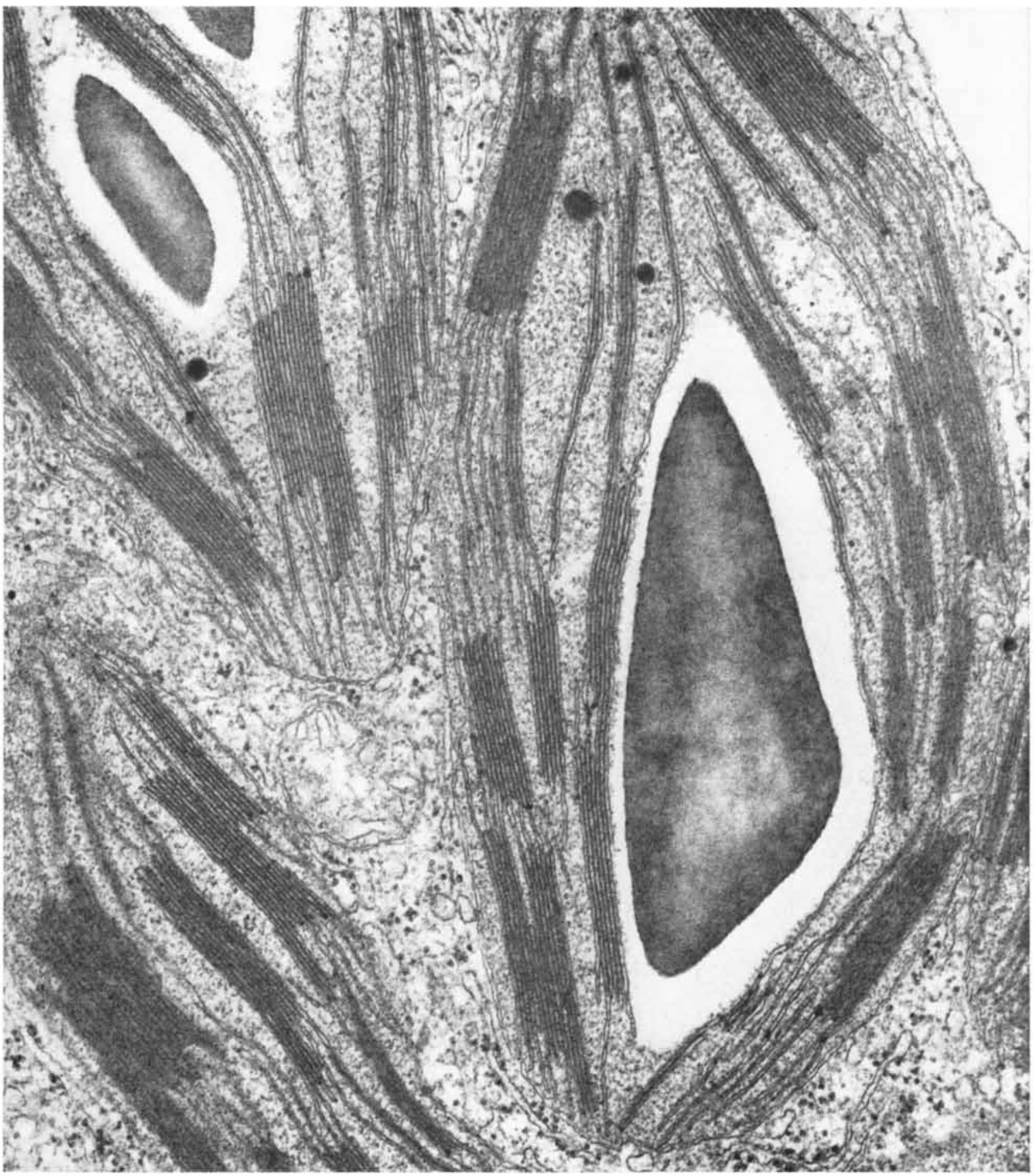
Each of the photosynthetic pigments has its characteristic absorption spectrum: it absorbs more or less light at different wavelengths depending on its molecular structure. For example, the two chlorophylls designated *a* and *b* have major and distinctive absorption bands in the blue and red regions of the spectrum [*see top illustration on page 62*]. When studied in isolation outside the chloroplast, each pigment also has a characteristic fluorescence spectrum. Inside the chloroplast, however, chlorophyll *b* fluorescence is never detected, even when the incident light is of a wavelength known to be absorbed by that chlorophyll. Similarly, fluorescence is never observed from the carotenoid pigments and the phycobilins. Only one of the pigments fluoresces naturally inside the chloroplast: chlorophyll *a*.

This surprising phenomenon has now been explained, largely through the work of Louis N. M. Duysens of the Netherlands. He showed that chlorophyll *b*, the carotenoids and the phycobilins do not participate directly in photosynthesis but rather act only as "antennas" to help gather light energy. When they absorb energy and become excited, they transfer their excitation energy to chlorophyll *a*. Only chlorophyll *a* is actively involved in the subsequent reactions of photosynthesis; when its energy cannot be used for photosynthesis, it dissipates its excitation energy as fluorescence.

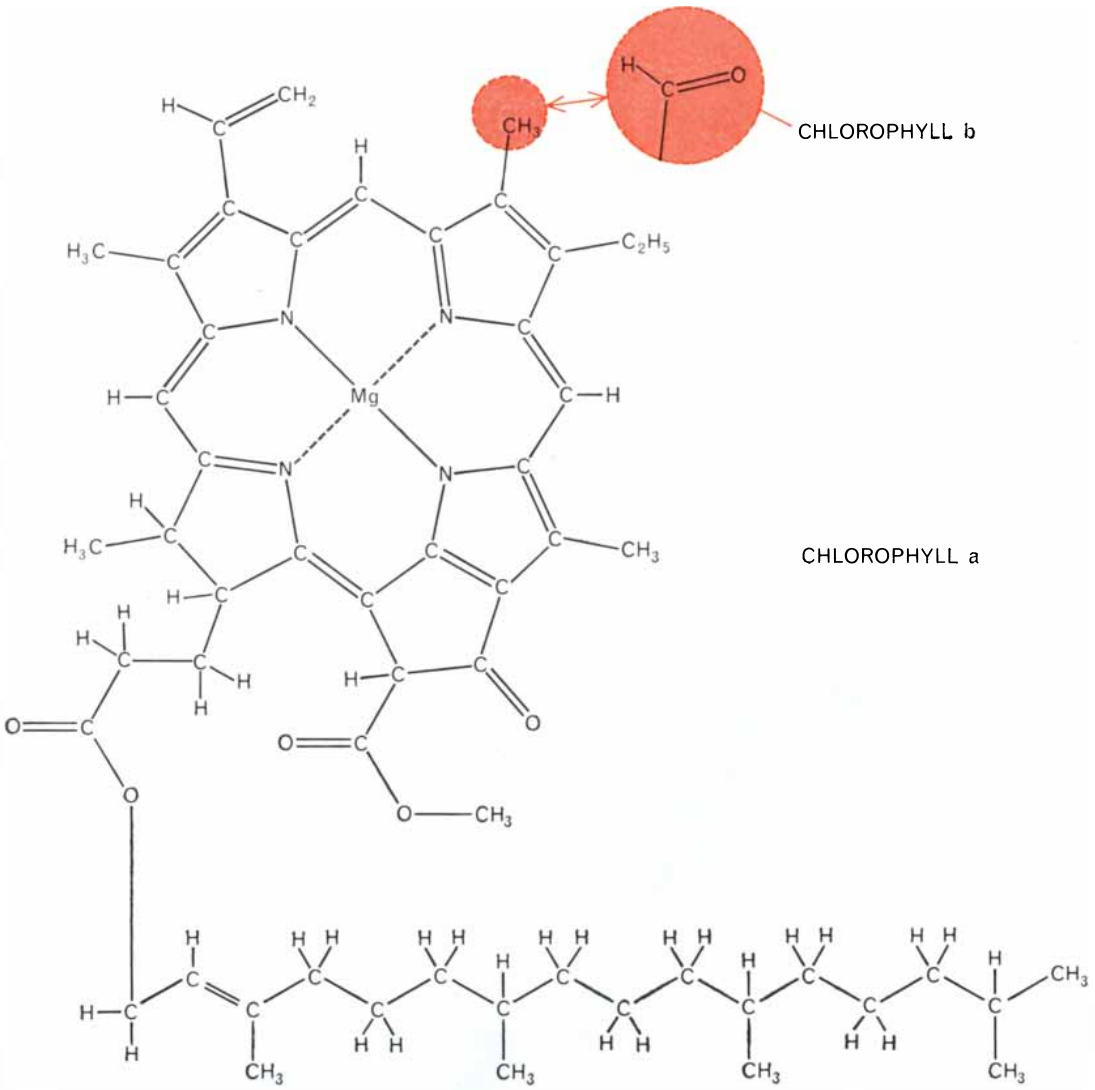
The mechanism for the transfer of excitation energy between pigment molecules in photosynthesis is not clearly understood, but a process called inductive resonance is one possibility. If an excited molecule is close enough to an unexcited one (say within 30 angstroms),

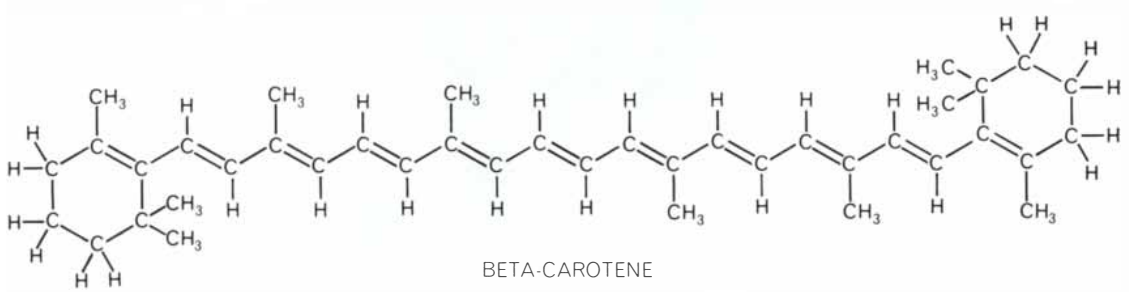
it can dissipate its energy by inducing an excited state in the neighboring molecule. In this way energy can pass from chlorophyll *b* to chlorophyll *a*. The reverse process is not possible, however, because to become excited chlorophyll *b* requires more excitation energy than an excited chlorophyll *a* can provide.

Ultimately the energy of excitation reaches a photosynthetic reaction center, where it is transferred to a special long-wavelength form of chlorophyll *a*. Because this pigment absorbs at a longer wavelength, and hence at a lower energy, than the surrounding pigment molecule, it can be considered a kind of energy sink. The transfer of excitation energy from an excited molecule of normal chlorophyll *a* to such a special chlorophyll *a* molecule probably takes place within 10^{-12} second, which is 1,000 times

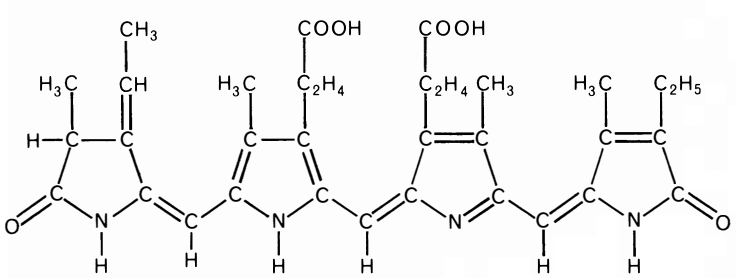


SITE OF PHOTOSYNTHESIS is the organelle known as a chloroplast, present in the cells of all higher plants and most algae. This electron micrograph made by Peter Hepler of Harvard University shows portions of three chloroplasts. Photosynthesis takes place inside the dark membranes that lie in long parallel bundles. The large triangular object in the chloroplast at the right is a kernel of starch, produced by photosynthesis. The chloroplast at the upper left contains two kernels. The magnification is 58,000 diameters.





BETA-CAROTENE



PHYCOCYANOBILIN

PHOTOSYNTHETIC PIGMENTS have the ability to capture photons and convert their energy into molecular excitation energy. Chlorophyll *a* is the pigment found in algae and in the leaves of higher plants. Chlorophyll *b* has the same structure except that a $-CHO$ group replaces a $-CH_3$ group in one corner of the porphyrin ring. Beta-carotene is another photosynthetic pigment present in many higher plants. Red and blue-green algae contain still a third class of pigments, the phycobilins, of which phycocyanobilin is one.

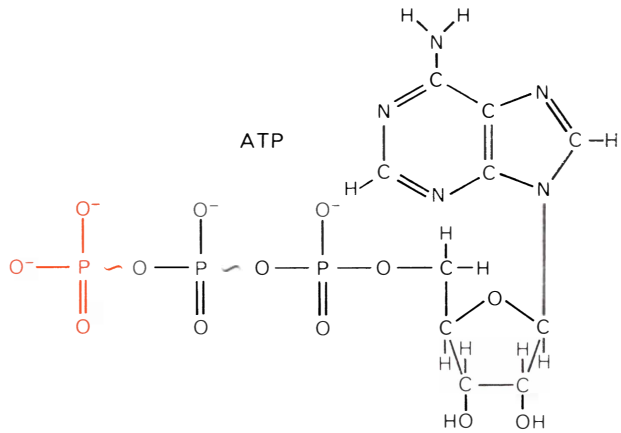
faster than the time taken for the "waste" energy of chlorophyll *a* to emerge as fluorescence. Thus there is ample time for an excited chlorophyll molecule to disperse its energy in a chemically useful way.

The First Chemical Steps

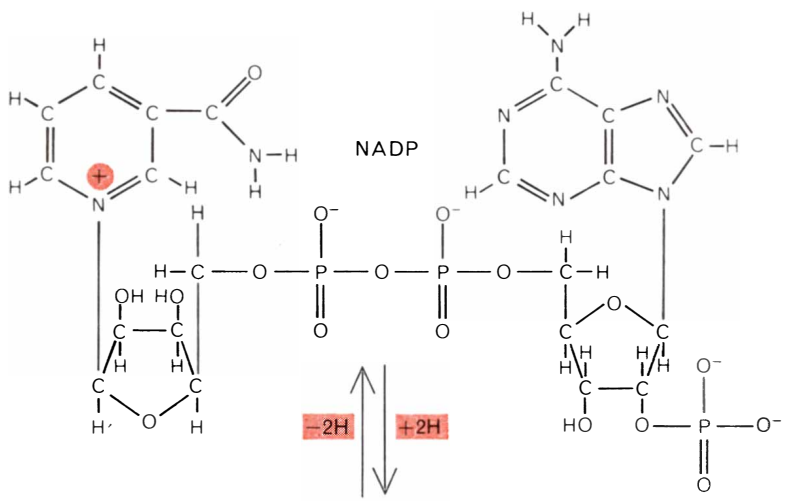
Once light energy has been relayed to the special chlorophyll *a* molecule, the energy sink in the reaction center, the chemistry begins: the excitation energy must be used to form an oxidant and a reductant. The oxidant must be capable of oxidizing water, that is, capable of splitting the water molecule into free oxygen, protons and electrons. (Actually two molecules of H_2O are split into one molecule of O_2 plus four electrons and four protons.) The reductant must accept the reducing equivalents (electrons and protons) that arise from the oxidation of water. Ultimately these equivalents will be used in the reduction of carbon dioxide. The oxidant and the reductant must be formed within the very short lifetime of the excited state of chlorophyll *a*. How this comes about constitutes one of the biggest gaps in our knowledge of photosynthesis, and a great deal of what follows must be conjecture.

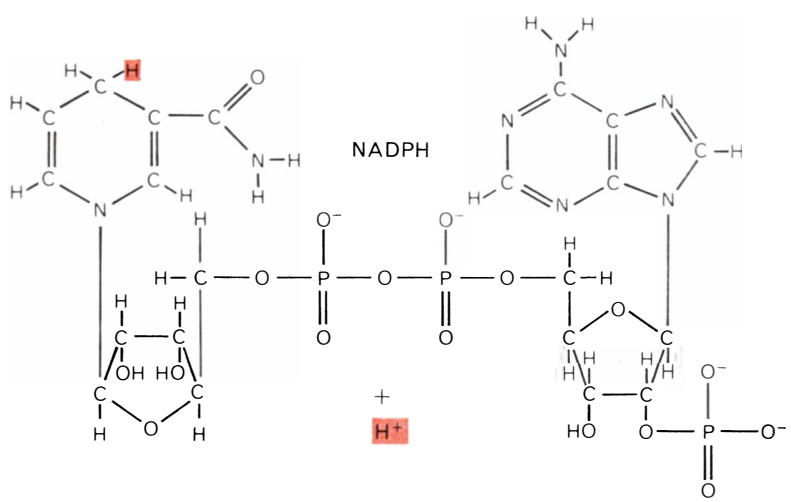
One simple way to visualize the initiation of the first chemical steps of photosynthesis is to imagine the existence of an electron-donor molecule D and an electron-acceptor molecule A. The donor in the oxidized form (D^+) will oxidize water and the acceptor in reduced form (A^-) will ultimately transfer its reducing equivalents to NADP, converting it to NADPH.

A simple model of the primary reaction sequence involving the donor, the acceptor and an excited molecule of chlorophyll *a* is shown in the top illustration on page 63. In this sequence the chlorophyll *a* in the reaction center is raised to an excited state by receiving excitation energy from surrounding pigment molecules. Each reaction-center chlorophyll molecule is in close association with the donor and acceptor molecules in the membrane of the chloroplast. When the chlorophyll returns to the ground state, the release of the excitation energy is sufficient to extract an electron from the donor molecule, thereby oxidizing it to D^+, and to transfer this electron to the acceptor, thus reducing it to A^-. Such charge-transfer processes are known to operate in nonbiological systems where the organic molecules involved have properties similar to those involved in photosynthesis.

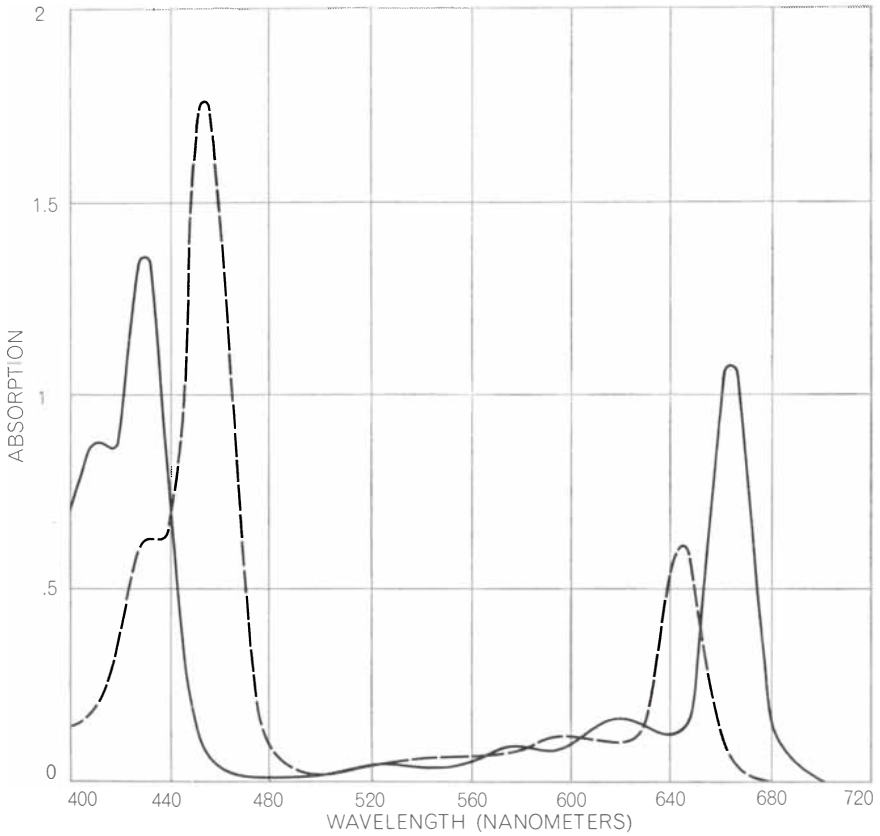


ADENOSINE TRIPHOSPHATE, or ATP, is produced from adenosine diphosphate (ADP), with the energy collected by the photosynthetic pigments. The wavy lines are links to energy-rich phosphate groups. If the last group (*color*) is removed, ATP becomes ADP. In the process ATP supplies energy for converting carbon dioxide into carbohydrates.

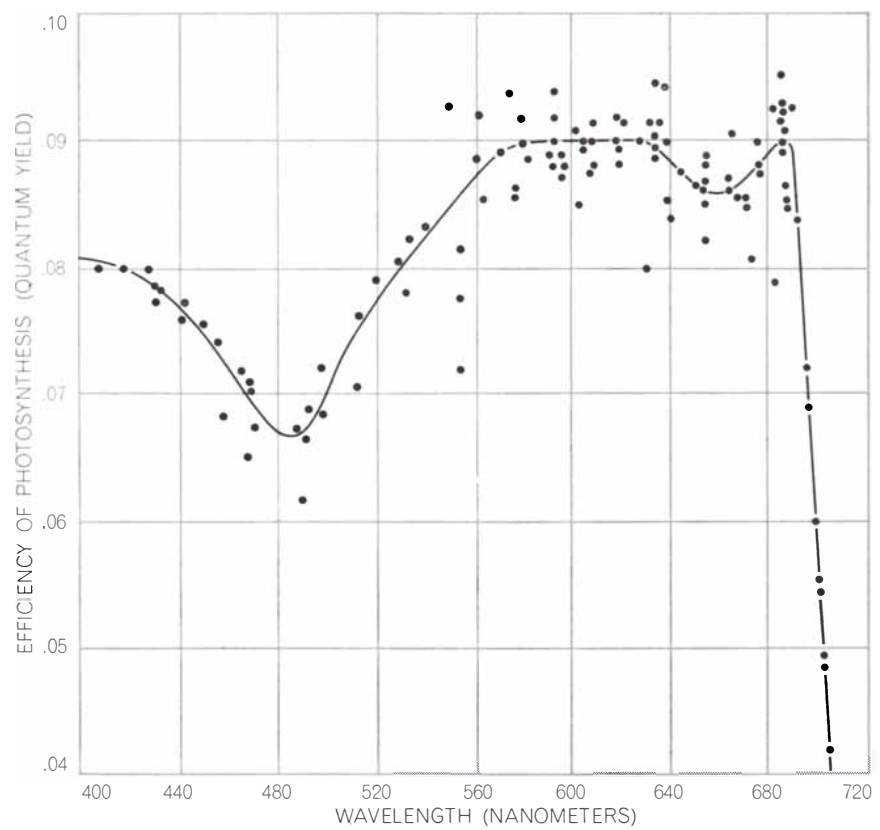




NICOTINAMIDE ADENINE DINUCLEOTIDE DIPHOSPHATE, or NADP, is reduced to NADPH during photosynthesis. NADP becomes NADPH by the addition of two hydrogen atoms. One binds directly to the molecule while the other loses its electron and is released as a proton (H^+). NADPH supplies "reducing power" for fixation of carbon dioxide.



ABSORPTION SPECTRA show that chlorophyll *a* (*solid line*) and chlorophyll *b* (*broken line*) strongly absorb blue and far-red light. The green, yellow and orange wavelengths lying between the peaks are reflected and give both pigments their familiar green color.



EFFICIENCY OF LIGHT ABSORPTION in the alga chlorella was determined by Robert Emerson of the University of Illinois. Efficiency of photosynthesis falls off sharply in the far-red region beyond 680 nanometers even though chlorophyll *a* still absorbs at that wavelength. If light of shorter wavelength is added to far-red light, efficiency rises sharply.

Regardless of how the charge transfer may be accomplished in the chloroplast, its net effect is to separate oxidizing and reducing equivalents. Very little is known about how the hypothetical D^+ participates in the oxidation of water with the concomitant evolution of oxygen. Much more is known about the transfer of reducing equivalents from the hypothetical A^- to NADP. With this step the mechanism of photosynthesis moves from a high-speed photochemical phase to a slower biochemical phase in which electrons are transported through a series of reactions, ultimately to yield NADPH and ATP.

The Biochemical Phase

Our understanding of the biochemical phase of photosynthesis owes much to investigations showing that two light reactions (and not one, as has been tacitly assumed so far) take place in the photosynthetic process used by algae and higher plants. Two experiments set the stage for this discovery. The first provided measurements of the rate of photosynthesis at different wavelengths of light over the range absorbed by the photosynthetic pigments. The result is a curve showing how the quantum efficiency of the process varies at different wavelengths [*see bottom illustration at left*]. The curve reveals a curious fact: in the far-red region, beyond a wavelength of 680 nanometers, the efficiency of photosynthesis falls rapidly to zero even though the pigments still absorb light.

This surprising result led to the second set of experiments, reported in 1956 by Robert Emerson and his colleagues at the University of Illinois. They found that although photosynthesis is very inefficient at wavelengths greater than 680 nanometers, it can be enhanced by adding light of a shorter wavelength, 650 nanometers for example. Moreover, the rate of photosynthesis in the presence of both wavelengths is greater than the sum of the rates obtained when the two wavelengths are supplied separately. This phenomenon, now known as the Emerson enhancement effect, can be explained if photosynthesis is assumed to require two light-driven reactions, both of which can be driven by light of less than 680 nanometers but only one by light of longer wavelength.

These two sets of experiments marked the beginning of an exciting period in the effort to understand the mechanism of photosynthesis. They gave rise to a provocative hypothesis and to several

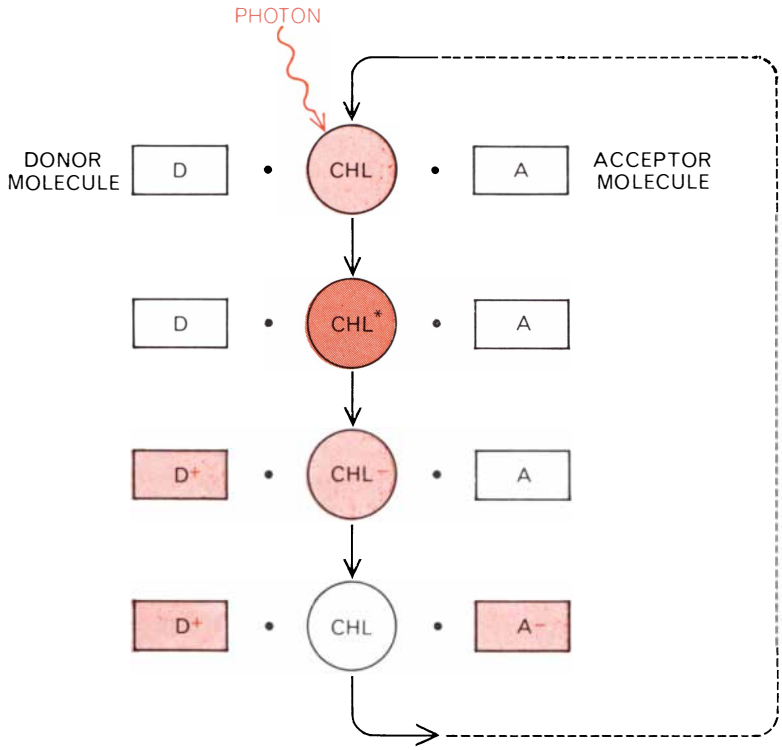
revealing lines of research. The hypothesis was provided by Robert Hill and Fay Bendall of the University of Cambridge. They proposed a scheme showing how electrons could be transported along a biochemical chain in which two separate reactions are triggered by light. Before describing the Hill-Bendall scheme I should briefly touch on some characteristics of electron transport.

One must distinguish first between a transfer in which electrons go *with* an electrochemical gradient (the easy direction) and a transfer in which the electrons go *against* that gradient (the hard direction). Electron-donor and electron-acceptor molecules can be characterized by the quantity called oxidation-reduction potential, which can be positive or negative and is usually expressed in volts. Electrons can be transferred from donors that have a more negative potential to acceptors that have a more positive potential without any input of energy. In fact, when electron transfer takes place along this gradient, energy is released; the greater the gap in potential between donor and acceptor, the greater the yield of energy. To transfer electrons against the electrochemical gradient, on the other hand, requires an input of energy. The greater the gap between the donor and the acceptor, the greater the energy required.

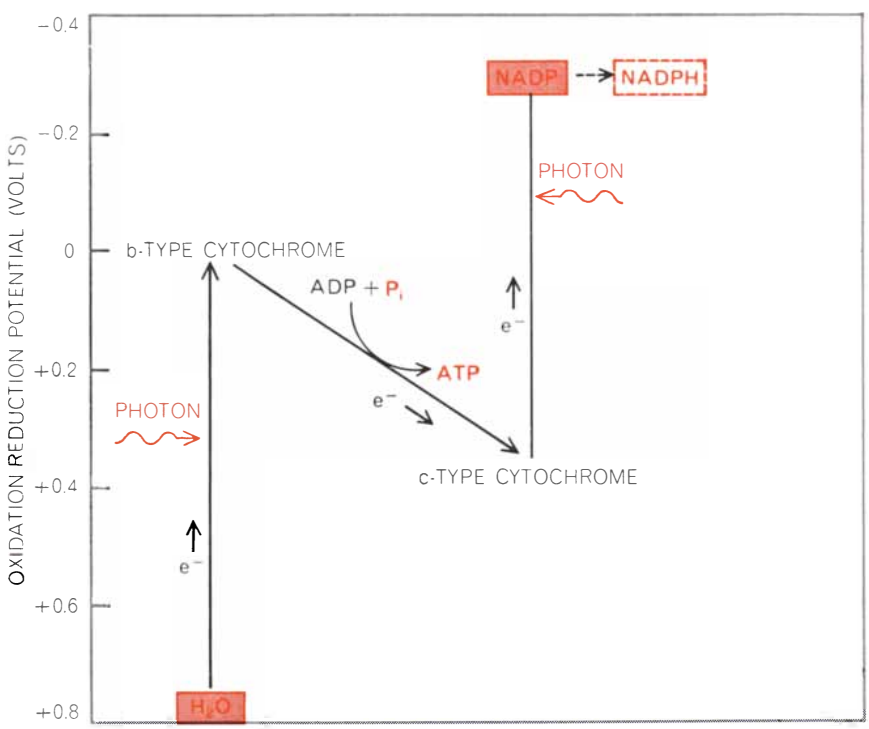
In the mitochondria of both plant and animal cells energy, in the form of ATP, is generated as a consequence of electron transport down an electrochemical gradient between a series of electron-donors and -acceptors called cytochromes. At least some of the electron-transport steps in photosynthesis, however, must go against an electrochemical gradient because the oxidation-reduction potential of water (the primary electron-donor) is +.8 volt whereas that of NADP (the terminal acceptor) is −.3 volt.

The Two Photochemical Systems

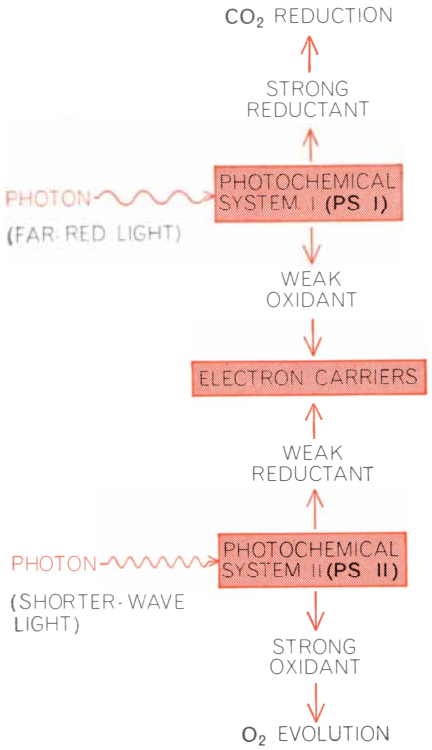
Hill and his co-workers had earlier identified and characterized a number of cytochromes found in the chloroplast; Hill and Bendall saw that ATP might be generated in photosynthesis if advantage were taken of the difference in oxidation-reduction potential between two of these cytochromes. One of them, a *b*-type cytochrome, has a potential close to zero and the other, a *c*-type cytochrome, has a potential of about +.35 volt. In the Hill-Bendall scheme, therefore, two light reactions provide the energy to go *against* the electrochemical



FIRST CHEMICAL STEPS in photosynthesis involve an electron-donor molecule (*D*) and an electron-acceptor molecule (*A*) in close association with a special chlorophyll (*Chl*) in the reaction center. An incoming photon can raise the chlorophyll to an excited state (*Chl**). When the excited chlorophyll returns to the ground state in less than 10^{-9} second, the energy released extracts an electron from *D*, oxidizing it to D^+, and transfers the electron to *A*, reducing it to A^-. Later D^+ oxidizes water and A^- reduces NADP to NADPH.



HILL-BENDALL MODEL of electron transport in photosynthesis suggests how electrons (e^-) removed from water can be boosted against an electrochemical gradient, finally reaching NADP. With the aid of protons, also provided by water, NADP is converted to NADPH. A change in an upward direction requires an input of energy, supplied by photons; a change in a downward direction yields energy. ADP is presumably converted to ATP on the downslope between the two cytochromes, which act as electron-acceptors and -donors.



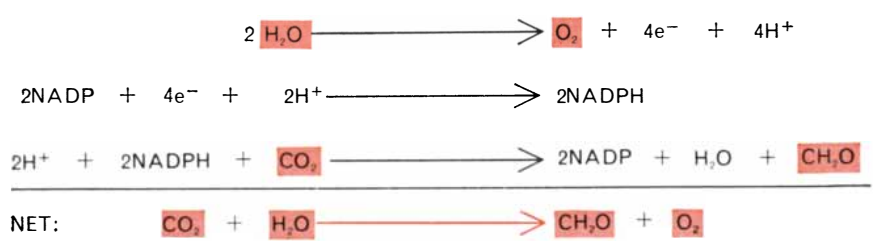
PS I AND PS II, two photochemical systems, cooperate in the fixation of carbon dioxide in algae and higher plants. Each system has its own reaction center containing a photosynthetic pigment. The pigment in PS I is a species of chlorophyll *a* known as P-700 because its maximum absorption is at a wavelength of 700 nanometers. The strong oxidant of PS II is able to oxidize water. The strong reductant of PS I has the power to reduce NADP to NADPH. The reactions driven by the photochemical systems are shown in the equations at the bottom of the page.

gradient while electron transport between the two cytochromes goes *with* the gradient [*see bottom illustration on preceding page*].

The Hill-Bendall formulation indicated that the two light reactions occur in two different photochemical systems [*see illustration above*]. Each system has a reaction center within which an oxidant and a reductant are formed. Photochemical system II (PS II) sensitizes a reaction that results in the oxidation of water and in the formation of a weak reductant. The chlorophyll in the reaction center of PS II has not yet been identified, but it is presumed to be some form of chlorophyll *a*. Photochemical system I (PS I) sensitizes a reaction that yields a weak oxidant and a strong reductant. The chlorophyll in the reaction center of PS I has been identified as a species of chlorophyll *a* whose absorption peak is at 700 nanometers and is therefore known as P-700. The two photochemical systems are linked in series by electron-carriers, so that the weak reductant produced in PS II is oxidized by the weak oxidant produced in PS I.

Duysens and his co-workers provided some of the early evidence for this model of two photochemical systems acting in series when they showed that the *c*-type cytochrome in the chloroplast is reduced by the shorter-wavelength light absorbed by PS II and oxidized by the longer-wavelength light absorbed by PS I. Such "antagonistic" effects indicate that the cytochrome lies in the path of electron flow between the two systems. Other investigators have since demonstrated similar antagonistic effects on the *b*-type cytochrome of the chloroplast and on P-700.

Additional evidence for the series model has involved the use of the potent weed killer DCMU (dichlorophenyldimethyl urea), which owes its effectiveness to its ability to inhibit the flow of electrons from water to NADP. In its presence both the *c*-type and the *b*-type cytochromes can be oxidized by PS I but they cannot be reduced by PS II. One can therefore assume that the DCMU acts at a site somewhere between PS II and the cytochromes [*see illustration on page 69*]. The photoreduction of NADP is thus blocked by DCMU, but it can be restored if an artificial electron-donor (such as a reduced indophenol dye) is introduced into the chloroplast. In the presence of the dye NADP can once again be photoreduced but now light absorbed by PS I alone is sufficient. The effect of DCMU indicates the existence of two light reactions coupled by a system of electron-donors and -acceptors.



CHEMISTRY OF PHOTOSYNTHESIS is summarized by these four equations. Water is oxidized, releasing free oxygen, electrons and protons. The electrons and two protons reduce NADP to NADPH. NADPH plus two protons and carbon dioxide yield NADP, water and carbohydrate (CH_2O). Thus carbon dioxide and water yield carbohydrate and oxygen.

Electron Path from PS II

The portion of the photosynthetic electron-transport chain that carries electrons from water to PS II is known as the oxidizing "side" of PS II. As mentioned above, the oxidation of water is effected by the oxidized form of a hypothetical donor molecule, D^+. Experimental evidence for electron transport between water and PS II has recently been provided by Takashi Yamashita and Warren L. Butler of the University of California at San Diego, but the nature of the electron-carrier (or carriers) involved, and its relation to *D*, has not yet been determined.

The reducing "side" of PS II is the portion of the electron-transport chain between PS II and its electron-acceptor *A*. The fluorescence properties of the chloroplast have provided information on the nature of *A*. If chloroplasts are irradiated with short-wavelength light, the yield of fluorescence is high, but if they are illuminated with the longer wavelength of light that can be absorbed by PS I, the fluorescence yield decreases. From these observations Duysens and his associates have inferred that when *A* is reduced by PS II, fluorescence is high, but when it is oxidized by PS I, fluorescence is low. They called the acceptor component *Q* rather than *A*, *Q* standing for quencher of fluorescence. *Q* in the oxidized form quenches fluorescence, whereas *Q* in the reduced form does not and therefore the fluorescence yield increases. The yield increases even more in the presence of DCMU, suggesting that the weed killer acts at a site between *Q* and PS I in the photosynthetic electron-transport chain.

The chemical nature of *Q* has not been determined with certainty. Norman I. Bishop of Oregon State University has obtained evidence suggesting that it may be a compound known as plastoquinone. Regardless of its chemical nature, *Q* is probably the electron-acceptor of PS II.

Electron Path from *Q* to P-700

Proceeding along the electron-transport chain from PS II to PS I, one finds

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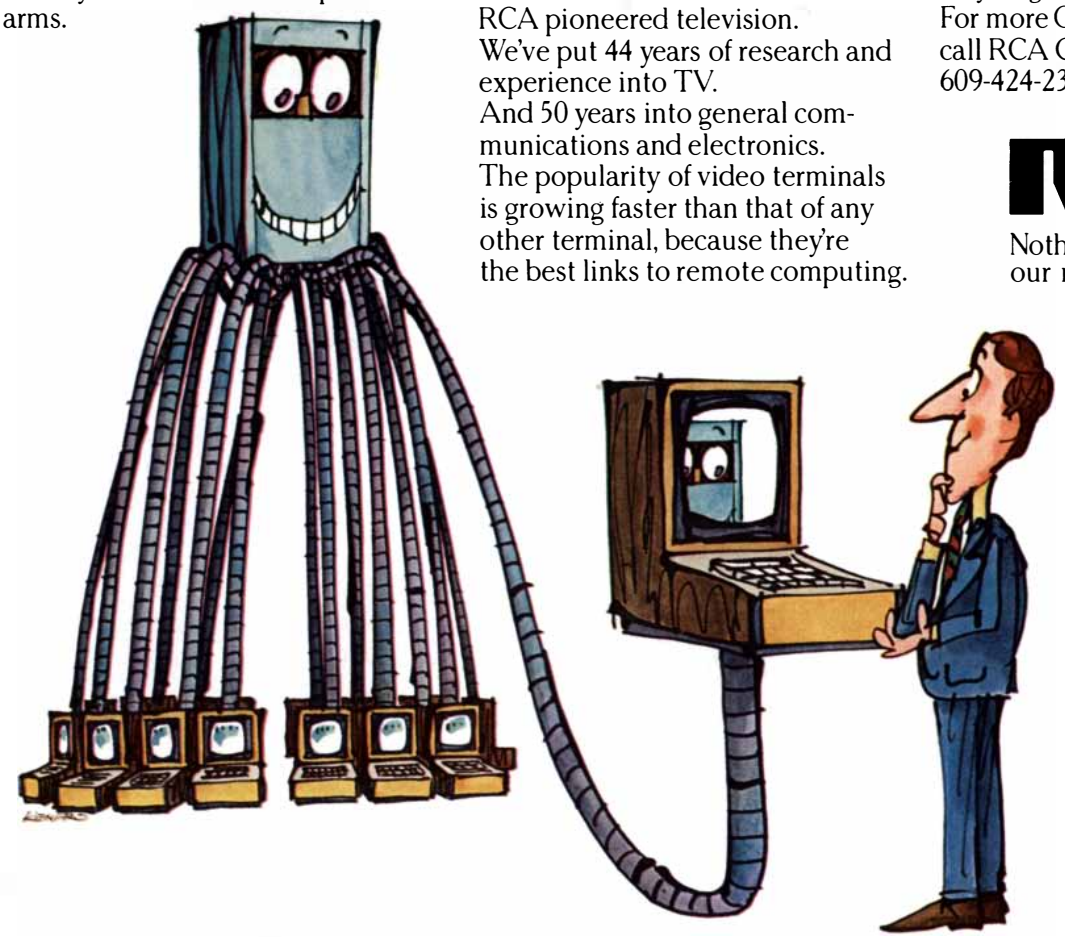

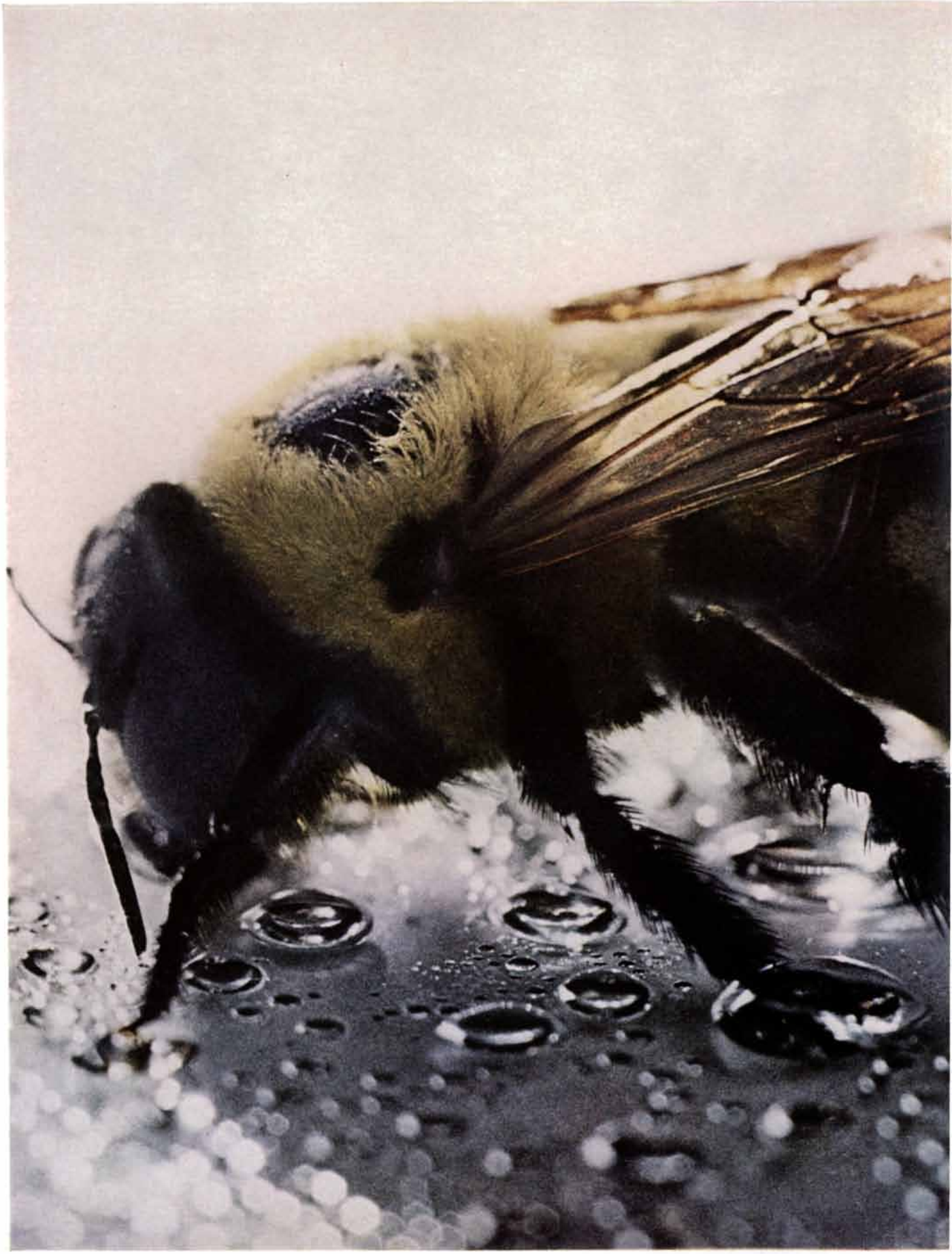

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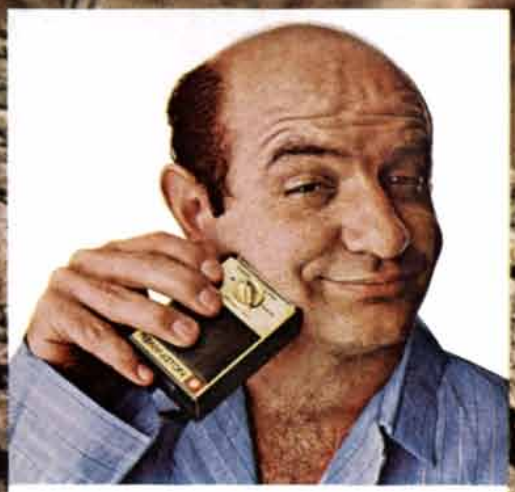

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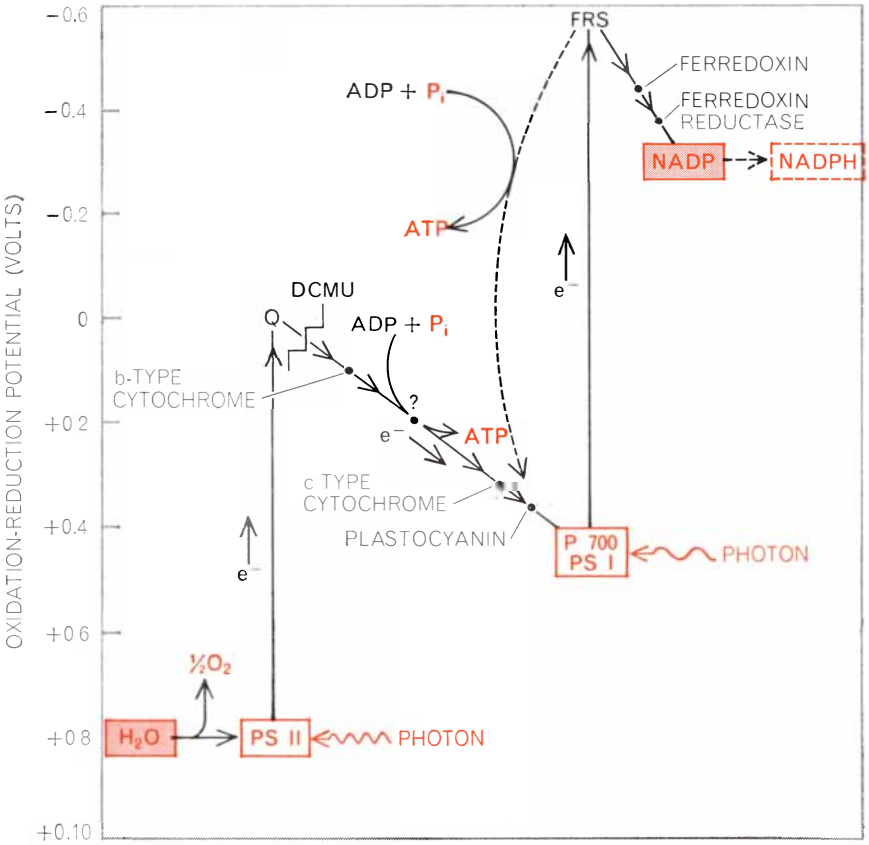
that there is a cytochrome on the downhill slope from *Q* to PS I. This is a *b*-type cytochrome. It is followed by a *c*-type cytochrome. The reduction of both cytochromes is sensitized by PS II; their oxidation is sensitized by PS I. As mentioned above, this differential oxidation and reduction pattern localizes the cytochromes between the two photochemical systems.

Between the *b*-type and the *c*-type cytochromes there is at least one more component, which is not yet identified. Evidence for its existence comes from experiments that Donald Gorman and I have conducted in the Biological Laboratories of Harvard University, using mutant strains of a unicellular green alga that had lost the capacity to carry out normal photosynthetic electron transport. Of the mutant strains, one lacked the *b*-type cytochrome, another lacked the *c*-type cytochrome and a third lacked an unknown component.

The third mutant strain proved to possess both cytochromes (*b*-type and *c*-type), but when it was illuminated with long-wavelength light of the kind absorbed by PS I, only the *c*-type cytochrome was oxidized. When light of the kind absorbed by PS II was used, only the *b*-type cytochrome was reduced. Since the first kind of light normally oxidizes both cytochromes and the second kind of light normally reduces both cytochromes, it was clear that some component was missing from the mutant strain that ordinarily acts as an electron-donor and -acceptor between the two cytochromes. For want of a specific identification we have designated it *M*.

Another component in the electron-transport chain is the copper-containing protein plastocyanin. Although this protein can act as an electron-acceptor and -donor, its role is not clearly understood. At present some experiments indicate that plastocyanin lies between the *c*-type cytochrome and PS I, and other experiments give equally convincing evidence that it lies on the uphill side of the *c*-type cytochrome.

We now come to P-700, the chlorophyll that absorbs far-red light in the reaction center of PS I. Its discoverers, Bessel Kok of the Research Institute for Advanced Study in Baltimore and George E. Hoch of the University of Rochester, showed that P-700 is oxidized by light absorbed by PS I and reduced by light absorbed by PS II. On being oxidized it transfers its electron to its electron-acceptor. It can then be reduced again by electrons coming from water and passed along the transport chain from PS II. The immediate electron-donor to P-700 is either the *c*-type cytochrome or plastocyanin or both.



ELECTRON-TRANSPORT CHAIN in photosynthesis follows the Hill-Bendall model (*see bottom illustration on page 63*). It shows how electrons removed from water are passed along by various acceptors and donors until they finally reach NADP and participate in its reduction to NADPH. Along the chain, at one or more places not yet clearly identified, energy is extracted to form ATP from ADP and inorganic phosphate (P_i). The energy for boosting electrons against the electrochemical gradient is supplied by photons that excite chlorophyll molecules in the two photochemical systems, PS I and PS II. Electrons leaving PS II are evidently accepted directly by a substance called *Q* (for quencher of fluorescence) and electrons leaving PS I by the ferredoxin-reducing substance (FRS). The downhill path from *Q* to PS I contains a number of donors and acceptors, which are discussed in the text. The path that transports electrons from FRS to NADP appears to be less complicated; the end result is NADPH. Many details of the electron-transport chain have been clarified with the help of a weed killer called DCMU, which interrupts electron flow to the right of *Q*.

The Path between P-700 and NADP

Moving along the electron-transport chain, we see that the electron donated by PS I, which has a potential of about +.45 volt, must travel against a large electrochemical gradient before it can reach NADP, which has a potential of −.3 volt. The electron-acceptor of PS I has been much debated ever since it was proposed a few years ago that the acceptor might be ferredoxin, an electron-acceptor and -donor molecule whose negative potential (−.43 volt) is even higher than that of NADP. It was clear that if light energy could boost an electron against the potential gradient from P-700 to ferredoxin, the final step to NADP would be downhill. The difficulty was that several investigators found that PS I can boost electrons against potentials even more negative than that of ferredoxin. It did not seem economical of nature to provide a greater boosting capacity than is actually required, and this cast doubt on ferredoxin's being the primary acceptor of electrons from PS I.

Recently Charles Yocum and Anthony San Pietro of Indiana University and Achim Trebst of the University of Göttingen have discovered what is apparently the true acceptor. A substance with a potential of about −.6 volt, it has been given the tentative name ferredoxin-reducing substance, or FRS. Its chemical nature is now under study. Its absorption spectrum suggests that it will turn out to have a complex structure consist-

ing of more than one molecular species.

We have now nearly reached the end of the photosynthetic electron-transport chain. The FRS transfers its electron to ferredoxin, and NADP is reduced to NADPH in the presence of an enzyme called ferredoxin-NADP reductase.

ATP Formation and CO_2 Fixation

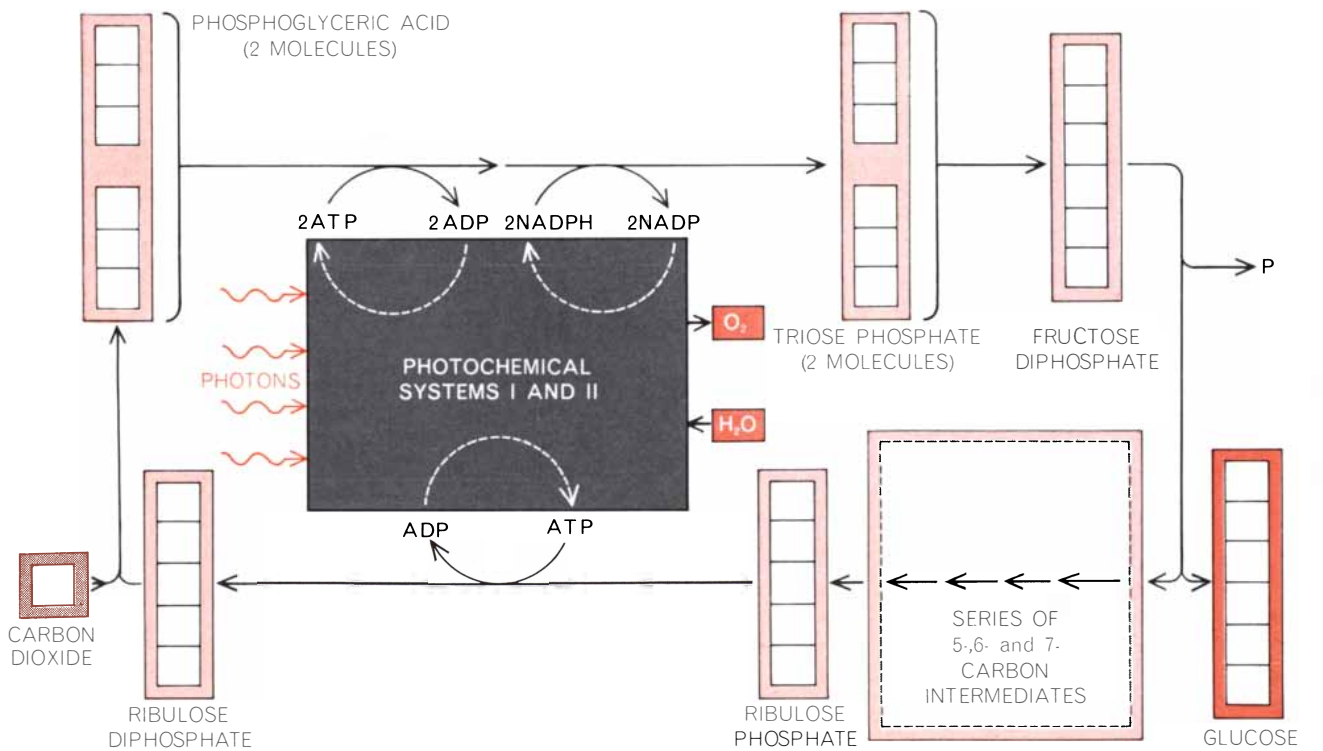
Much current research is focused on how the production of ATP is coupled to photosynthetic electron transport. Theoretically, as Hill and Bendall originally suggested, sufficient energy is available in the downhill flow of electrons between the *b*-type and the *c*-type cytochromes to phosphorylate a molecule of ADP, converting it into a molecule of ATP. And indeed there is evidence for a site of ATP formation between the two cytochromes. There is also evidence for a cyclic flow of electrons around PS I (most likely involving FRS), and ATP formation is coupled to this electron flow.

In spite of extensive investigation there is uncertainty regarding the mechanism of the coupling of ATP formation and electron flow not only in the chloroplast but also in mitochondria. To review current opinions regarding the mechanism would require an article in itself.

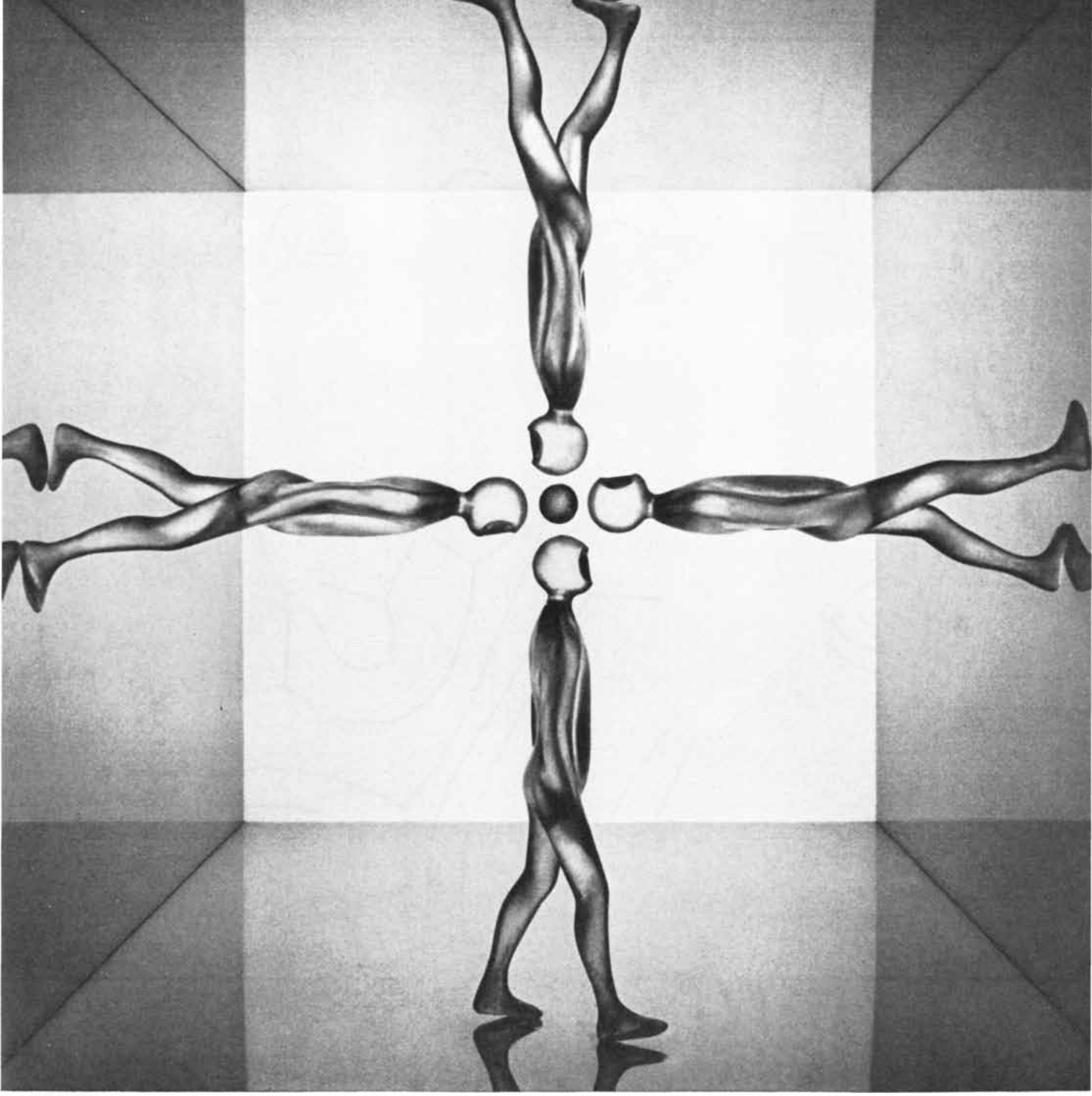
We have now reached the last phase of the photosynthetic process: the reduction of carbon dioxide to carbohydrate. Much of our knowledge of this final phase is due to the work of Melvin Calvin, James A. Bassham and Andrew A. Benson of the University of California [see "The Path of Carbon in Photosynthesis," by J. A. Bassham; SCIENTIFIC AMERICAN, June, 1962]. In this cycle one molecule of ribulose diphosphate and one molecule of carbon dioxide react, with the aid of suitable enzymes, to form two molecules of phosphoglyceric acid (PGA). The two molecules of PGA are converted to two molecules of glyceraldehyde phosphate in a reaction that requires two molecules of NADPH and two of ATP. One other step requires ATP (the production of ribulose diphosphate from the monophosphate), so that the overall requirement is three molecules of ATP and two of NADPH for each molecule of carbon dioxide reduced to carbohydrate [*see illustration below*]. This sequence is thought to represent the pathway of carbon dioxide fixation in higher plants, algae and photosynthetic bacteria.

Quite recently, however, M. D. Hatch and C. R. Slack in Australia have shown that there is a different kind of pathway in certain species of tropical grasses. The first step of CO_2 fixation in these grasses involves the carboxylation of phosphopyruvic acid (rather than of ribulose diphosphate), yielding oxaloacetic acid, which then serves as a precursor of PGA.

We have now followed the mechanism of photosynthesis from the initial trapping of the electromagnetic energy of light, through the conversion of energy into chemical energy, then through the electron-transport steps that lead to the generation of NADPH and ATP and finally to the terminal events of carbon dioxide fixation. We have seen that some parts of the process are much better understood than others. The most enigmatic part is the one associated with events at photochemical system II. The means by which four electrons and four protons are extracted from water with the concomitant evolution of a molecule of oxygen is one of the most fascinating problems still to be solved.



FIXATION OF CARBON DIOXIDE is achieved by a cycle of chemical reactions powered by photons that are trapped by the two photochemical systems. These systems package part of the energy in the form of ATP and remove electrons and protons from water, releasing oxygen. The electrons and protons enter the cycle in the form of NADPH. Two molecules of NADPH and three of ATP are required to fix one molecule of carbon dioxide, shown entering the cycle at the lower left. In the cycle each white square represents a carbon atom. The carbon atoms from CO_2 can be incorporated into a variety of compounds and removed at various points in the cycle. Here six atoms of carbon supplied by CO_2 are shown leaving the cycle as glucose, $C_6H_{12}O_6$, a simple carbohydrate.



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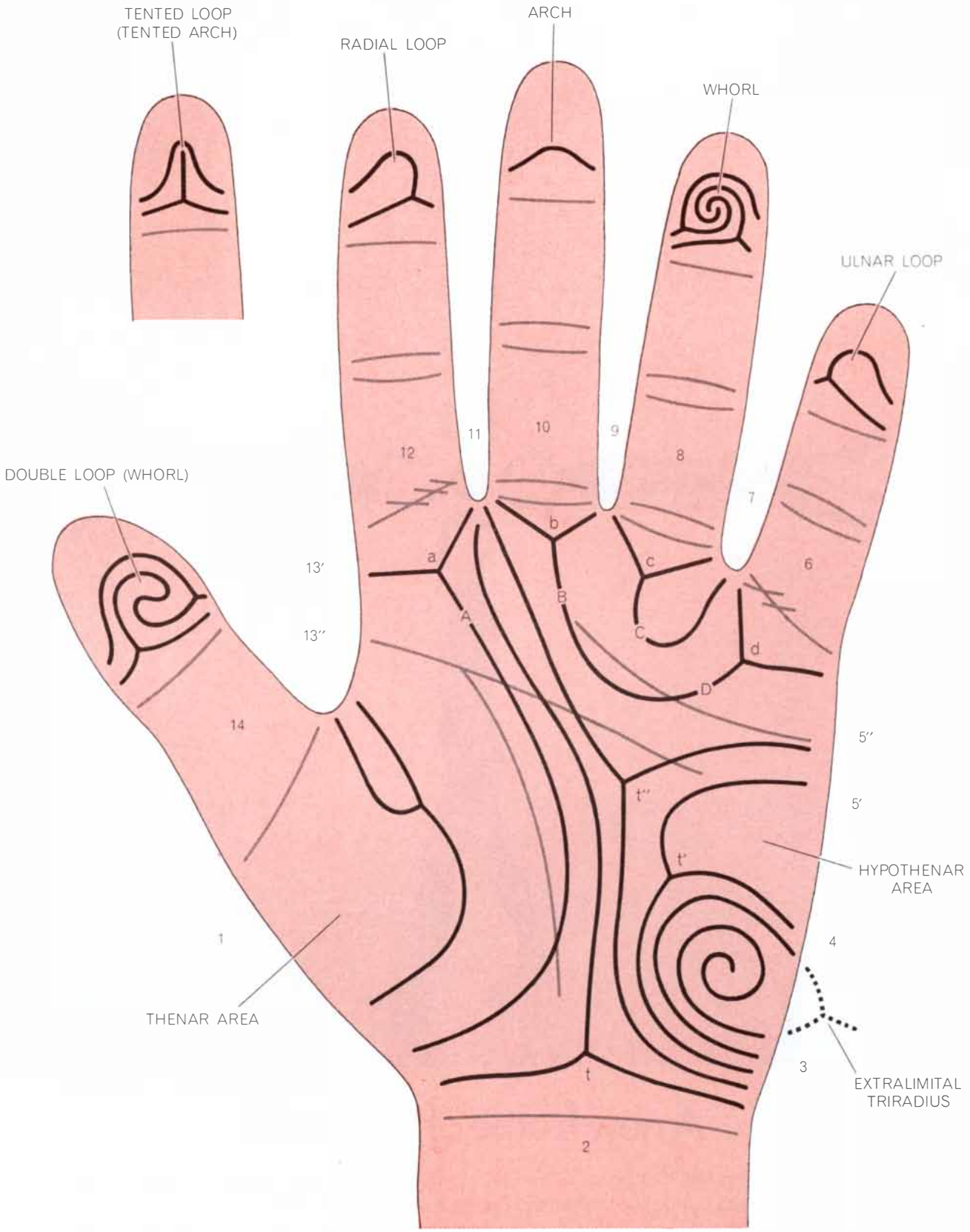


DIAGRAM OF HAND demonstrates the types and names of patterns of the ridged skin on the hands and feet. A definition of the patterns is achieved by tracing the three spokes of a triradius, which is formed where three fields of parallel ridges meet, and continuing them to the outer edges of the ridging. A number of such tracings have been made in heavy lines on this palm; the thinner gray lines are skin creases. The main lines *A*, *B*, *C* and *D* are spokes of the triradii *a*, *b*, *c* and *d*, and their exits are indicated by the numbers *1*, *6*, *7* and *10* respectively. The triradii labeled *t*, *t′* and *t″* are called axial; they lie approximately on the axis of the fourth digit. A number of basic patterns, such as whorls and loops, are identified on the fingers by their customary dermatoglyphic names.

DERMATOGLYPHICS

Fingerprints and the similar ridges on the palm of the hand and the sole of the foot have more uses than identification: they are also of value in anthropology, medicine and genetics

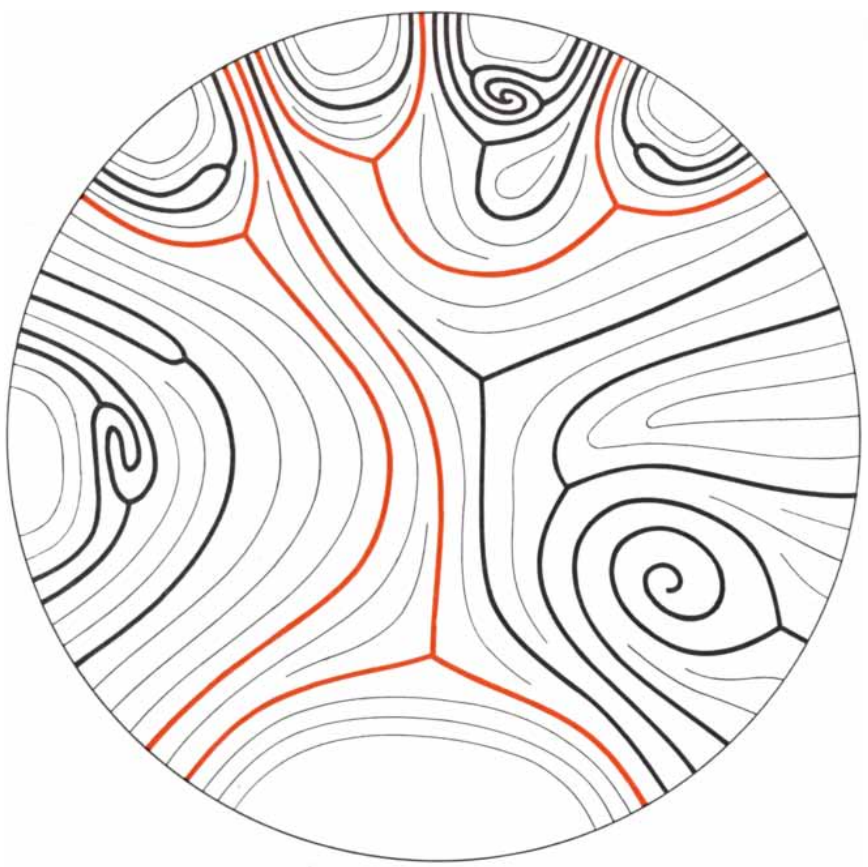
by L. S. Penrose

Every human being has a wholly distinctive set of fingerprints. Their complex patterns of parallel ridges and furrows remain unchanged throughout life and are nearly indestructible. These qualities make fingerprints an ideal means of personal identification, as Sir Francis Galton pointed out in 1890. The epidermal ridges that cover the palmar surfaces of fingertips, the palm of the hand and the sole of the foot are not, however, of interest only to the criminal investigator. Such highly personal traits can serve as valuable indexes of human variation, and they are increasingly useful in anthropology, medicine and genetics. Dermatoglyphics, as Harold Cummins of Tulane University named the study of epidermal ridges in 1926, cuts across all these disciplines.

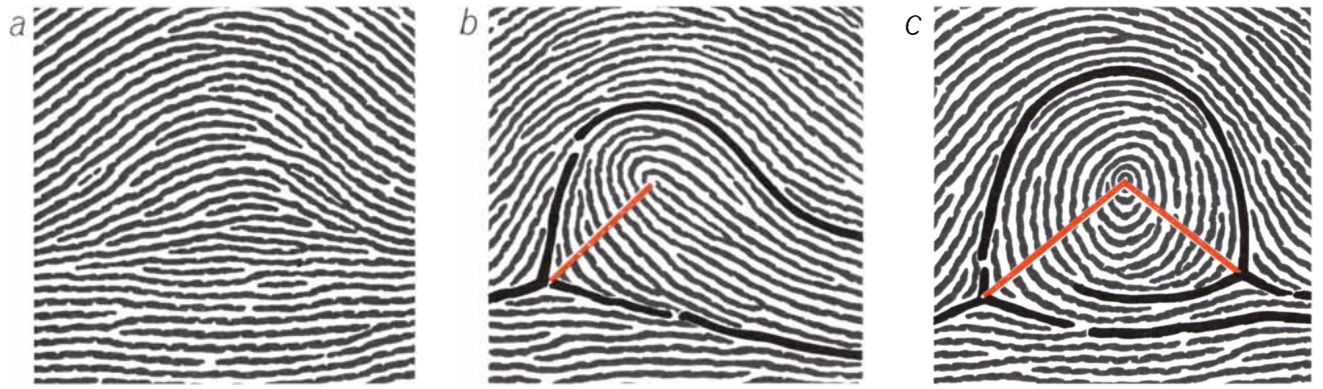
The epidermal patterns are formed early in fetal life. At about the 12th week of gestation undulations appear on the inner surface of the epidermis. It is these undulations that later develop into a structure of ridges and furrows that contain the ducts of sweat glands, whose pores are spaced along the surface of the ridges [*see bottom illustration on next page*]. The structure increases in size as the infant grows, but the pattern is preserved unchanged; fingerprints have been shown to remain unaltered for intervals of more than 70 years. Provided that the lowest part of the epidermis is not destroyed, the pattern regenerates even after serious injury to the skin. The horny outer layers of the ridged skin are so tough that the pattern can be clearly seen on the fingers of Egyptian mummies preserved for more than 2,000 years.

When the prints of any two individuals are compared, innumerable differences in pattern can be observed on the fingers, palms and soles. This applies even to pairs of identical twins; the general configuration of their prints may be similar but there are variations in detail. Moreover, the prints of different fingers of the same person are all different from one another.

Strictly defined, dermatoglyphics does not include the study of the creases, wrinkles and cracks beloved of palmists, although these features have subsidiary significance in relation to some dermatoglyphic problems. The best-known peculiarity of this kind is the so-called simian crease, a transverse fold in the palm that is normally rare but occurs frequently in Down's syndrome, or mongolism. The cracks, smaller than the creases, tend to develop with age; they show up as white lines on prints. They have some scientific interest, but like the



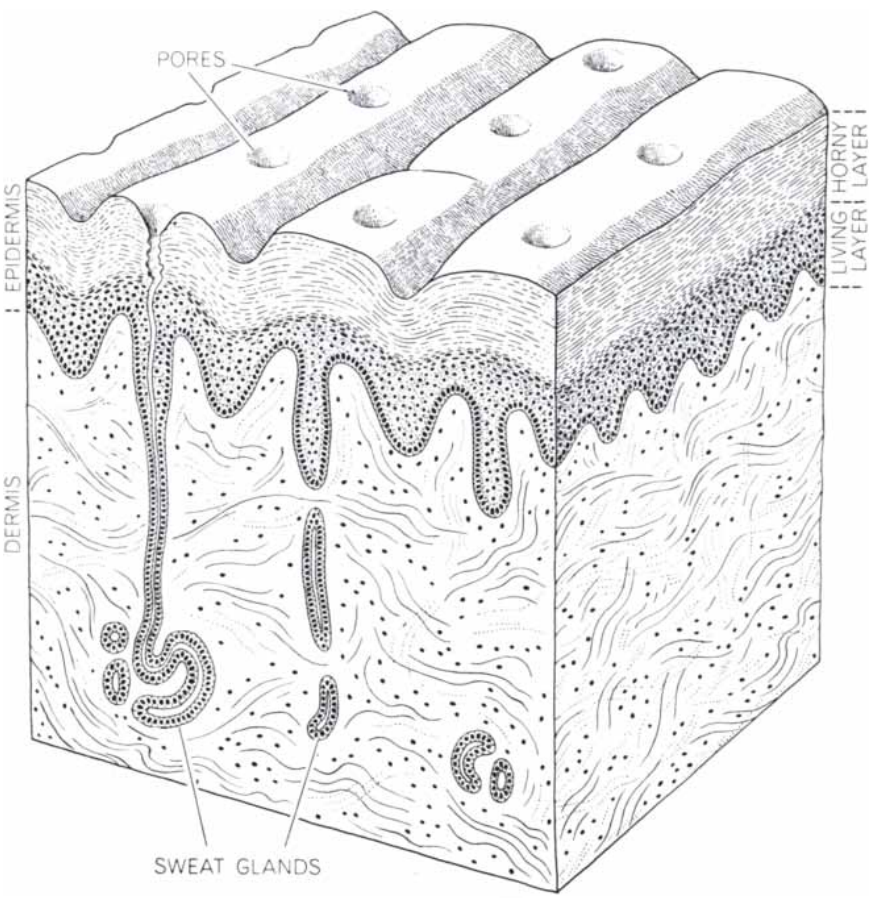
TOPOLOGICAL MAP of the hand portrayed on the opposite page shows 11 loops and 15 triradii. Removal of all loops would leave four "essential" triradii; the lines radiating from them are in color. The five small gaps represent the fingernails; the large gap represents the wrist. The ridge lines exit at right angles to the circumference except at the six gaps.



TYPICAL CONFIGURATIONS of human fingerprints include (*a*) the arch, (*b*) the loop and (*c*) the whorl. Heavy lines trace the spokes of triradii. The colored lines superposed on prints *b* and *c* go outward from the cores to the triradii. Ridges of a pattern are counted where they cross the colored lines to measure the size of the pattern. Count in *b* is 10 and in *c* 12 at left and 10 at right.

creases they are less well defined and less characteristic of the individual than the epidermal ridges.

Surfaces covered by systems of parallel lines are found in many different living organisms. Examples range all the way from the stripes on the coat of a zebra to the alignment of cells in the nasal mucosa of chickens and gulls and the furrows on the bark of tree trunks. It is commonly assumed that the function of epidermal ridges is to increase touch sensitivity and efficiency in gripping by inducing friction at the surface of contact. Ridged skin similar in many respects to that in man is found on the hands and feet of primates, although there the patterns tend to be more complex and more difficult to analyze. No such ridges are found on the feet of cats or dogs.



STRUCTURE OF SKIN reveals, in the living layer of tissue below the dead horny layer at the surface, undulations that form the characteristic ridge pattern. The ridges contain the ducts of sweat glands, and the pores of the glands are spaced along the ridges.

There are certain basic topological constraints on lines that are parallel in any small field but that can curve gradually. Such lines can form cusps and can fan out in different directions without disturbing the continuity of the field. However, two kinds of complementary discontinuity can arise: loops and triradii [*see bottom illustration on page 79*]. A loop is formed when the parallel field turns through 180 degrees, that is, when a field turns around and meets itself. The core of the loop is in principle a single line that comes to an abrupt end. A triradius is formed when three fields meet. In a large parallel field the occurrence of a loop requires a triradius to neutralize or correct it and vice versa. Two loops close together form a whorl, which in the limiting case can be a series of concentric circles. Two loops require a pair of triradii to correct them, and this arrangement is commonly found on the fingertips. When no loop or triradius is present, the configuration is called an open field; on the fingertip it is termed an arch. One peculiar kind of pattern, a loop whose core is the spoke of a triradius, is called a tented loop or a tented arch.

Patterns are defined by tracing the three spokes of the triradius as they wind across the ridged skin. These spokes are called main lines, and by means of them the entire pattern on a palm or a sole can be summarized. The core lines of loops can also be traced. On the fingertips a loop is specified as ulnar if the direction of its core is toward the ulna (the forearm bone on the side opposite the thumb) and as radial if it points toward the radius, or toward the thumb side of the hand.

The places where the main lines disappear at the edge of the ridged skin

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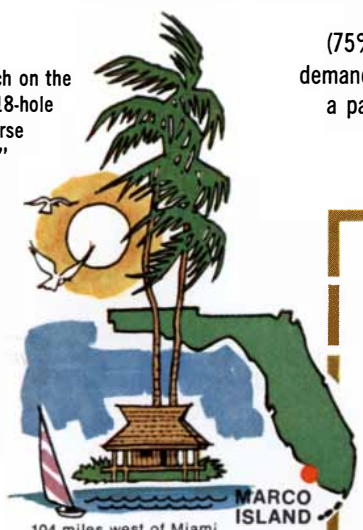

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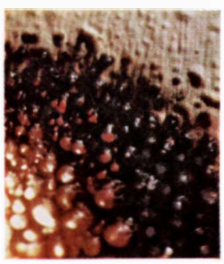

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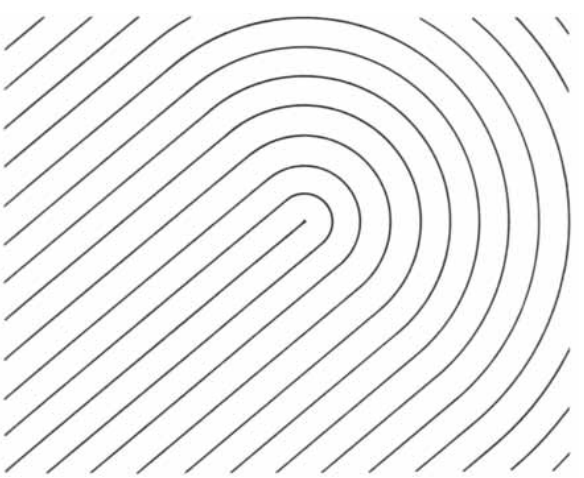
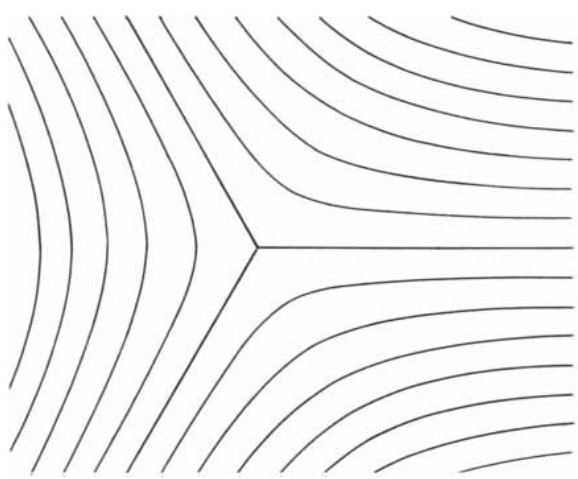
UNIQUENESS OF PATTERN on every human finger is demonstrated by prints of the left index fingers of identical-twin sisters. Both patterns can be described as whorls, but they differ greatly in detail. Patterns also differ from finger to finger of same person.

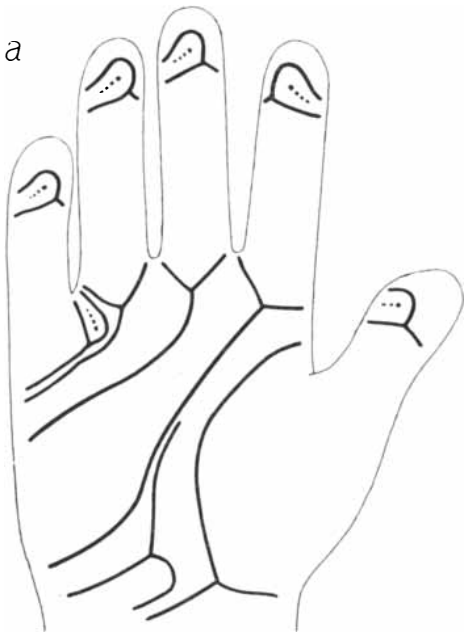
surface of the palm or sole are called exits. These exits have been used for many years to distinguish different types of pattern, some of which are of anthropological interest because their frequency may differ among ethnic groups. On the soles it may be extremely difficult to trace the main-line exits, and so it is simplest, for purposes of classifying different types of pattern, to note the presence or absence of loops and the positions of triradii.

As a general rule the streams of lines tend to exit approximately at right angles to the edges of the ridged area of the hand (or foot) except at the tips of the fingers and the wrist. This peculiarity enables one to represent the ridged pattern on the palm (or sole) by a circular topological map in which the fingernails and the wrist are equivalent to loops [*see illustration on page 73*]. Now, if any bounded area, such as a circle, is covered with a parallel system of lines that are at right angles to the edge at all points, at least two loops must appear somewhere on it. For every loop in excess of two there must be a triradius. On the hand the fingernails each substitute for one loop and the wrist substitutes for another. As a result it is possible to devise a simple relation among the numbers of loops, triradii and digits (which normally number five) on a limb: the number of triradii plus one is equal to the number of loops plus the number of

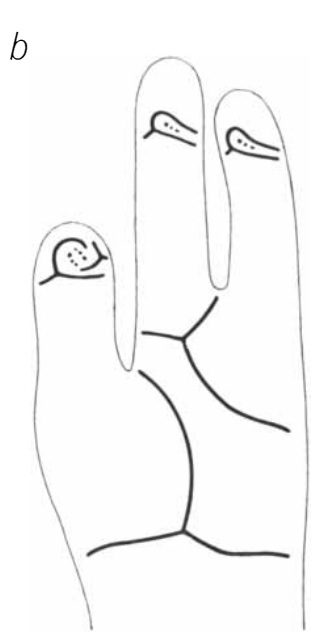




GEOMETRY OF RIDGES rests on a basic pattern of parallel lines. Two kinds of discontinuity, which are complementary, can occur. Loops are formed (*left*) when a field of parallel lines makes a turn of 180 degrees. The core of the loop is the single line that ends abruptly in the center of the loop. A triradius is formed (*right*) where three fields of parallel ridges meet. In a large parallel field the occurrence of a loop requires a triradius to neutralize it; correspondingly the occurrence of a triradius requires a loop.



11+1=7+5



6+1=4+3

9+1=8+2

12+1=7+6

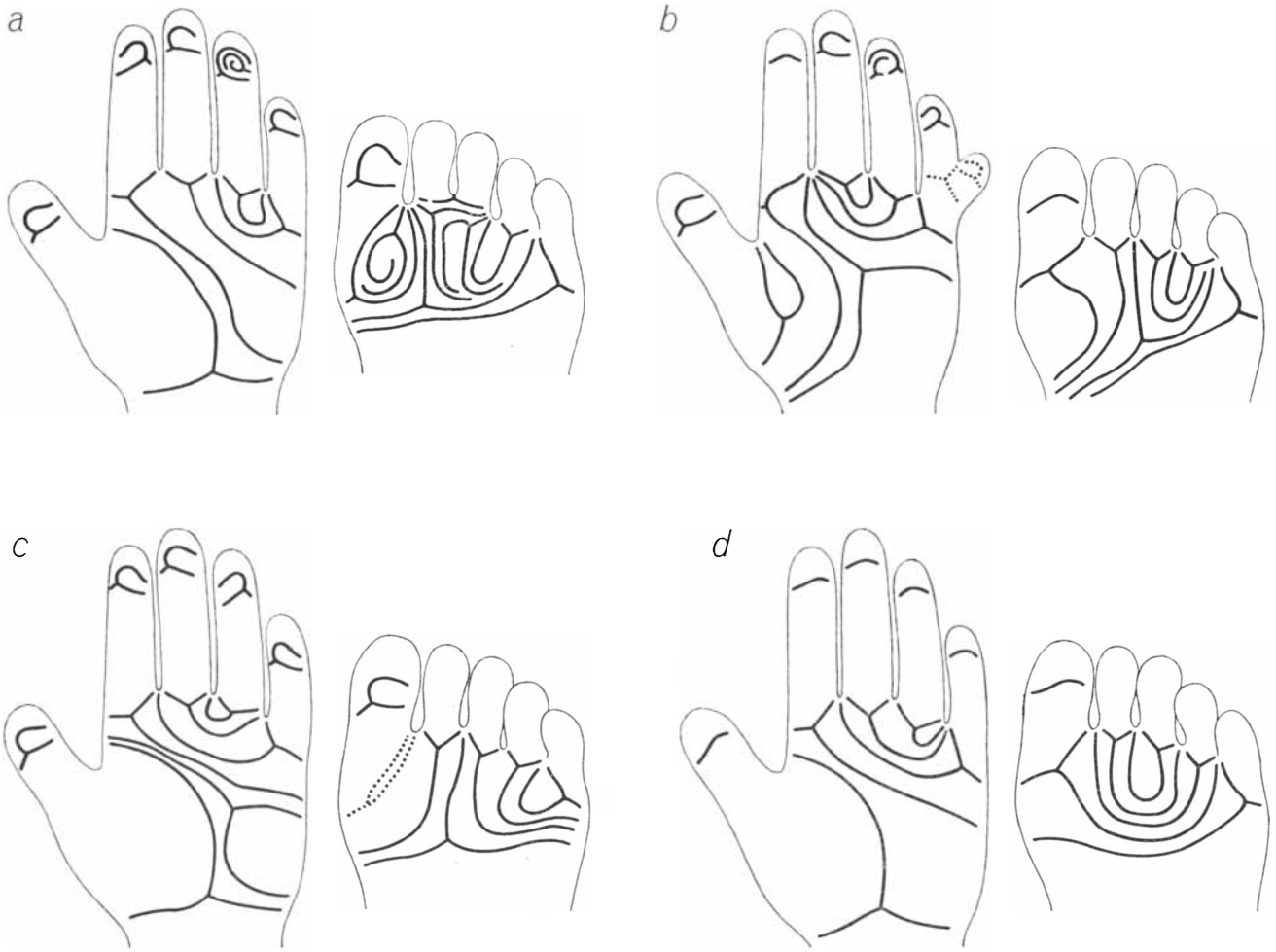
CONSISTENT RELATION appears, even in abnormal hands and feet, between the number of loops, L, the number of triradii, T, and the number of digits, D. It is expressed in the formula $T + 1 = L + D$ and manifested here in the normal left hand (a) and abnormal right hand (b) of the same person, in the right hand (c) of a patient with ectrodactyly, or congenitally absent digits, and in left foot (d) of a patient with a congenitally extra digit.

digits. On a normal hand or foot the number of triradii must therefore exceed the number of loops by four. Exceptions to this rule arise when the ridges for a short distance lie parallel to, instead of at right angles to, the edge. In such circumstances a triradius (or loop) that belongs to the pattern can lie just beyond the ridged surface; it is "extralimital" but must be counted in applying the formula.

The formula is useful in checking that all triradii on a palm have been recorded. It is particularly convenient in studying patterns on the sole, because triradii between the toes are frequently awkward to print and the whole configuration cannot be appreciated unless their positions can be identified. The formula applies in developmental defects in which the number of fingers or toes is altered: If there is an extra finger or toe, it is associated with an extra triradius; if digits are missing, there are fewer triradii.

Little is known about the developmental conditions that determine the orientation of epidermal ridges. The conventional view has been that the ridges represent lines of tension, and that they run at right angles to the direction of pressure in the embryonic epidermis. On the whole the lines seem to take approximately the shortest paths; if they continued from the ball of the finger, the palm or the sole onto the back surface of a limb, they would encircle the digit, the hand or the foot. Yet they are not contour lines or geodesics. An alternative suggestion for the origin of ridges, which would agree well with most of their properties, is that they follow not lines of tension but rather lines of greatest positive curvature (or of least negative curvature) in the embryonic epidermis. In the early stages of formation of the limb buds in man, the pads that form the developing palm and sole have been supposed to produce the tension required to align the ridges. On the other hand, the pads could provide curvature to which the growing skin may be sensitive. Lines of curvature on a smooth surface have a parallel arrangement; loops occur on ellipsoids and triradii occur on saddle shapes of certain kinds. The shape of the fetal human fingertip is not incompatible with what would be required if the lines of curvature were to produce a loop and a triradius, as is commonly found.

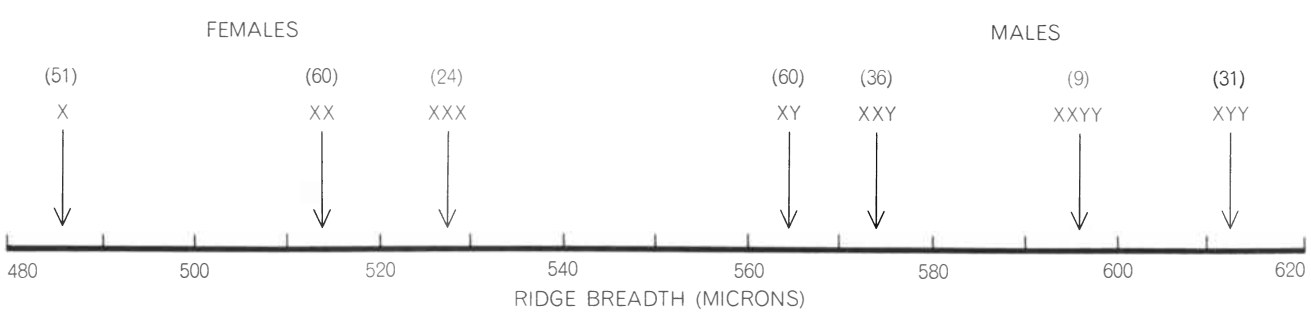
The natural variation demonstrated by epidermal ridge patterns has been studied in different populations by anthropologists and in families by geneticists. Hereditary influences have been



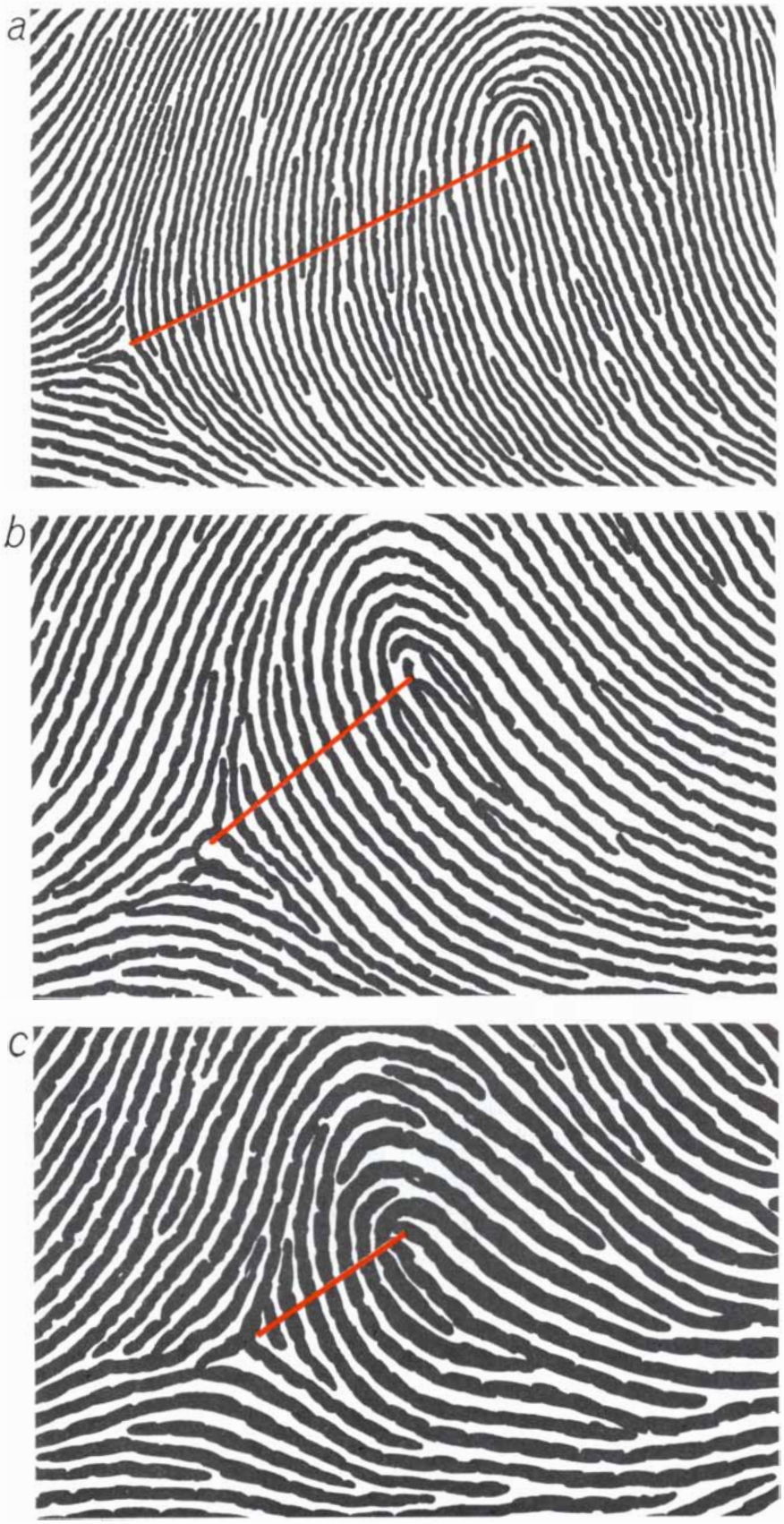
PALMS AND SOLES of normal persons and patients with inherited defects are compared. The normal pattern is at *a;* the sole often shows a triradius between the second and third toes that is associated with webbing. The other patterns represent trisomy, where a normal pair of chromosomes has become three. In 13–15 trisomy (*b*) the thenar pattern, the *t″* on the palm and the *S* pattern on the sole are characteristic. Mongol hand (*c*) has a *t″* triradius and a radial loop on the fourth digit; sole has a reduced pattern at base of the great toe and a loop between the fourth and fifth toes. All regions in 17–18 trisomy (*d*) show low pattern intensity.

clearly demonstrated, but the mode of transmission of the types and locations of patterns is incompletely understood. The patterns are not independent entities: their types grade into one another and can interfere with one another. With some fingers or palms analysis may be very easy; with others there may be much disagreement as to how best to describe the main-line configuration. There is also a large element of chance even in the details of the main-line patterns, so that average values should be based on data from many members of a given population. Such values indicate, for example, that Chinese and some other Eastern populations such as the Javanese have more whorls on the fingertips, that is, more complex patterns, than western Europeans. Africans in the Congo have fewer whorls and Bushmen have the fewest of any known population.

Various indexes have been used to measure pattern intensity, but the sim-



MEAN RIDGE BREADTH, measured in the interval between triradii *a* and *b* of the palm, is correlated with body size and number of sex chromosomes. Normal females, with *XX* sex chromosomes, have narrower ridges than normal *XY* males. An additional sex chromosome tends to increase the ridge-width value above the normal mean; absence of a sex chromosome, to diminish ridge width.



DIFFERENT RIDGE COUNTS appear in reproductions at the same scale of thumbprints of females with different numbers of *X* chromosomes. A print (*a*) of a woman with Turner's syndrome, meaning that she has one *X* chromosome instead of the normal two, shows an abnormally large number of ridges, in this case 33. A print (*b*) of a woman with a normal *XX* complement of chromosomes has 12 ridges. Females with more than two *X* chromosomes tend to have fewer fingerprint ridges; a print (*c*) of an *XXX* woman has only eight ridges.

plest method is to count the number of loops, always counting a whorl as two loops. Another method of quantifying ridge patterns is to enumerate the ridges between the core of a loop and the appropriate triradius. This ridge count measures the size of the pattern and is used in classifying prints for identification as well as for scientific studies. An arch has a count of zero, as do some very small loops, including the special kind of loop known as a tented arch. The average count for a fingertip loop is about 12 ridges.

For a whorl there are two possible counts, and the larger of the two is conventionally taken as a measure of the pattern size [*see top illustration on page 74*]. Adding the measurements on all 10 fingers yields a number, which can range from zero to 300, called the total ridge count. It serves as a convenient index in genetic and clinical investigations. The loops on the area of the sole nearest to the great toe have been similarly quantified. Other useful counts can be made between pairs of triradii, in particular between those designated *a* and *b* on the palm. The distance between these points can also be measured. Dividing the distance by the ridge count gives the mean ridge breadth, or repeat distance, in that area.

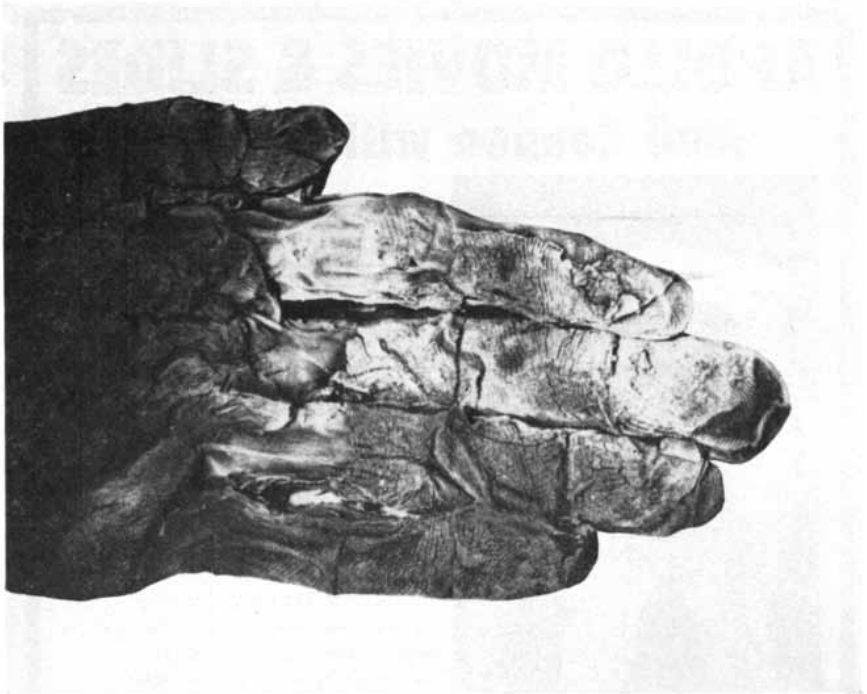
One of the special uses of such measurements is to obtain data for the study of hereditary influences on pattern formation. The traditional method of comparing members of families—by the presence or absence of particular loops and triradii—has shown that genetic factors influence these patterns among all populations studied so far. No precise dependence on Mendelian factors has been demonstrated, however, and environmental causes of variation (and even pure chance effects) are highly significant. Pattern intensity (the total number of loops on fingers, palms or soles) is also genetically determined, but there is much unpredictable variation. The total ridge count on each finger, which is less influenced by chance than the pattern types are, has been studied in parents and children; it has been shown to be a multifactorial character in which the effects of genes are additive. There is no indication of sex-linked inheritance, that is, of control by genes in the *X* chromosomes, which govern sex.

The main interest in dermatoglyphics at the present time is directed toward the peculiarities that accompany certain abnormal developmental conditions. If a disease disturbs limb growth at an early enough stage in development—

during the first three months of embryonic life—it can alter the dermatoglyphic patterns. As I have noted, polydactyly, or the presence of an extra digit, leads to the presence of one more triradius than is normal; the developmental absence of digits (ectrodactyly) has the reverse effect. When, as the result of a genetic accident or drug poisoning (as by thalidomide), the fetal limbs are damaged at an early stage, the event is reflected in the palmar ridge patterns. Children infected with intrauterine rubella ("German measles") are reported to show abnormal pattern configurations. Webbing of two or more digits also produces marked alterations in the ridge patterns. (It should be noted that a slight webbing of the second and third toes is so common that it must be considered a normal variation.) Unusual hereditary conditions can cause grossly peculiar configurations [*see illustration on opposite page*].

Most remarkable, perhaps, are the alterations found when there is chromosomal aberration. The trisomic conditions, in which a normal pair of chromosomes has become a trio, all have characteristic—one can almost say stereotypic—pattern distortions. In Down's syndrome (trisomy of chromosome No. 21) the central position of the triradius *t* and the tendency for all finger patterns to be ulnar loops were first noted by Cummins in 1935. (These features can occur normally also; it is their frequency that is significant. Ulnar loops are found on all 10 fingers in 4 percent of the population but in 32 percent of individuals with Down's syndrome, for example.) There are other noteworthy signs, such as the absence of pattern or a very small loop on the pad at the base of the great toe, where complex patterns are normally common. A radial loop on the fourth fingertip is most unusual on normal hands but occurs fairly often in Down's syndrome. A correct diagnosis of this syndrome can almost always be made from a good set of prints of the hands and feet.

Trisomy of one of the large acrocentric chromosomes (No. 13, No. 14 or No. 15) leads to gross deformities, among them polydactyly, and the dermatoglyphics tend to be very peculiar. As in Down's syndrome, radial loops appear at unusual sites—on the fourth and fifth finger—whereas normally they are often found on the index finger. There is also a central palmar triradius, more displaced even than in Down's syndrome. Patterns are found much more frequently on the thenar area of the palm (at the base of the thumb) than is true of the general population, and a characteristic



HAND OF MUMMY, preserved for more than 2,000 years, still shows a pattern of ridges. The pattern endures through life and long afterward when the body is preserved. Part of the explanation is the toughness of the outer layers of ridged skin on palms, fingers and soles.

rare S-shaped pattern is seen on the sole. Trisomy of chromosome No. 17 or No. 18 is associated with the absence of loops on the fingers; arches are found on all 10 fingers in some 85 percent of the cases, whereas normally this phenomenon is most unusual (only one person in 200). The palm and sole are peculiar in that the normal amount of pattern complexity is reduced.

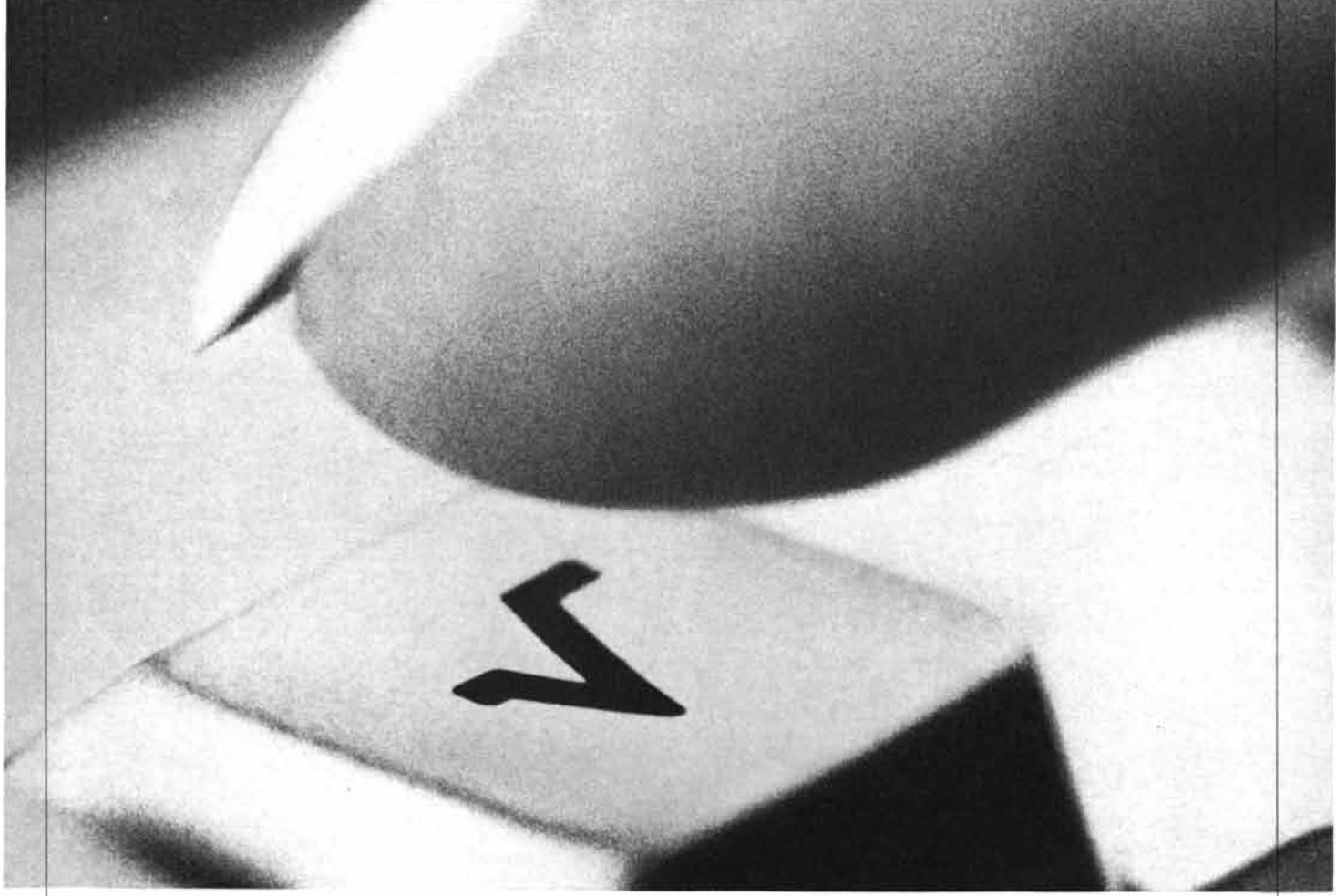
Abnormality of the sex chromosomes produces dermatoglyphic disturbances that are not immediately obvious but that have been demonstrated by collecting groups of cases of the same kind and analyzing the prints. The most notable peculiarity occurs in Turner's syndrome, a condition in which a woman has only one *X* chromosome instead of two. The main feature is the large number of ridges in the finger loops [*see illustration on page 82*]. The total ridge count averages about 165, whereas for normal females the mean value is 127. The patterns tend to be large but the ridges themselves are narrow, a feature that can be demonstrated also on the palm. Females with more than two *X* chromosomes—three, four or even five—tend to have peculiarities opposite to those found in Turner's syndrome: the size of the fingertip patterns tends to be small, and the total ridge count is progressively lowered by the addition of each aberrant *X* chromosome. The mean total ridge count for two known *XXXXX* females is only 17.

Somewhat similar observations have been made on males who have too many sex chromosomes. An extra *Y* chromosome, although it leads to increased stature, does not appreciably alter the dermatoglyphic patterns. In association with increased body size, however, there is a broadening of the ridges; the mean ridge breadth in the *a-b* interval of the palm was 612 microns in one large series of cases compared with the normal male average of 565. The dermatoglyphics in cases of Klinefelter's syndrome (in which a male has two or more *X* chromosomes instead of only one) deviate from those of the normal *XY* male in the feminine direction. The mean total ridge count for 57 *XXY* males was 114 compared with the control mean of 145 for *XY* males. An extra *Y* tends to slightly reduce the pattern size, as defined by the ridge count; additional *X* chromosomes have more effect, approximately the same in the male as in the female. In association with the pattern reduction on the fingertips there are simplified patterns on the palm and sole. One cannot diagnose any of these conditions from the prints alone, but knowledge of the dermatoglyphics may be a help in exceptional cases.

An interesting new field of investigation is opened up by these observations. Much is known about the action of genes in determining individual chemical differences but little is known about the mechanism of morphological change caused by the loss or triplication of entire chromosomes. In trisomic conditions and comparable ones development seems to proceed essentially as it should, based on the particular genes present in the chromosomes, and yet the results are distorted. For example, patients with Down's syndrome or Klinefelter's syndrome have patterns that show a familial likeness to their parents' patterns and those of their brothers and sisters—but with some added peculiarities. These facts raise a puzzling question: How can the sex chromosomes so strongly influence a dermatoglyphic character, such as total ridge count, that is not sex-linked?

A possible clue to how these distortions arise is found in Turner's syndrome. In early fetal life there is generalized swelling, or edema, notably of the neck and limbs, that subsides gradually later. What if in such a case the fingertips also swell and therefore present a larger surface than is normal to be covered with ridges? This would explain both the increased number of ridges and their reduced breadth after the edema has disappeared.

Now, a disturbance of the fluid content of tissues is a common feature of organisms with aberrant chromosomes. Polyploid plants (those with more than the usual two sets of chromosomes) tend to be larger than the original diploids from which they are derived, and this has been attributed to increased water content of their cells. In animals it is known that certain kinds of gross chromosomal aberration may be associated with the occurrence of blisters in the embryo. Disorders of blood-vessel formation are common in many types of chromosomal error in man. In Turner's syndrome, where a chromosome is absent, we find the opposite effect to the one in polyploid plants: fluid collects between the cells, and the cells may be slightly smaller than normal. In Klinefelter's syndrome and others associated with too many *X* chromosomes there may be, conversely, cellular enlargement associated with a slight degree of intracellular dehydration, and therefore contraction of the fingertip. The suggestion can reasonably be made that the distortions of dermatoglyphic patterns that are associated with chromosomal aberrations have a mechanical origin rather than being direct results of gene chemistry.



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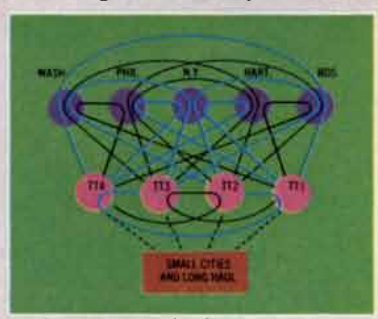
Lockheed has better ways to make better decisions.

Plan for future air travel involves new route concept • Disaster simulator prepares decision makers for crises • Computerized loading model predicts airlift flights per mission • Airline fleet economic analysis evaluates proposed routes

Making a decision involves making a choice. And to make the best decision, all options must be looked at logically and objectively. But the more complex the situation, the harder this becomes. Lockheed, by applying scientific techniques and analytical tools to decision-making situations, is able to approach them more systematically—helping government and business make better decisions with fewer headaches. Some brief examples follow.

Air travel plan for 1980. With air transportation demand increasing geometrically, with airlines ordering more and bigger jets, with airport expansion programs under way, how will all of tomorrow's passengers, planes, and airports best be integrated?

Certainly, a more logical and systematic approach than today's is called for. And one such concept was recently developed by analysts at Lockheed.



Transfer terminal route concept.

They chose the heavily populated Northeast Corridor (Washington, Philadelphia, New York, Hartford, Boston) in 1980 for study. They used the well-known MIT demand equation, modified to include origin incomes and destination attractiveness, to determine 1980 intracorridor travel demand. Applied to 46 corridor cities, the model indicates over 215,000 intercity passengers daily. Of these, 55% will travel between major cities, 5% between minor cities and 40% between major cities and minor cities. Long-haul traffic entering and leaving the corridor is projected at almost 400,000 passengers daily, apportioned among cities by population.

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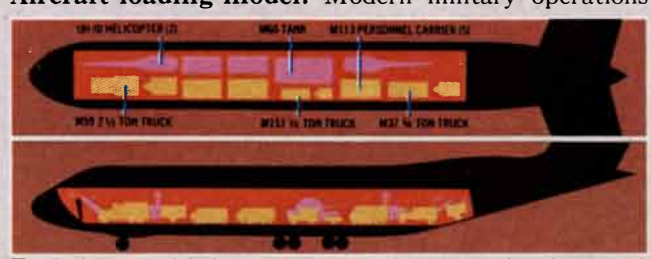
The concept would establish 4 transfer terminals, each situated on low-cost land midway between the 5 major cities. Several intracorridor airline routes (as illustrated) would connect the transfer terminals with each other and with convenient airports and vertiports in and around the major cities, and would connect the major cities with each other. All nonstop. Shuttle service by VTOL or V/STOL would be provided between the transfer terminals and their surrounding small cities. Long-haul passenger traffic would enter and leave the corridor only through the transfer terminals, while long-haul cargo shipments would use major-city airports.

The transfer terminal concept would assure good load factors for the airlines and provide 90% of all passengers —both intracorridor and long-haul—with fast, frequent, nonstop or one-transfer service.

Training for disasters. In disaster situations—floods, fires, riots, earthquakes, even military attacks—quick and often irrevocable decisions must be made. Yet the men whose job it is to make them may never have experienced such situations before.

Providing experience in crises is the main purpose of Lockheed's disaster environment simulator. Developed under contract to the Texas Hospital Association, it is a computer system that dynamically simulates the medical effects of disasters. Personnel responsible for managing medical and transportation resources can use this gaming instrument to try out various disaster-control plans for different situations without the real-life consequences. By systematically evaluating the results, effective operational policies can be formulated.

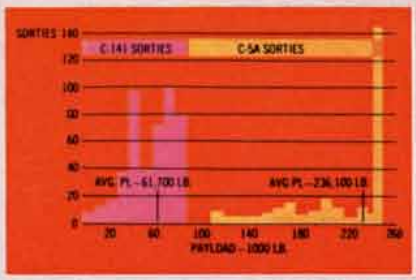
Aircraft loading model. Modern military operations depend increasingly on successful airlift. And airlift success depends greatly on accurate estimates of the number of sorties (aircraft loads) needed. So Lockheed analysts have developed a computer model that simulates and thereby predicts the results of aircraft loading.



Typical C-5 vehicle load generated by Lockheed's loading model.

The loading model can work with any 2 aircraft types (for instance, the C-141 and the C-5) simultaneously and in any ratio. It considers the dimensional and weight limitations of the aircraft, then selects items for placement in cargo compartments by a heuristic procedure that simulates manual load planning. (See 1st illustration.)

The program output shows the vehicles, troops and palletized cargo comprising each load, plus payload and area utilization. A summary gives the payload frequency distribution for each aircraft type. (See 2nd illustration.)



Payload frequency distribution between C-141 and C-5.

In practice, this means that with a given amount and mix of cargo to be airlifted, the number of sorties needed by available transports can be predicted accurately.

Airline fleet planning. Any endeavor as complex as operating an airline, no matter how well managed, can benefit greatly from a more organized method of making decisions. With this in mind, Lockheed has developed a series of computer programs that airlines are using to help analyze their air transportation operations.

At the heart of these programs is an airline system simulation model, whose inputs are coordinated with the airline. The simulation model is then coupled with men who have airline planning experience.

The model is put into motion by balancing 2 sets of factors. One is passengers seeking to satisfy their travel needs from an array of potential services. The other is the desire of the airline to offer service, motivated by a profit objective. Because it simulates a real-world situation, the model also takes into consideration expansion of service needed to meet competition as well as compliance with government regulations.

What comes out is the number of flights required by different types of aircraft to serve an airline's total route system, the operating expenses incurred to offer this level of service, and the revenue generated. Based on this information, flight schedules, the total aircraft requirements, system load factors and utilization, earnings, and discounted cash flow return on investment are optimized.

The activities mentioned here are only a few of Lockheed's current R&D efforts in problem-solving. If you are an engineer or scientist interested in this type of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.

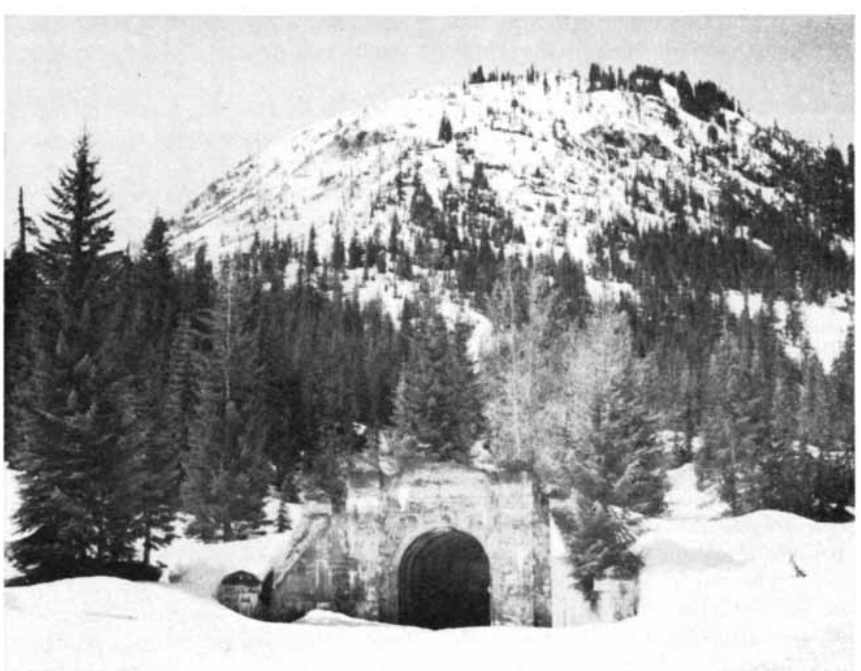
Measuring Earth Strains by Laser

Large interferometers operating with laser beams make it possible to detect tiny distortions of the earth's crust with unprecedented sensitivity. One of these laser strain meters is 1,020 meters long

by Victor Vali

The solid earth is in a continuous state of strain. The most obvious and powerful form of this strain is an earthquake, which consists of a series of shocks representing abrupt changes in the strain state of the earth's crust and mantle. These shocks are composed of pressure waves and shear waves, and they are followed by other strains: Rayleigh waves (analogous to waves in water) and Love waves (long waves undulating at right angles to the direction of propagation). Still other kinds of strain persist for days or years, and some strains are so weak and slow as to be undetectable by seismographs. These include microseisms with strain amplitudes of only a few parts in 10^{10} and with wave periods of a few seconds, and tides in the solid earth with amplitudes of a few parts in 10^{8} and wave periods of 12 hours. The recording and analysis of these strain states reveal much about the earth's internal activity and structure.

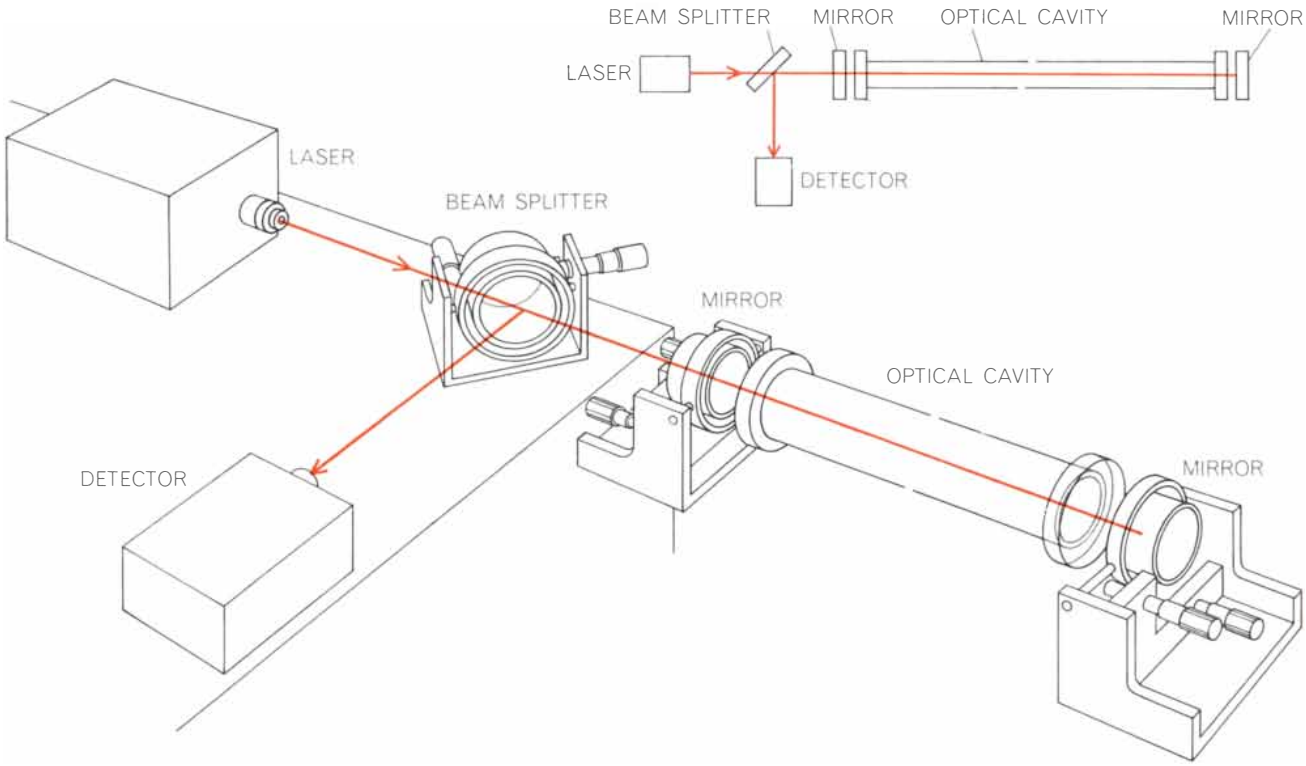
Until recently the most accurate instrument for monitoring strains was the Benioff gauge, developed 30 years ago by the late Hugo Benioff of the California Institute of Technology. The Benioff gauge is so sensitive that it can detect a change in strain amplitude in the earth's crust as weak as one part in 10^{9}. In the past few years, however, there has been much interest in strain gauges that are even more sensitive. This interest has been stimulated partly by the possibility that if a greater range of seismic frequencies could be analyzed, information might be obtained that would permit the prediction of earthquakes. With ultrasensitive gauges it might also be possible to determine if the gravitational waves predicted by the general theory of relativity actually exist.



ONE-KILOMETER LASER STRAIN METER (*opposite page*) **occupies abandoned railroad tunnel at Stevens Pass, Wash.** (*above*). **At the left is a 1,020-meter evacuated pipe that contains the laser beam and protects it from atmospheric changes. In the foreground is a dehumidifier; in the middle is the vacuum pump. This strain meter, some 500 meters underground, was built by the author and R. C. Bostrom of the University of Washington.**

The invention of the laser has enabled workers at a number of institutions, including my colleagues and myself at the Boeing Scientific Research Laboratories and the University of Washington, to develop such instruments. Called geophysical laser strain meters, these instruments are basically large interferometers: devices for measuring changes in length by the constructive and destructive interference of light waves. In principle they should be able to measure strain amplitudes with an accuracy of a few parts in 10^{15}. Some of these instruments already operate with an accuracy as high as one part in 10^{12} for brief periods.

This is clearly an advance on earlier earth-strain gauges such as those of the Benioff type. The Benioff gauge consists of a long cylinder of fused quartz mounted so that the earth can move back and forth under it. One end of the cylinder is fixed in bedrock and the other end has a readout system that continuously measures the distance between it and a post also planted in bedrock. Such a readout device may consist of a circuit connecting a plate on the end of the quartz cylinder to a plate attached to the post. The two plates serve as a condenser in an electric oscillator, and as a horizontal strain increases or decreases the distance



LASER METER MEASURES STRAIN by recording earth motion. In this strain meter, patterned on a Fabry-Perot interferometer, the laser at left projects beam through beam splitter set at an oblique angle at left center. The beam splitter passes the beam on to a partly reflecting mirror in the center. Some of the light is reflected back by this mirror and enters the detector. The rest of it enters an optical cavity through the mirror at right and is reflected back by the third mirror at lower right. As the beam returns down the optical cavity its waves interfere with those entering the tube, creating an interference pattern. When earth strains change the distance between the two mirrors, the fringes in the interference pattern move. The beam splitter deflects the interference pattern to the detector so that fringe movement can be recorded. The inset at upper right shows usual arrangement of this kind of instrument.

between them, the resonant frequency is recorded.

Such an instrument is vulnerable to variations in temperature, barometric pressure and humidity, all of which can change the length of the cylinder. It is also difficult to make a fused-quartz cylinder that is longer than 20 or 30 meters. This fact limits the accuracy of the gauge because the bedrock on which the instrument is mounted is nearly always fractured, a condition that allows local effects to mask the regional or global strain state of the earth. If these strain conditions are to be averaged out so that more general strain states can be recorded, the gauge must be able to make measurements over greater distances.

About five years ago my colleagues R. S. Krogstad and W. Vali and I decided that these limitations might be overcome by adapting a laser interferometer to serve as a strain gauge. The advantages of such a gauge can be seen in a 1,020-meter instrument that R. C. Bostrom and I have developed, which is located in an abandoned railroad tunnel some 500 meters underground at Stevens Pass, Wash. This gauge is basically an extended interferometer of the Fabry-Perot type. In it a beam of red light (at a wavelength of 6,328 angstroms) from a helium-neon laser traverses the entire length of a 1,020-meter aluminum tube. Before the beam enters the tube it passes first through a partly reflecting mirror mounted at an oblique angle to it and then through a second partly reflecting mirror at right angles to it [*see illustration above*]. Half of the light passes through the oblique mirror, and a substantial amount of it is reflected back from the second mirror, strikes the other side of the oblique mirror and is directed into a detector mounted at right angles to the main beam. The rest of the light travels the length of the tube, strikes a third mirror at the other end and is reflected back to the second mirror. Some of it passes through the second mirror and is directed, along with the light originally reflected from the other side of that mirror, into the detector.

The two mirrors at the ends of the tube form a resonant cavity in which the light waves traveling down the tube can interfere with the light waves traveling back. At the detector the interference is visible as a pattern of parallel light and dark "fringes," with the light fringes representing the constructive interference of light waves and the dark fringes destructive interference. The two mirrors are mounted on granite blocks fixed in bedrock, and when an earth strain slightly changes the distance between them, the position of the fringes shifts.

Laser strain gauges can also be built on the principle of the Michelson interferometer. Whereas the Fabry-Perot interferometer has one "arm," or main light path, the Michelson has two. The original light is split into two beams, which are directed by a system of mirrors so that they interfere with each other as they travel in opposite directions on the same rectangular path.

The first advantage of the laser strain meter lies in its length. Whereas the length of the Benioff gauge is limited to 20 or 30 meters, the length of a laser strain meter is practically unlimited, and therefore its sensitivity can be very high. The beam from a laser spreads very little, even after being reflected. The light waves in the beam can also maintain

their coherence over a considerable distance, that is, the waves stay in step. Such a beam can be projected over almost any terrestrial distance and reflected back to its point of origin without drastic reduction in intensity or coherence. Thus an interference pattern can still be easily formed even over a long path.

Like the Benioff gauge, the laser strain meter is affected by atmospheric conditions. Changes in pressure, temperature and composition create turbulence that can disturb the laser beam; therefore the 1,020-meter tube of the Stevens Pass instrument is evacuated. Virtually the entire light path of the instrument is confined within the tube. Only a millimeter of air separates the main mirrors from the ends of the tube, which are closed by optical flats coated to minimize reflection. The fact that the instrument is located deep underground insulates it from the random thermal strains set up by the daily heating and cooling of the earth's surface, which are normally not very interesting to investigate.

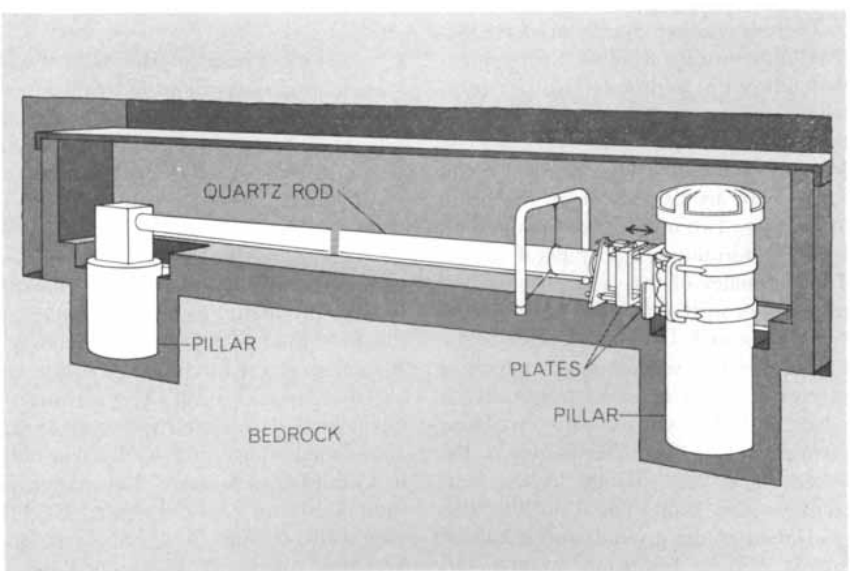
The Stevens Pass instrument and some other laser gauges detect changes in the strain state of the earth by registering the movement of fringes. To follow the movement of a fringe the Stevens Pass strain meter has a mechanism that locks on to it the way a space probe's navigation sensor locks on to a star. This mechanism consists of a galvanometer fitted with a mirror. The mirror reflects light from the fringe into photomultiplier tubes that in turn control the current flowing through the galvanometer. When the tubes detect a decrease in the light level, indicating that the fringe is no longer centered on the mirror, the current flowing through the galvanometer is increased and turns the mirror so that it centers the fringe again. A piezoelectric crystal or the driving mechanism from a high-fidelity loudspeaker can also be used as a tracking device.

The galvanometer can trace the movement of a fringe to within 1 percent of the distance between fringes. Since the distance between two consecutive fringes represents half the wavelength of the light used in the interferometer, the distance between fringes in the laser strain meter is equivalent to about 30 angstroms—roughly 15 times the diameter of an atom. The noise level in a laser is so low that measurements down to 10^{-5} part of a fringe separation are practical. Such an accuracy would permit measurements of earth strain up to a few parts in 10^{15} over 1,020 meters. Normally the 1,020-meter instrument detects microseisms with an amplitude of one part in 10^{10}, and for short periods of time its sensitivity is equivalent to one part in 10^{12}.

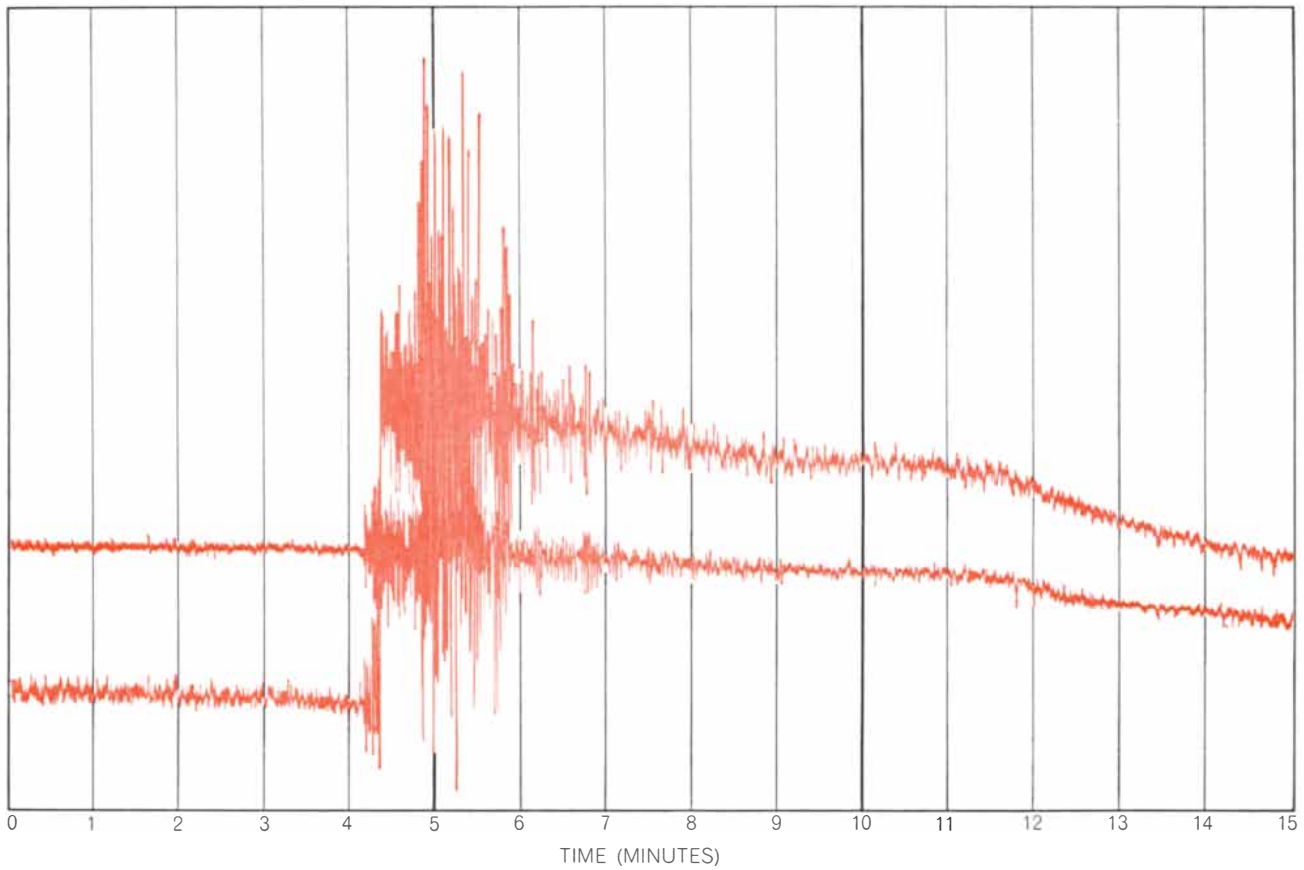
What kind of phenomena do the moving fringes disclose? Microseisms are observed, and when there are storms in the North Pacific, the strain amplitude detected by the instrument increases by a factor of five or more. The power spectrum obtained from the instrument (that is, the spectrum of energies at various wavelengths) shows pronounced peaks around seven seconds per wave that are due partly to microseisms and partly to resonances of the tunnel in which the instrument is located. There is a strong peak at seven minutes per wave; it is caused by minute fluctuations in the pressure of the atmosphere. A third strong reference point in the power spectrum is the 12-hour wave of the earth tides.

The displacement of fringes must of course be read out in some form. In order for the readout system to follow displacements of more than a few fringes it is provided with a limiting switch that interrupts the fringe-following mechanism after it has traveled a distance of a fringe or so. After the mechanism has been interrupted it returns to an equilibrium point and picks up the adjacent fringe. Because the mechanism must traverse the distance between the fringe it has been following and the next fringe there is a discontinuity in the recorded curve corresponding to a displacement of the ground that shifts the fringes by half a wavelength. This conveniently and continuously calibrates the system. The direction of the discontinuity in the curve reveals the direction in which the ground is moving.

In principle this kind of readout system can record any amplitude of earth motion. When motions are recorded on a reel of paper, for instance, the shape of the curve traced corresponds to the movement of the fringe-following mechanism. When the mechanism returns to pick up the next fringe, the tracer returns to its starting place also and begins a new curve. If the mechanism had no limiting switch, the curve representing the movement of fringes would have to be continuous because the tracer would have no way of returning to an equilibrium point. Such an arrangement would make the recording system impossibly cumbersome. A system capable of simultaneously recording earth strains with an amplitude of one part in 10^{12} and earth tides with an amplitude of five parts in 10^{8} would need a paper recording strip 20 meters wide! Similar considerations apply to magnetic tape, which



BENIOFF GAUGE is the most sensitive of the nonlaser strain meters. It can detect a change in strain amplitude as small as one part in 10^{9} for long periods of time. When a strain state changes, it increases or decreases the distance between the end of the horizontally mounted fused quartz rod at left and the upright pillar at right. The plate attached to the pillar and the plate on the end of the rod serve as an electrical condenser, and a change in the distance between them causes a change in the resonant frequency of the circuit. Humidity, pressure and temperature limit the Benioff gauge's accuracy by causing its length to change.



UNDERGROUND EXPLOSION at the Atomic Energy Commission's Nevada test site was recorded by a Fabry-Perot interferometer at the Kern River fault site in California. The shock lasted for more than a minute. Because the instrument consists of two cavities or arms the record of this explosion shows two traces, the upper one from a 10-meter arm and the lower from a 25-meter arm.

can accommodate only about four orders of magnitude of signal change.

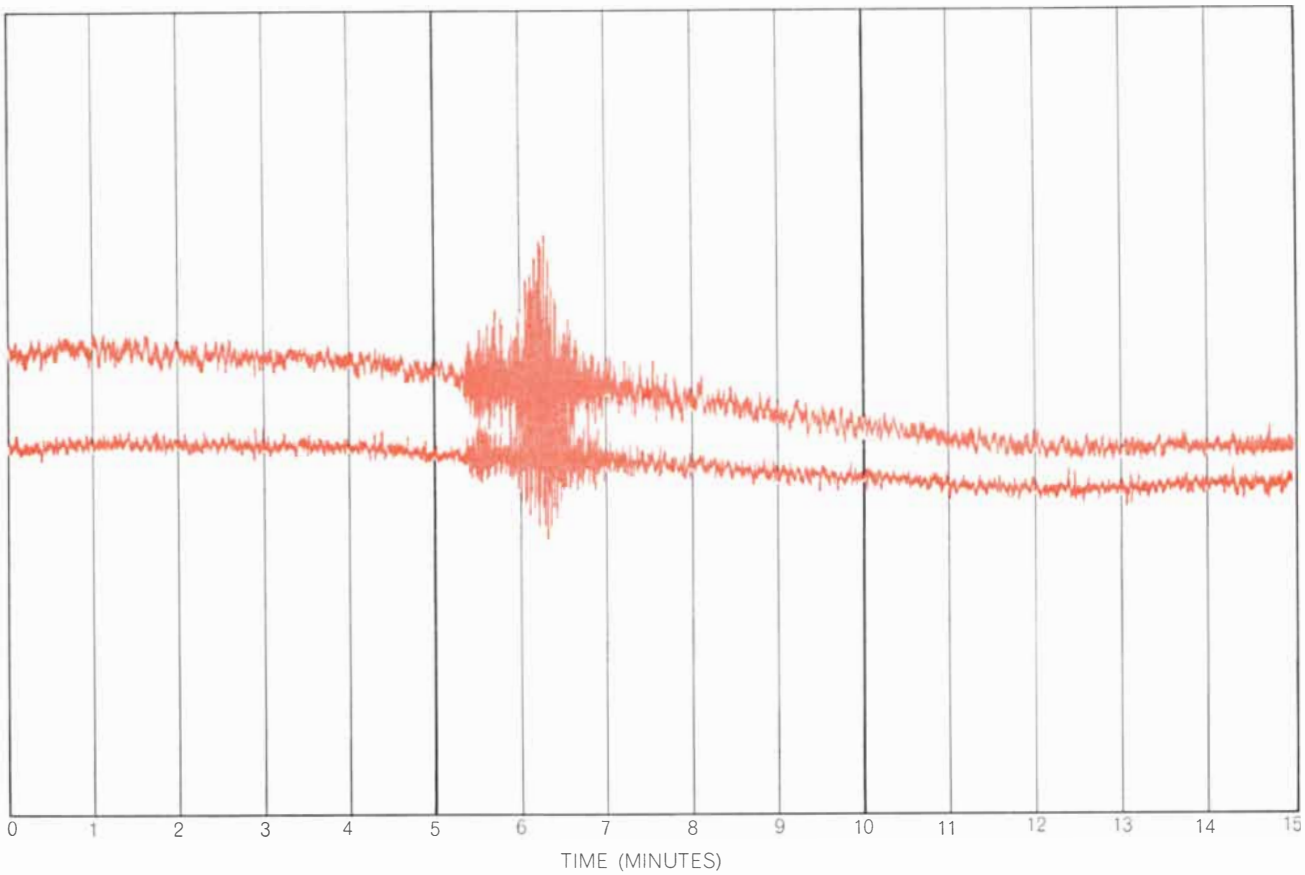
There is another equally accurate system for measuring absolute displacement that offers the additional advantage of having no moving mechanical parts. In this system, which was proposed by John L. Hall of the University of Colorado, there are two lasers. In the beam of one laser two mirrors are mounted on bedrock, forming a Fabry-Perot cavity. The frequency of this laser is controlled by changes in the distance between the mirrors caused by earth strains. The light from the second laser, which is maintained at a constant frequency, is mixed with the light from the first laser, giving rise to a "beat" frequency in the mixed light. The change in the beat frequency is proportional to the displacement of the ground, and it can be measured by a frequency counter and recorded.

A final major advantage of laser strain meters is the linearity of their response: the frequency of the ground motion does not affect the strength of the signal. Moreover, a laser strain meter does not have any mechanical resonances of its own to complicate the interpretation of results.

Several other laser interferometers representing innovations in this field are now recording earth strains or are being put into operation. One of them is the forerunner of the Stevens Pass instrument: the first geophysical strain meter, which Krogstad, R. W. Moss and I proposed and built five years ago. In order to test the accuracy of this instrument, it was originally installed parallel to the California Institute of Technology's Benioff gauge at the Big Dalton Canyon site in Glendora, Calif. The instrument has since been modified and moved to an abandoned mine on the Kern River fault in California, a location that minimizes thermal strains. Now operated by Jolleroy Gauger and D. V. Slade of the Douglas Advanced Research Laboratories and myself, it monitors the shear motion across the fault. It consists of one Fabry-Perot cavity that is 10 meters long and another that is 25 meters long.

The observed amplitude of earth tides detected by this instrument is about 10 times larger than normal, indicating a magnification of strain across a fault. Another interesting phenomenon observed at this site is the fine structure of the fault motion. A typical recording shows a cluster of back-and-forth motions that usually continue for a few minutes. The earth normally returns to its original strain state after the event ends. Sometimes, however, a new strain state is established. These events could be caused by small strains some distance from the recording site. When such a strain is relieved, the original strain state at the instrument is reestablished.

Some of the events recorded at the Kern River site are caused by earthquakes and some by underground explosions in Nevada. With only one instrument—a strain meter with two arms at right angles—one can determine the location and magnitude of the event. The distance can be determined from the difference in arrival time of the pressure waves and the shear waves. The direction can be determined from the relative strength of the pressure waves at each interferometer arm. The absolute amplitude of the pressure or shear waves reveals the magnitude of the event. Explo-



EARTHQUAKE at Corralitos, Calif., registered as a short pulse on the two arms of the strain gauge at the Kern River fault site. Earthquakes tend to generate more shear waves than pressure waves, whereas nuclear explosions release the major part of their energy in the form of pressure waves. The Corralitos earthquake was a minor tremor that lasted only a minute and generated little energy.

sions can often be distinguished from earthquakes because their shear waves are comparatively weak compared with their pressure waves.

An 800-meter Michelson strain meter is being operated by Ralph H. Lovberg and Jonathan Berger of the University of California at San Diego. The interferometer mirrors and the readout system are mounted on pillars set 10 feet in the ground to minimize the effects of thermal strain. Small buildings shield the pillars from the wind and uneven solar heating. The long vacuum pipe that encloses the optical paths runs aboveground. This calls for an ingenious system to compensate for thermal expansion and contraction, which amounts to several inches at the air gaps between the pipes and the interferometer mirrors.

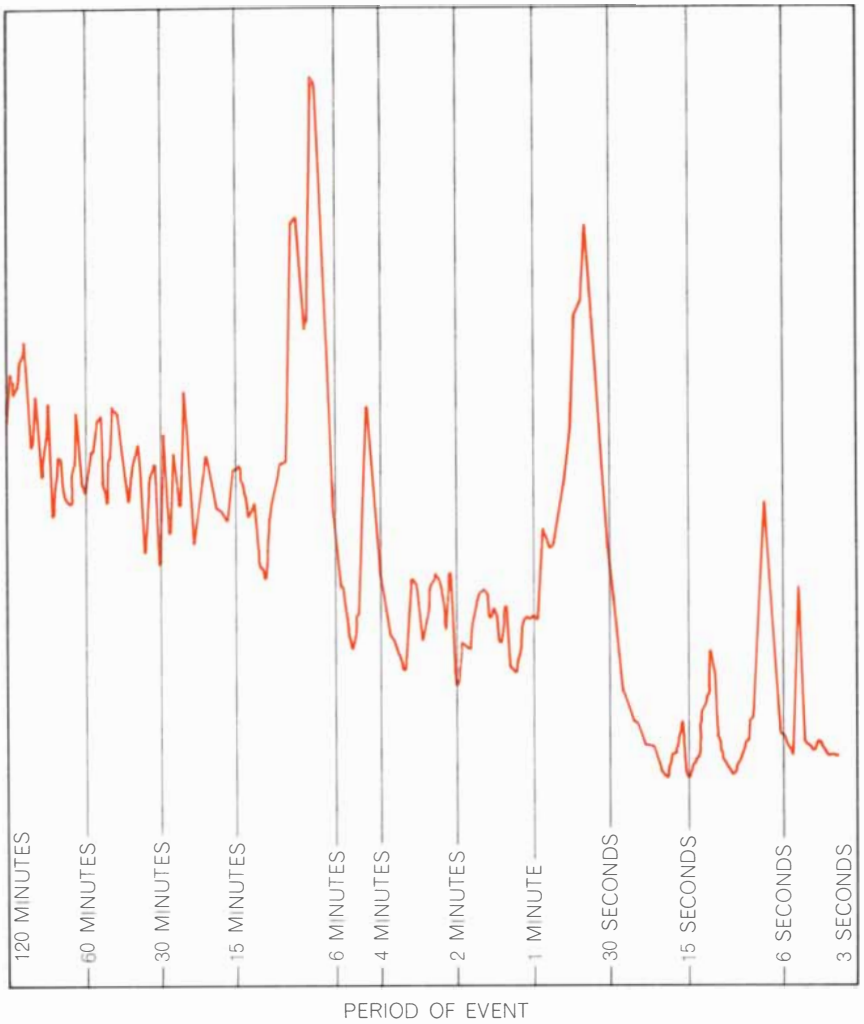
A variation on the Michelson instrument has been developed by Anthony F. Gangi of Texas A. and M. University. His interferometer consists of an arm, one meter in length, that is fixed to bedrock and a second arm whose length is adjusted by a mechanism that keeps it equal to the length of the first arm, so that the interference pattern remains stationary. The ground displacement is therefore proportional to the voltage needed to change the length of the adjustable arm.

Hall, J. E. Faller and Peter L. Bender of the University of Colorado have built a 30-meter Fabry-Perot interferometer in an abandoned gold mine near Boulder, Colo. This instrument is being converted to a strain meter of the beat-frequency type. A laser strain meter for measuring relative displacements between two directions has been developed by H. J. van Veen, J. Savino and Leonard E. Alsop of the Lamont-Doherty Geological Observatory of Columbia University. Two lasers a meter long are mounted at right angles with their end mirrors (forming the laser cavity) fixed to bedrock. The beat frequency between these two lasers reveals the relative displacement. Since the lasers themselves are within the distance to be measured, the accuracy of the system is limited.

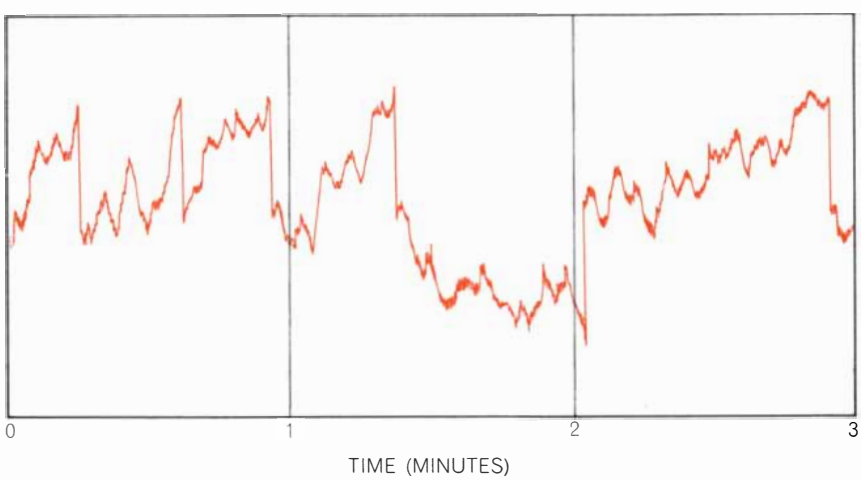
The only serious difficulty that any of these systems have encountered is the instability of the laser wavelength. A change in wavelength could cause inaccuracies because the resulting fringe shift or beat frequency could not be distinguished from one caused by a strain. With specially built lasers that are placed in a thermally and acoustically quiet environment the drift of the wavelength can be made less than one part in 10^{10} per hour. This is not low enough, however, for ultrasensitive strain measurements such as those that would have to be made to detect gravitational radiation.

Two different systems for stabilizing frequency are in operation. One system, developed by Lovberg and Berger, is based on a 30-centimeter rod of fused quartz that is well insulated acoustically and is placed in a temperature-controlled environment. This rod in effect forms the cavity of a Fabry-Perot interferometer, and part of the light emitted by a laser is deflected into the cavity. If the wavelength of the laser light changes, the output of this system also changes, and it is fed back to the laser so that the original wavelength can be restored. The system is as good as the length standard that forms the stabilizing cavity.

Hall and Richard L. Barger have sta-



POWER SPECTRUM, a spectrum consisting of all the seismic frequencies causing strain, was recorded by the Stevens Pass interferometer over six days from May 28 through June 2, 1968. At right the first group of small peaks represents microseisms and tunnel resonances with periods lasting from three to 12 seconds. The highest spikes represent minute changes in air pressure in the tunnel that correspond to the lowest resonances of the tunnel itself.



MICROSEISMS recorded by the Stevens Pass gauge correspond to a strain amplitude of one part in 10^{10}. Amplitude can increase at least fivefold when storms appear off the coast.

bilized the laser light source of their Fabry-Perot instrument by locking its wavelength to a line in the infrared spectrum of methane at 3.39 microns. Since the frequency of this line is determined by atomic constants, the problem of guaranteeing the mechanical stability of a length standard is avoided. The half-width of methane's 3.39-micron line is about one part in 10^{12}, so that it may be possible to achieve a corresponding laser stability with it.

Laser strain meters, along with Benioff gauges and other instruments, may play a role in revealing the causes of earthquakes such as the one that struck Alaska in 1964. The scientific and engineering data available today are not adequate to prevent casualties. Where large earthquakes will occur can be predicted, but it is impossible to estimate their magnitude accurately or to tell when they will take place. It is known, however, that the material of the earth's mantle, where earthquakes occur, is not brittle but must creep at a certain rate before an earthquake-producing fracture or slippage takes place. Continuous recording of strain in areas of high earthquake probability might therefore be very valuable. A group of geophysicists headed by W. T. Pecora of the U.S. Geological Survey is asking the Government to support a 10-year program to study the possibilities of earthquake prediction and prevention that would include such fault-monitoring.

A related and relatively inexpensive engineering application of the laser strain meter would be a continuous monitoring of the strain state of man-made structures such as dams and large buildings. Some of the things one would want to know are the effects of earthquakes on these structures, the change of strain as caused by the changes in the ground, and the changes in the structure itself. Mine collapses might conceivably be predicted by placing strain meters in appropriate locations where the creep rate could be measured.

Evidence in other areas of geophysics may also be provided by these instruments. There are, for instance, indications that North and South America are drifting away from Europe and Africa at the rate of a few centimeters per year. This motion originates at the mid-Atlantic rift, most of which is submerged in the ocean. A segment of the rift, however, crosses Iceland, and there it could be spanned with a laser strain meter to determine the rate of drift. Another interesting location for placing a strain meter to determine the fine structure of

crustal movement is the Barbados Ridge. This is a zone of compression where the floor of the Atlantic is moving with respect to the islands of the Caribbean at the rate of a few millimeters per year.

A laser strain meter might also be set up that would use the entire earth or the moon as a receiving antenna for detecting gravitational radiation. According to the general theory of relativity, a rotating or oscillating mass such as a double star should emit gravitational waves. The forces of these waves that would interact with a detector are transverse to the direction of propagation, as electromagnetic radiation is. These waves produce expansions and contractions; therefore a planetary body "feeling" them would oscillate slightly in shape. Such changes in shape give rise to weak strains that could be detected by an ultrasensitive strain gauge.

In 1961 Robert L. Forward of the Hughes Research Laboratories and his colleagues reported their attempt to detect interstellar gravitational radiation with the earth as the receiving antenna. The data were obtained with a Benioff gauge at the Lake Isabella site in California during a seismically quiet period. In spite of these favorable conditions the power spectrum of the gauge did not show any peaks at the normal vibrational modes of the earth. Such peaks would be expected if the form of the planet were oscillating. Forward was therefore only able to set an approximate upper limit for the effects of gravitational radiation. The increased length and sensitivity of geophysical laser strain meters make it desirable to continue the search for gravitational radiation by the use of such instruments.

Gravitational radiation might also be recognized by its peculiar polarization characteristics. When light is linearly polarized, that is, when its waves undulate in a single plane, a filter that can detect the polarization will encounter the same polarization state with each rotation of 180 degrees. Einstein's equations predict that gravitational radiation would be polarized in such a way that a detector would encounter the same state with each rotation of 90 degrees. Therefore if the earth were the receiving antenna, it could be expected to detect the same polarization state once every six hours. To put it another way, if the gravitational radiation came from a fixed direction in space, the amplitude of the radiation and accordingly the strain it would create would be modulated in six-hour periods.

A simultaneous observation of this radiation from the earth and the moon would constitute convincing proof of its existence. Since there would be no relation between the noise spectra on the moon and on the earth, a common strain (slightly shifted in phase) could not be dismissed as the result of some unidentified internal cause.

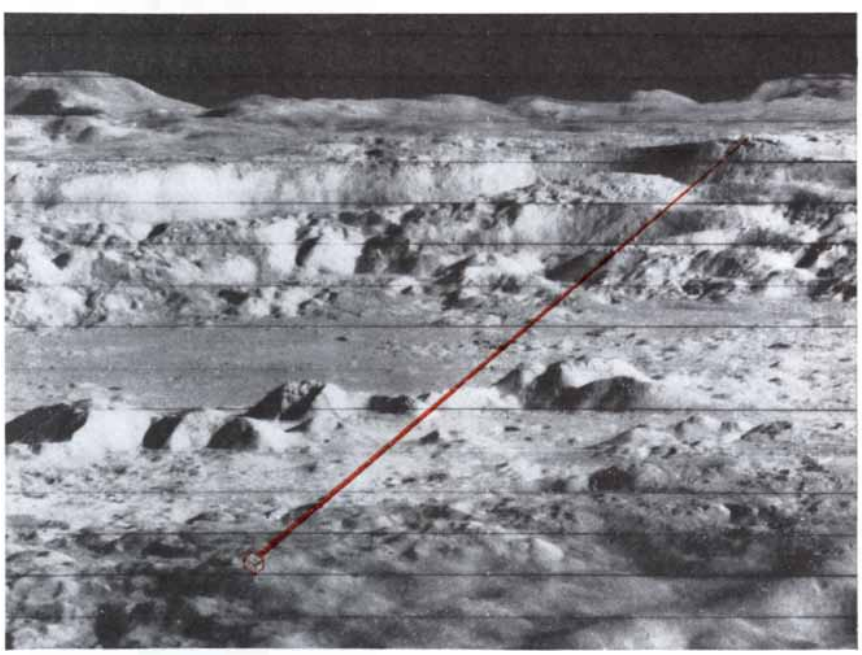
Because the moon has no atmosphere the lunar measurement would not require any long evacuated pipes. One of the best places to put a laser strain meter would be across the crater Copernicus. It is about 100 kilometers in diameter and its rims are high enough to be above the horizon. Furthermore, it is one of the areas that may be explored in future lunar landings.

The moon appears to be a particularly good gravitational antenna. The tides in the solid moon have a period of 27 days, in contrast with the terrestrial period of 12 hours. On the basis of the general similarity in constitution between the moon and the earth it has been estimated that the lunar tides have an amplitude of two meters or more. There is increasing evidence, however, that this value may be far too high.

The discovery of mass concentrations ("mascons") under some lunar maria indicates, according to Zdeněk Kopal of the University of Manchester, that the rigidity of the moon is at least 1,000 times higher than has been thought. This means that the amplitude of the lunar tides is less than a centimeter. On this basis the change in the diameter of the crater Copernicus during one lunar-tide cycle is less than .5 millimeter, corresponding to about 2,000 fringes in the interferometer.

Kopal has estimated that a detectable moonquake caused by the impact of a meteorite will take place on the average less than once in a century. In any case relatively small meteors are not effective in generating seismic waves on the moon because their energy is spent in the regolith, the moon's granular surface layer. Preliminary results from the *Apollo 11* seismograph confirm that the moon is an extremely quiet body.

The period of the lowest normal mode of lunar oscillation is about 15 minutes. This is some 3,000 times shorter than the period of the lunar tides, so that there should be no difficulty in discriminating between such oscillations and lunar tides even when the amplitude ratio is 10^5 or more. The observation of lunar oscillations would be of interest in itself, whether the cause is the impact of meteorites, moonquakes or gravitational radiation. The exact frequency of the oscillations and the way they die out would reveal much about the internal constitution of the moon.



GRAVITY-WAVE ANTENNA could be made of the entire moon by spanning the crater Copernicus with a 100-kilometer strain meter. Because gravity waves would make the moon's shape change, strains would run through its mass that would be detectable by such a gauge. Copernicus is a good location because there is an uninterrupted line of sight from one rim to the other; elsewhere the curve of the lunar surface and its unevenness would interrupt the beam. Line in the illustration represents the gauge's light path. No vacuum tube would be necessary on the moon. Lunar ground vehicles would be needed to install the instrument.

What are computerized systems looking for?

How "moist" is the moon dust?

Of the 142 scientists analyzing moon dust brought to earth with Apollo 11, one, at least, will be searching for signs of water. Using Nuclear Magnetic Resonance and computer techniques, Dr. Stanley L. Manatt at the Jet Propulsion Laboratory will be characterizing the kind of hydrogen in moon dust and how much of it might be ascribed to water. He'll also be looking for the hydrogen-deuterium ratio; signs of heavy hydrogen might contribute to historical tracing of the bombardment of the moon's surface by solar high energy protons and deuterons.

In his experiments, Dr. Manatt will be using Hewlett-Packard computerized instrumentation. He'll first use a Hewlett-Packard programmed frequency synthesizer to sweep his magnetic resonance spectrometer over the range of resonance interest. Then a Model 5480A Signal Averager to enhance the signals resulting from resonance and resonance decay by lifting them out of their noisy environment. His Hewlett-Packard 2115A computer, besides controlling the experiment, will perform integration and lineshape analyses functions to give him quantitative information and Fast Fourier Transforms to produce precise visual readouts in the frequency domain of other nuclear magnetic resonance properties.

Through computer manipulation of statistical data in non-destructive nuclear magnetic resonance spectrometry, studies of moon dust samples may reveal information on lunar water availability and on the origin and history of the moon.

We'll be happy to send you more information on the 5480A, $9950, and our mini-computers, starting at $9950.

How to make the sound of music sweeter.

While integrated and thick film circuitry has contributed much to the listening pleasure you receive from ever smaller and more durable AM/FM radios, it's also introduced new problems with testing.

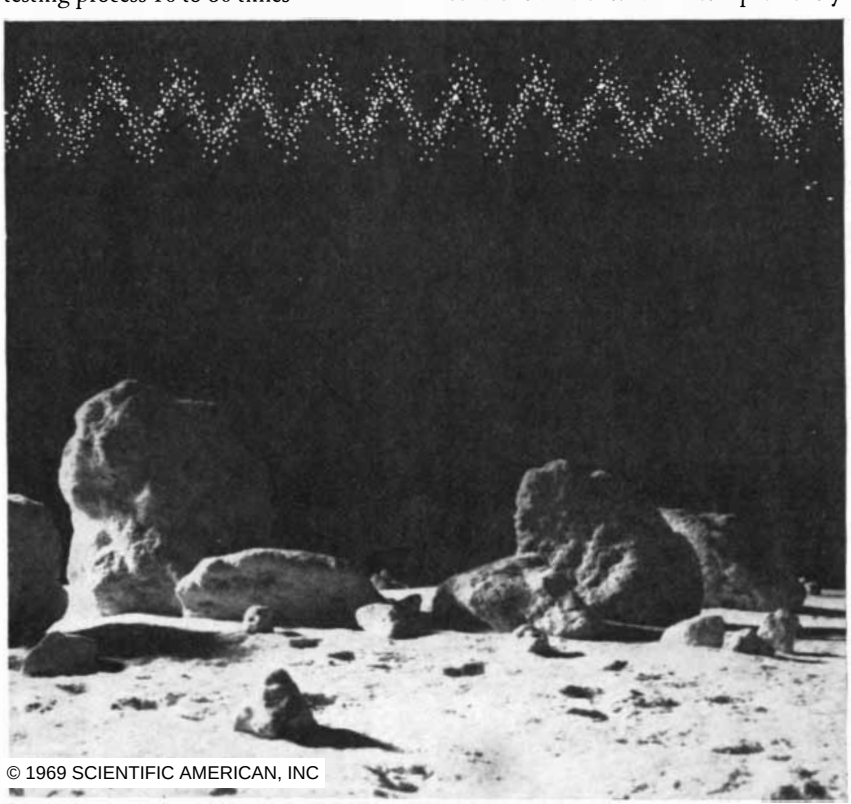
In the manufacture of quality radio sets, complete, lengthy testing of each IC added substantially to the manufacturing costs, and many of the high-density circuits were actually too small to test completely.

But now there's a system that makes possible and economically feasible complete checks of all IC's. One major manufacturer is using it to make the testing process 10 to 60 times faster than previously possible.

Complete circuit tests, including RF, IF, audio, local oscillators and other stages, can be made in less than 10 seconds. Individual steps can be checked in milliseconds. And the beauty of this fast, extensive testing is that it also improves the quality of the set. The tests are designed to give the entire circuit very narrow performance parameters. This inevitably means a better product. In these inflationary times, the cost saving in the production is important in enabling radio manufacturers to hold the line on price.

The automatic test system is the 9500A, typical of those delivered by the special HP Systems Division. It consists of several standard Hewlett-Packard instruments, controlled by one of our computers. The computer controls stimuli and the IC connections to which they're applied, then accepts and records measurement data.

This computer-controlled stimulus-response system can be applied to a wide range of production and quality control situations. It makes a previously



complicated task a simple matter for any technician.

A detailed report on the 9500A system, which costs from $50,000, is given in the August 1969 Hewlett-Packard Journal. Write us for a copy.

How to make an ally of the undersea world.

With hydrostatic pressures up to 10,000 psi and near-freezing temperatures, the ocean depths pose as great a problem for exploration as they hold promise for mankind's future.

The promises include aquatic farming, underwater communications and transportation, perhaps even marine colonies when the earth becomes too crowded to support us all. To find out what's possible and what isn't, new ways to accumulate accurate data have had to be devised.

This data collection includes acoustic noise studies, internal wave observation, seismic refraction operations and studies in temperature changes. Measurements in these areas require a stable ocean surface vessel that can probe the depths in all weather conditions.

This stability has been found in the FLIP ship, operated by the Marine Physical Laboratory of the Scripps Institution of Oceanography, University of California, San Diego. FLIP resembles a ship for its forward 50 feet. The final 300 feet look more like a cigar tube. When FLIP's in position, ballast tanks are filled and the vessel floats in a vertical position, bow up, with very little motion, even in rough seas.

To help this floating laboratory get maximum information in the shortest possible time, Scripps' scientists needed a real-time computation ability. A Hewlett-Packard computer is being used to fill this need and has become an important part of the fact-finding missions.

This system, with background as well as foreground capabilities, performs three jobs at the same time. In the foreground, it collects data with programmed tests; simultaneously, in the background, it facilitates development of new programs for subsequent tests and processes the data from the continuing tests. Previously, data could only be processed on shore. This ruled out the practicality of on-line repetition of the dynamic ship board experiments, results of which are subject to the changing conditions of the seas and to navigational repeatability. In addition, the computer is rugged enough to perform even under the most adverse climatic conditions.

This 2005A Real-Time Executive computer, which is just as much at home in a factory as it is at sea, is priced from $75,000. A brochure on this foreground/background computer system is yours for the asking.

The growing rate of computer uses might be of interest to you. Whether your problem is manipulation of statistical data, production line testing, or the solution of complex measurement and analytical problems. Hewlett-Packard is deeply involved in computer techniques for acquiring data and making it more useful. If you could use some computer assistance, give us a call. Hewlett-Packard, 1506 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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HOW AN INSTINCT IS LEARNED

A study of the feeding behavior of sea gull chicks indicates that an instinct is not fully developed at birth. Its normal development is strongly affected by the chick's experience

by Jack P. Hailman

The term "instinct," as it is often applied to animal and human behavior, refers to a fairly complex, stereotyped pattern of activity that is common to the species and is inherited and unlearned. Yet braking an automobile and swinging a baseball bat are complex, stereotyped behavioral patterns that can be observed in many members of the human species, and these patterns certainly cannot be acquired without experience. Perhaps stereotyped behavior patterns of animals also require subtle forms of experience for development. In other words, perhaps instincts are at least partly learned.

In order to investigate this possibility, I chose a typical animal instinct for study: the feeding behavior of sea gull chicks. My colleagues and I have observed the animals in their natural environment and in the laboratory, where we have conducted a number of experiments designed to elucidate the development of the feeding behavior. Our conclusion is that this particular pattern of behavior requires a considerable amount of experience if it is to develop normally. Moreover, the study strongly suggests that other instincts involve a component of learning.

Sitting quietly in a blind near the nest of a common laughing gull, which breeds on coastal marsh islands in eastern North America, one can watch the feeding of the chicks. The parent lowers its head and points its beak downward in front of a week-old chick. If some time has passed since the last feeding, the chick will aim a complexly coordinated pecking motion at the bill of the parent, grasping the bill and stroking it downward. After repeated pecking the parent regurgitates partly digested food. The pecking motion of the chick is thus seen to be a form of begging for food. If one watches further, one sees the chick peck at the food, tearing pieces away and swallowing them. Pecking is therefore also a feeding action. When the chick and the one or two other chicks in the nest have had their fill, the parent picks up the remaining food and swallows it.

Further observation reveals several intricacies in the interaction of the parent and the chicks. If the parent fails to elicit pecking by merely pointing its bill downward in front of the chicks, it may swing its beak gently from side to side. Such a motion usually stimulates pecking. After the parent has regurgitated food onto the floor of the nest it waits for the chicks to feed. If they do not, the parent lowers its beak again and appears to point at the food. This action is likely to stimulate pecking. If it fails, the parent picks up the food in its mandibles and holds it in front of a chick. If this action elicits pecking, the parent drops the food again so that the chick can eat it readily.

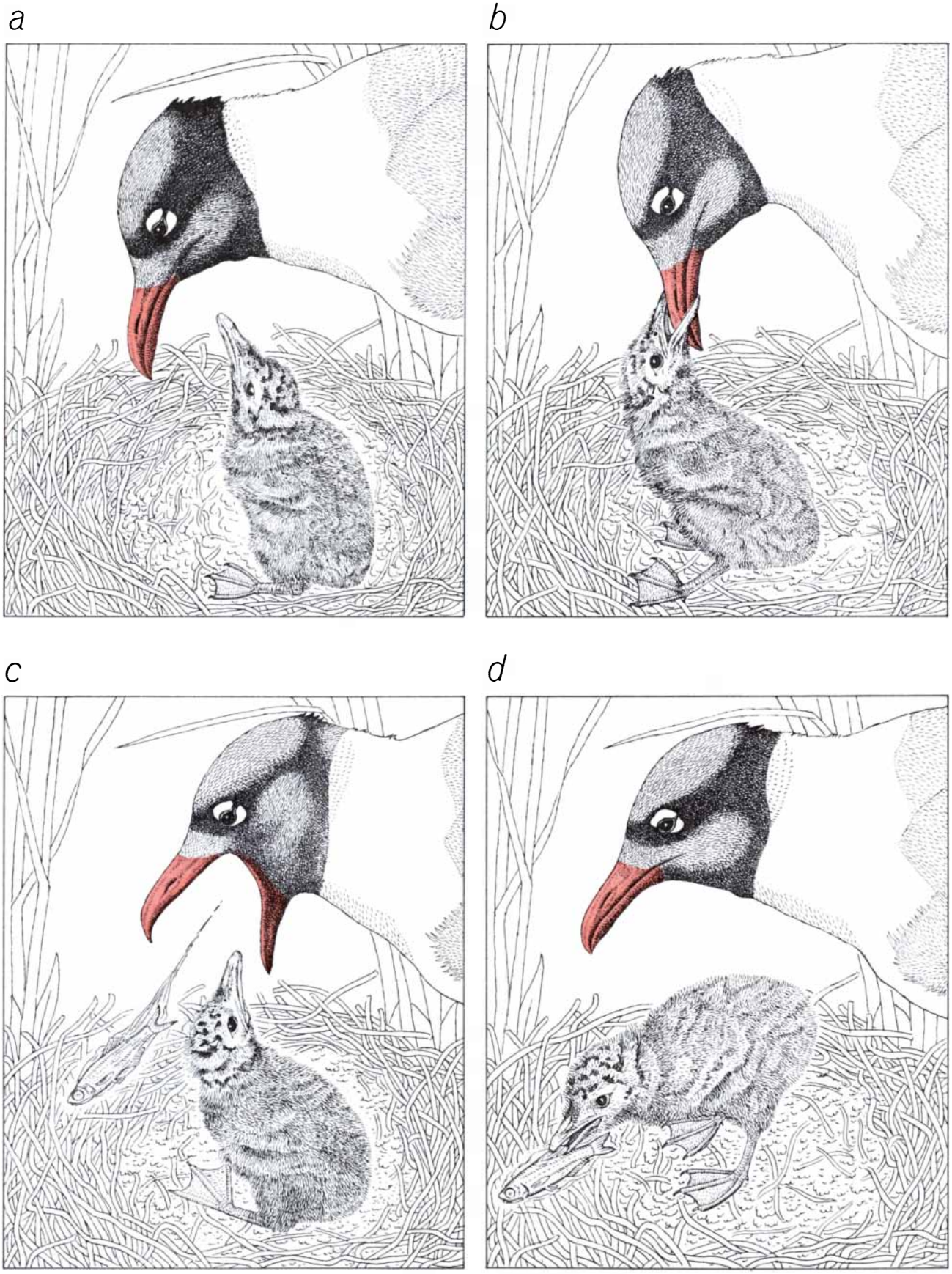
We find in this apparently simple pecking behavior a number of questions concerning the possible role of experience in the development of begging. How does the chick come to stroke the parent's bill with its begging peck and to tear at the food with its feeding peck when the two movements are basically so similar? Why does the chick rotate its head sideways in the begging peck but not in the feeding peck? Does the chick require practice to perfect its aim and coordination? How does the chick come to peck when it is hungry and not peck when it is sated? Why does the chick not peck at the parent's red legs or other objects in its environment? How does the chick recognize food?

In order to answer these and many other questions our group studied chicks experimentally from the time of hatching through the first week of life. By that time the feeding behavior is well established. Moreover, by restricting the study to a short period after hatching we could be sure of controlling several of the elements of development in order to assess their contribution to the behavior. As is often the case, the study raised more questions than it answered, but it also provided a good deal of information.

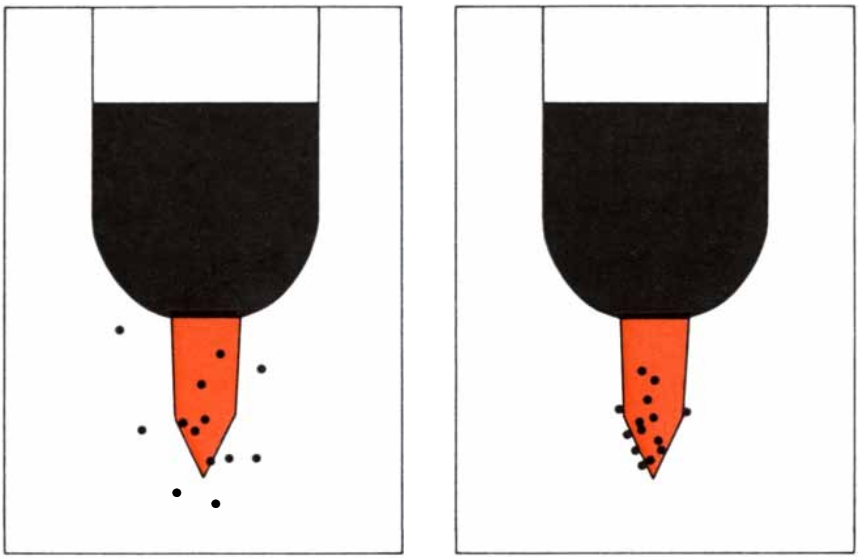
Let us consider first the accuracy of the pecking aim. In order to investigate this matter we painted diagrammatic pictures of parent gulls on small cards [*see top illustration on page 100*]. The card in use was mounted on a pivoting rod that could be moved horizontally back and forth in front of a chick. We collected eggs in the field and hatched them in a dark incubator so that the chicks would not have received any visual stimuli before the test. Each chick was confronted with the two-dimensional model of the parent during the day of hatching and was allowed to make about a dozen pecks at the moving model. Each peck was marked on the card with a penciled dot.

Having made sure that the chick could be identified later, we put it in a nest in the field in exchange for a pipping egg (one that was almost ready to hatch). The chick thus began to experience normal rearing by its foster parents. On the first, third and fifth day after hatching we went to the nesting area and gathered up half of the chicks for further tests, and on the second, fourth and sixth day we tested the others. On each gathering day a chick was tested again on the model and then put back in the nest.

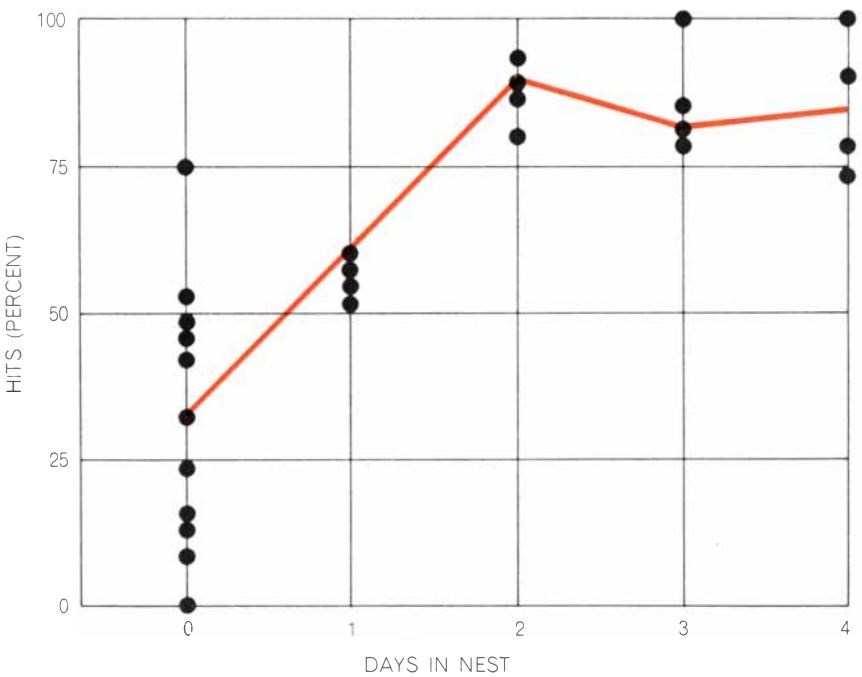
The tests showed that on the average only a third of the pecks by a newly hatched chick strike the model. On the first day after hatching more than half of the pecks are accurate, and by two days after hatching the accuracy reaches a steady level of more than 75 percent.



NORMAL FEEDING BEHAVIOR of a laughing gull chick includes two separate but related types of pecking. A chick about three days old, which has largely perfected the feeding pattern, is portrayed. As the parent lowers its head (*a*) the chick aims a highly coordinated begging peck at the parent's beak, grasping the beak (*b*) and stroking it downward. Parent then regurgitates partly digested food onto the floor of the nest (*c*) and the chick begins to eat it (*d*) with a pecking action that is called the feeding peck.



PAINTED CARDS bearing a schematic representation of the head of an adult gull were presented to chicks to test their pecking accuracy. Pecks are identified by dots. At left is the erratic record of a newborn chick, at right what the same chick did two days later.



IMPROVING ACCURACY of pecking by an experimental group of chicks is charted. Each circle represents the record of one chick. After testing on cards at the time of hatching, the chicks were put into nests and fed by adult gulls. Half of the group was tested on the cards again on the first and third day and the other half on the second and fourth day. Fewer chicks are represented on those days than on the day of birth because it was not always possible to find each chick. The colored line shows the median accuracy for the chicks tested.

The record of a typical chick shows that the strokes become much more closely grouped and that in particular the horizontal error is greatly reduced.

How does this rapid increase in accuracy come about? In order to find out we designed a more extensive experiment involving the use as controls of two groups of chicks reared in the wild. Three experimental groups were reared in dark brooders so that they would not have any visually coordinated experience in pecking. One experimental group was force-fed in the brooder. A second group received no food for two days; the chicks lived on their ample reserves of yolk. The members of the third group did not hatch normally; instead the experimenter broke open the egg as soon as pipping started, took the chick out and placed it in an incubator. The reason for this procedure was to see if the movements of normal hatching had any effect on the accuracy of pecking.

On various days after hatching the chicks of all groups were photographed pecking at the stuffed head of an adult laughing gull. From the films we could ascertain the percentage of accurate pecks. Chicks of all five groups demonstrated an increasing accuracy with age, but only in the two control groups did the figure reach the normal level of more than 75 percent hits. The denial of the hatching experience had no effect on accuracy, but the denial of visual experience after hatching had a strong effect.

The most conservative interpretation of these results is that visual experience is necessary for the development of full accuracy in pecking but that a certain amount of improvement in accuracy is achieved without experience. Perhaps this amount results from improved steadiness of stance. Here again an element of experience may enter in, since the improvement in stance can most plausibly be attributed to the chick's practice in standing in the dark incubator.

How does the chick come to position itself at the correct distance to strike the bill or the model accurately? Our observations of newly hatched chicks suggest that a self-regulating form of behavior based on depth perception is at work. If an inexperienced chick is too close to the target at first, its pecking thrust against the bill or model is so strong that the chick is thrown backward as much as an inch. If the chick starts out too far from the target, the pecking thrust misses and the chick falls forward as much as two inches. Older chicks rarely make such gross errors, suggesting that the experience of overshots and undershots has helped the chick learn to adjust its distance.

It has often been implied that hunger is a learned motivation. Our experiments suggest that hunger has at least an unlearned basis from which to develop further. Several experiments showed that, as one might expect, if chicks were fed to satiation and tested with models at various times after feeding, the pecking rate increased with time since feeding. The same pattern appeared, however, with chicks we gave no opportunity to "learn" hunger. Chicks hatched and reared in dark incubators were force-fed to satiation when they were between 24 and 48 hours old and then were tested in light on models. At one hour after feeding they pecked at a mean rate of 6.2 pecks per two minutes and at two hours at 10.2 pecks, which is a statistically reliable difference.

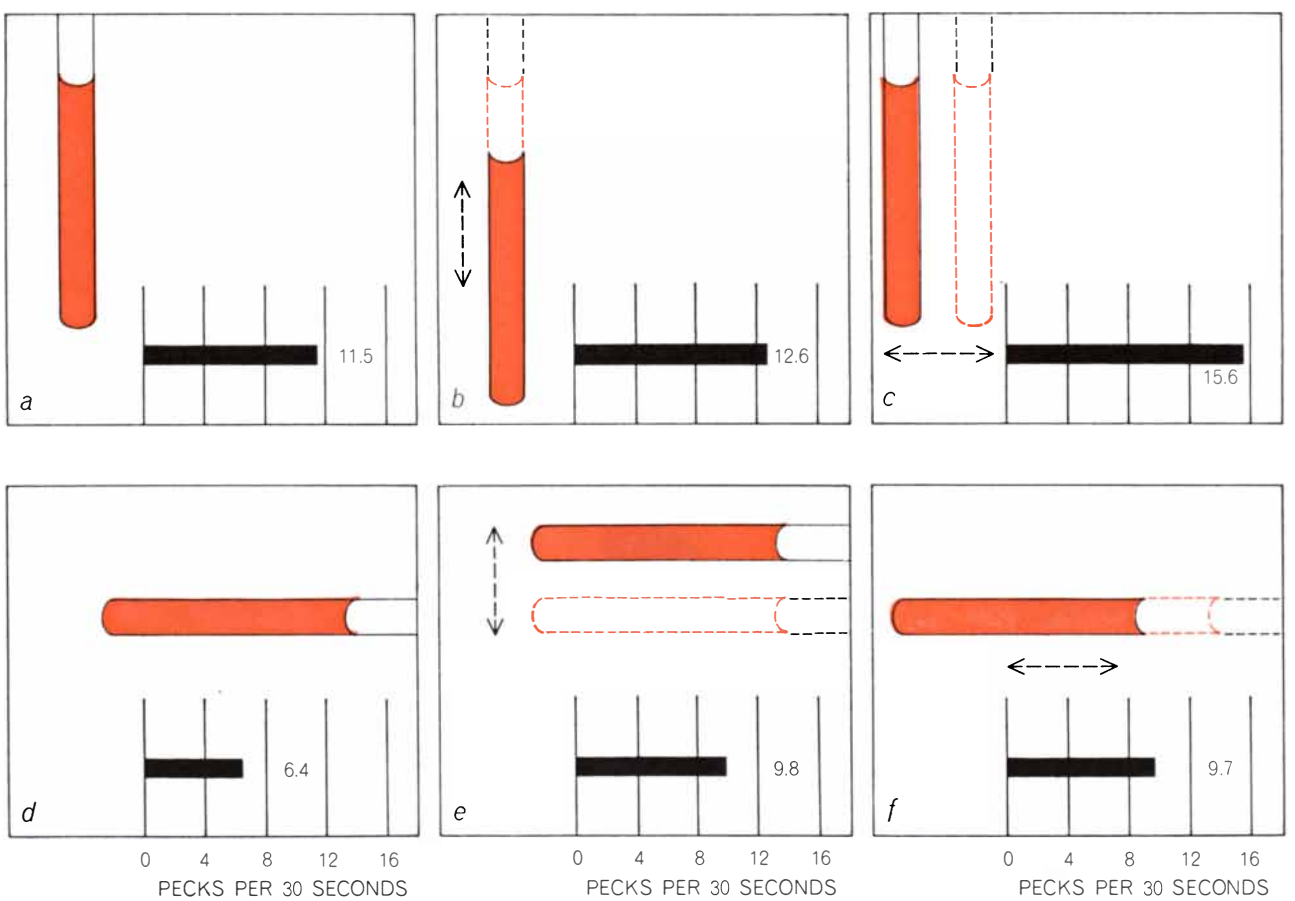
By means of high-speed motion pictures we analyzed in detail the motor pattern of the begging peck. In a chick several days old the pattern, by then well developed, includes four major components: (1) the opening and subsequent closing of the bill; (2) the motion of the head up and forward toward the beak of the parent and then down and back toward the chick's body; (3) the rotation of the head to the side in anticipation of grasping the parent's vertical beak and then the return rotation to the vertical position, and (4) a slight push upward and forward with the legs [*see illustration on page 99*]. A frame-by-frame analysis of the motion pictures revealed considerable variation in the synchronization of components from peck to peck of individual chicks and from chick to chick. The variation decreases somewhat with age. Presumably the decrease reflects increasing coordination, although we have not investigated the phenomenon in detail.

Among the interesting points that emerged from the films was the observation that with chicks reared in the wild the anticipatory rotation of the head became more frequent with age. To see what effect visually guided pecking experience had on this change, we analyzed the films of the five groups of chicks used in the experiments on pecking accuracy. The results indicated that chicks reared without pecking experience seldom showed any development of the head-rotation component of pecking. A chick reared in the wild does not show the rotation on the day of hatching but then acquires it and improves it rapidly.

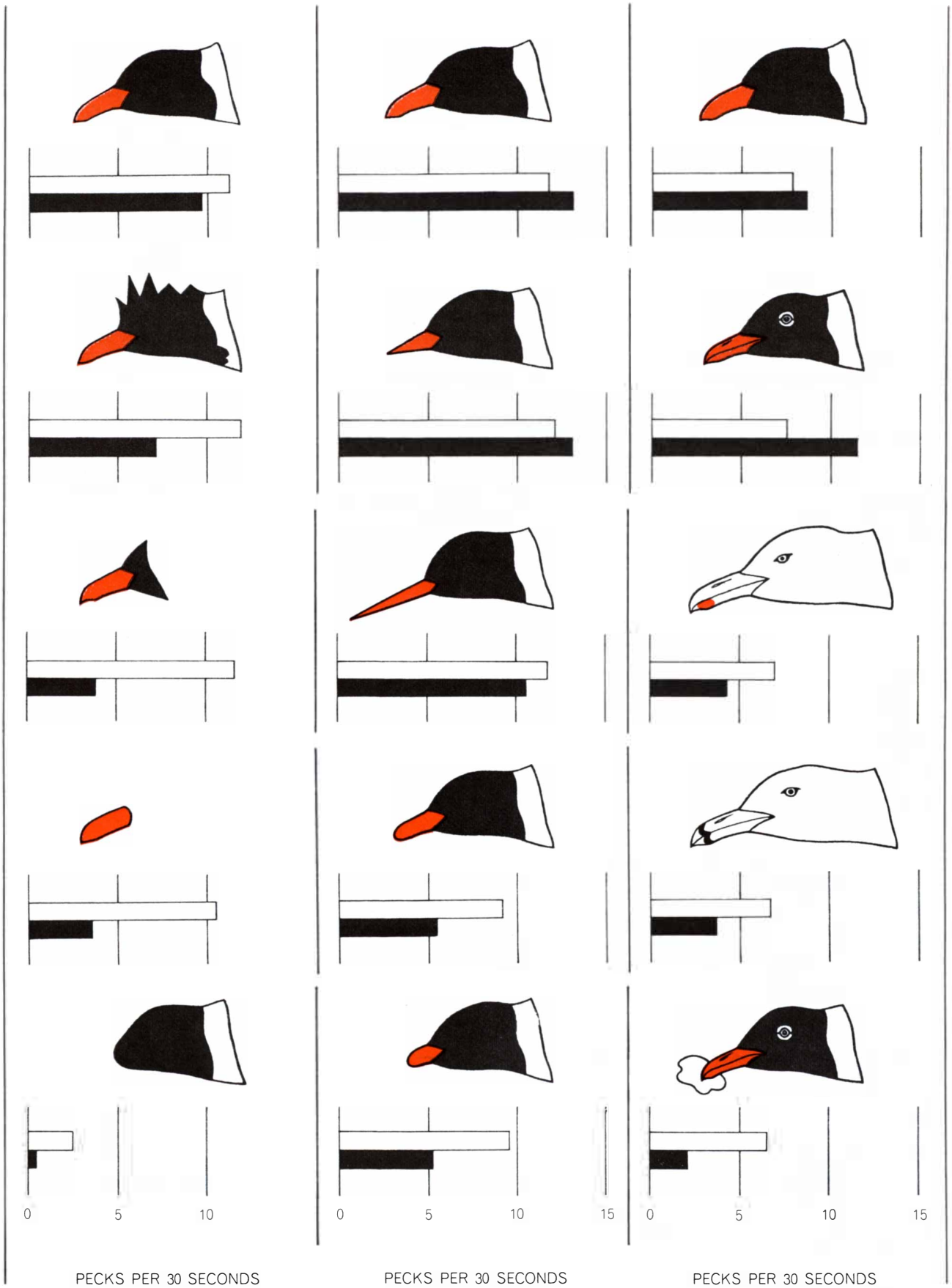
We do not know how experience brings about this development, but the films provide a suggestion. Sometimes when a naïve chick is striking forward with its mandibles spread apart and the parental bill or the model is not exactly vertical, the chick's upper mandible goes to one side of the target and the lower mandible goes to the other side. The thrust of the forward head movement then forcibly rotates the chick's head to the side. Perhaps this is how the rotary movement in anticipation of grasping the parental bill is learned.

One of the most interesting questions about pecking is how the chick recognizes its parent. Observations from a blind show that chicks do peck at objects other than the bill of a parent, including other parts of the parent's body, but that most of the pecks are aimed at the parental bill—increasingly so with age. These observations suggest that the newly hatched chick has only a vague mental picture of the parent and that the picture becomes sharper with age and experience. We investigated the question by making a number of models of heads and beaks [*see illustration on next page*]. By systematically eliminating or changing parts of the models we could discover the most effective stimulus for pecking. Usually a model was mounted on a rod that could be moved on a pivot in time to a metronome, so that the speed of movement would be known and could be controlled. In each experiment a chick was presented with five models, which were offered in a random order, and the number of pecks (usually per 30 seconds) was recorded.

The first problem was to find the most



TESTS OF STIMULI were made with wooden dowels approximately the width of an adult gull's beak. The mean number of pecks in 30 seconds by a group of 25 chicks was recorded for (*a*) a vertical rod held stationary; (*b*) the same rod moved vertically; (*c*) the rod moved horizontally; (*d*) a stationary horizontal rod; (*e*) same rod moved vertically, and (*f*) the rod moved horizontally.



FEATURES OF HEAD that elicit the most pecks were tested with models presented in groups of five to newly hatched chicks (*white bars*) and older chicks (*black bars*). All the chicks were laughing gulls. The group of models in the column at right included models of the herring gull (*third from top*) and the ring-billed gull (*fourth from top*). A model holding food in its bill is also depicted.

effective stimulus for naïve chicks, which had been kept in dark incubators until being tested about 24 hours after hatching. In the first three experiments the naïve chicks responded equally to all five models presented except for the model lacking a bill. These experiments established that newly hatched chicks are responding primarily to features of the parent's bill rather than to features of the head or even to the presence of the head.

One of the first three experiments revealed an unexpected finding: laughing gull chicks do not discriminate between a model of their own parent and a model of an adult herring gull. The adults of these two species are strikingly different in appearance. The laughing gull has a black head with a red bill; the herring gull has a white head and a yellow bill with a red spot on the lower mandible. The laughing gull chicks responded to this red spot on the model.

If laughing gull chicks fail to distinguish their parent from the herring gull, what would herring gull chicks do? In order to answer this question and others we went to a large colony of herring gulls on an island of the Grand Manan archipelago in the Bay of Fundy and tested herring gull chicks with models of both species. The result was the same: newly hatched chicks failed to discriminate between the two species in their pecking. This result suggested that the chicks of both species were responding to simple features of form and movement provided by the red bill of the laughing gull or the red spot of the herring gull.

Even though the optimum stimulus for eliciting pecks is evidently a simple one, it apparently has features that enable the chick to distinguish it from other simple forms in its environment, such as the red leg of a parent or a blade of grass, because pecks are rarely aimed at such targets. We investigated the matter with simple dowel rods made of wood and painted red. A rod was presented to a chick both vertically and horizontally, and in each orientation it was held stationary, moved vertically and moved horizontally. Every vertical stimulus received higher peck rates than every horizontal one, but the most effective vertical rod was the one moved horizontally. This result accords well with the natural situation in which the parent's vertical bill is likely to be moved horizontally in front of the chick.

Further analysis of the results showed that the vertically moved vertical rod elicited no more pecks than the stationary vertical rod. In addition, both horizontal and vertical movement of the horizontal rod were equally effective and curiously were more effective than the stationary horizontal rod. The most cautious interpretation of these results is that two kinds of movement are instrumental in eliciting pecks from the newly hatched laughing gull chick. The first is horizontal movement, and the second is movement across the long axis of the rod. This interpretation explains why a vertical rod moved vertically is no more effective than a stationary vertical rod, since both stimuli lack both horizontal movement and movement across an axis. With a horizontal rod, however, vertical movement is across the long axis and therefore is as effective as horizontal movement (along the axis), and each kind of movement is better than no movement.

The next step was to try various speeds of movement of a vertical rod. We used five different speeds with three diameters of rod. The results showed that a width of about eight millimeters was preferred, independent of the rate at which the rod was moved, and that a speed of movement of 12 centimeters per second was chosen over higher and lower speeds regardless of the width. These results demonstrate well the exactness of the match that evolution has brought about between stimulus and responsiveness. The parent's beak measures 10.6 millimeters from front to back and 3.1 millimeters laterally; the mean width of beak seen by the chick is thus about eight millimeters. Furthermore, the horizontal soliciting movement of the parent's beak was calculated from high-speed motion pictures made at the nest and was found to average 14.5 centimeters per second.

A recent experiment has added another item to this picture of a chick's ideal stimulus. Vertical rods projecting from above the chick's eye level are much preferred to those that come from below. The preference is also shown for oblique objects. Such a choice would reduce the chick's responsiveness to the parent's legs, which of course project from the ground and join the parent's body at just about the chick's eye level.

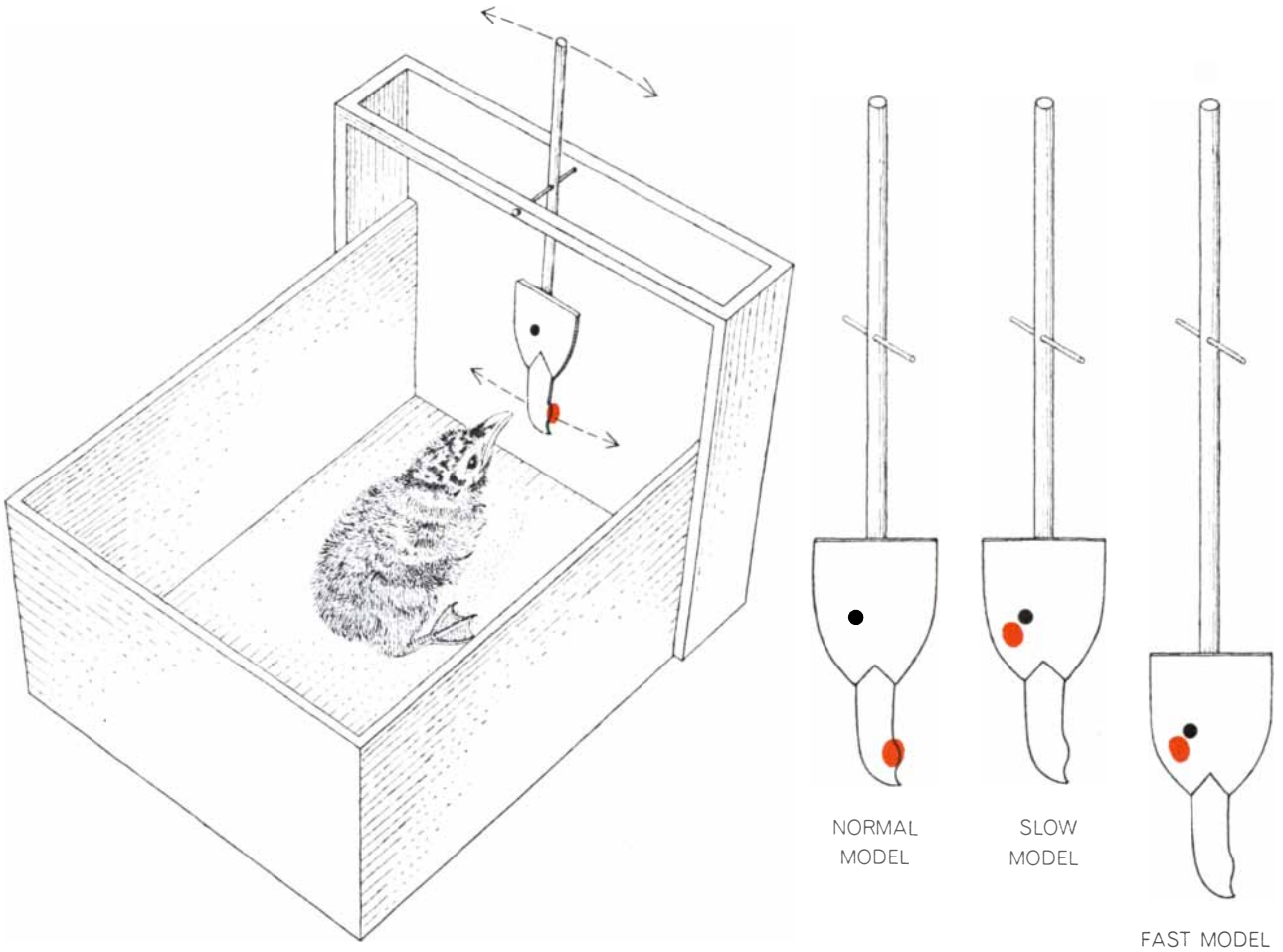
We now understood, at least roughly, how the newly hatched chick discriminates between its parent's beak and other objects in its environment. The question we addressed next was whether or not this perception changes during the first few days of life. We presented the same three series of five simple cardboard models each to week-old chicks and found a large difference between those results and the results with newly hatched chicks. Older chicks were sensitive to small differences in shape and detail of the head and beak. Moreover, the older chicks discriminated readily between their laughing gull parent and the model of the herring gull. To see if older herring gull chicks also came to prefer their own parent, we marked individual chicks and tested them on about the fourth day of life and about the seventh. The longer they had been in the nest, the greater their response to the model of their own parent and the less to the model of the laughing gull.

Was this change in perception due to conditioning experience with the parent that feeds the chick? To find out we worked with herring gull chicks that had been reared in an incubator. We divided them into three groups. If a chick was in the first group, it was fed a small amount of food when it delivered several pecks to a model of a laughing gull; if it was in the second group, it was fed for pecking at a model of its own species. The third group, which served as a control, was fed without first pecking at any model. At the end of two days of training each group was responding more, in discrimination tests without a reward of food, to the model on which it had been trained. Although the experiment is preliminary, it suggests that conditioning with a reward of food could account for the changes seen in wild chicks.

In sum, our findings indicate that the newly hatched chick responds best to a very simple stimulus situation. Although the experimenter can construct a model that is even more effective than the parent, the characteristics of the parent match the chick's ideal more closely than any other object in the environment. As a chick is fed by its parents, however, it develops a much more specific mental picture of the parent. Chicks a week old peck only at models that closely resemble the parent.

Our results did not appear consistent with certain earlier findings of the ethologists Nikolaas Tinbergen and A. C. Perdeck, who studied the herring gull. They found that if the red spot on the beak of the parent gull was moved to the forehead of a model, the model received few pecks. Since all the stimulus elements were thought to be the same in the two models, merely arranged differently, this classic experiment has been interpreted as showing the highly configural nature of the newly hatched herring gull's perception of the parent.

We thought the question of whether or not all the stimulus elements are in



LABORATORY APPARATUS was designed to test the effect of three models of the herring gull on the pecking rate of chicks. The normal model had the gull's red spot in its natural position on the beak. The "slow" model had the spot on the forehead; the spot moved more slowly than the one on the "fast" model when it was swung back and forth because it was closer to the pivot point.

fact the same needed investigation. The Tinbergen-Perdeck models were hand-held, so that when the model was moved in a pendulum-like manner with the hand as the pivot point, the spot on the forehead moved more slowly than the spot on the beak and through a shorter arc. Moreover, a chick had to stretch higher to peck at the forehead spot.

For these reasons we repeated the Tinbergen-Perdeck experiment, adding a third model. It was a forehead-spot model mounted on a rod in such a way that the forehead spot was the same distance from the pivot point as the bill spot was in the other model [*see illustration above*]. In addition our apparatus had a floor of adjustable height so that the chick's eye could always be positioned level with the red spot, whether the spot was on the bill or on the forehead. We called our third model the "fast" forehead-spot model, because the spot on it moved faster than the one on the "slow" Tinbergen-Perdeck model. If our hypothesis about movement were correct, the new, fast forehead-spot model should be as effective as the bill-spot model.

The results were unequivocal. Newly hatched chicks responded as readily to the fast forehead-spot model as to the conventional model with the spot on the bill. Now we tested the same chicks after they had had three days in the nest and then seven days. This test showed that, as we had now come to expect, the bill-spot model improved steadily in relation to both the old and the new version of the forehead-spot model.

The classical interpretation of the Tinbergen-Perdeck experiment was that it demonstrated the existence of an innate releasing mechanism, which was conceived to be an unlearned perceptual mechanism that is activated by highly configural stimuli. Our experiment shows the gull chick's perception to be activated by a less configural simple shape when it is unlearned and by a highly configural shape when it is learned. The experiment suggests the need for reinvestigation of other results thought to be examples of innate releasing mechanisms.

The results also suggest the need for reinterpretation of another widely held concept in the behavioral sciences: classical conditioning. In the familiar example represented by the experiments of Ivan Pavlov an animal is presented with a new conditioning stimulus before it receives or just as it receives the usual stimulus that elicits the response of interest. After a number of these paired presentations the animal comes to respond to the conditioned stimulus alone. Pavlov's classic experiment involved ringing a bell before a dog was exposed to the smell of food; in time the dog would salivate merely in response to the bell.

Psychologists have long wondered how useful this cross-modal conditioning is to animals in their ordinary activities. Why should such a learning capability be evolved when it seems to be so little used under normal conditions? Our results suggest an answer worthy of further testing. As the chick develops its perceptual preference it is responding to simple features of the parent (the unconditioned stimuli) but is being presented

simultaneously with all the complexities of the parental head (the conditioned stimulus). As a result of feeding, the chick comes to demand the more subtle features of the stimulus before it will peck.

This developmental process, which I have termed "perceptual sharpening," can be distinguished from the classical conditioning of laboratory experiments by the fact that the conditioned and unconditioned stimuli are physically identical. Perhaps the capability for classical conditioning has evolved primarily as a mechanism for perceptual sharpening, and the traditional experiments involving classical conditioning are in fact dealing with what is essentially an artifact of perceptual sharpening. At this stage my argument is no more than a hypothesis.

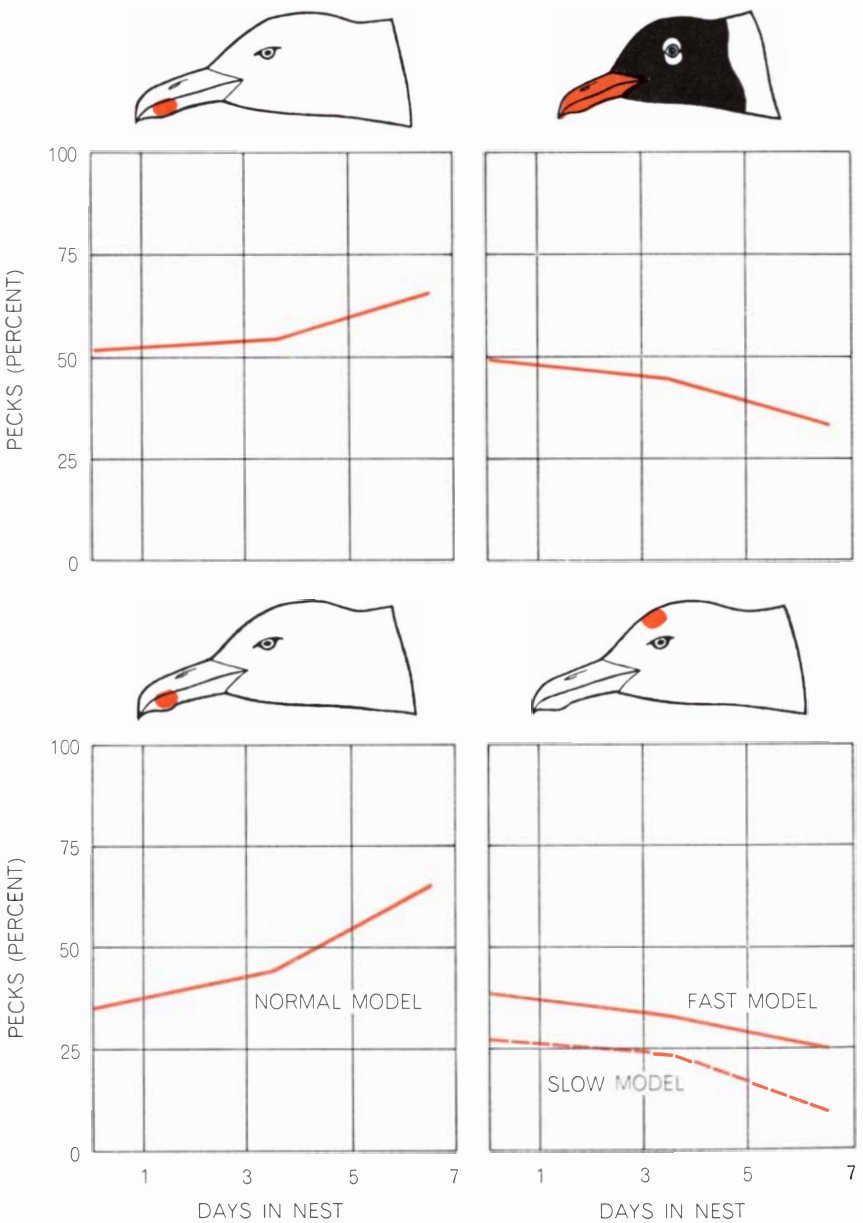
Although we have studied many more aspects of pecking that cannot be related briefly here, one should be mentioned: the recognition of food. Do newly hatched chicks recognize food when they encounter it? To find out, we placed food in dishes in the four corners of a small box and watched incubator-reared herring gull chicks find their first meal. The number of seconds taken to find food was inversely related to the pecking rate. This is the result to be expected if chicks are finding the food solely by trial and error.

If the chicks are allowed to feed until satiated and are then removed from the box until they are hungry again, they find food in the box much more quickly. The time required reaches a minimum by the third trial. This change cannot be attributed to an increase in the pecking rate, since the pecking rates in the second and subsequent trials are only slightly higher than in the first trial. The experiment shows that chicks can learn rapidly to identify food, or at least its location.

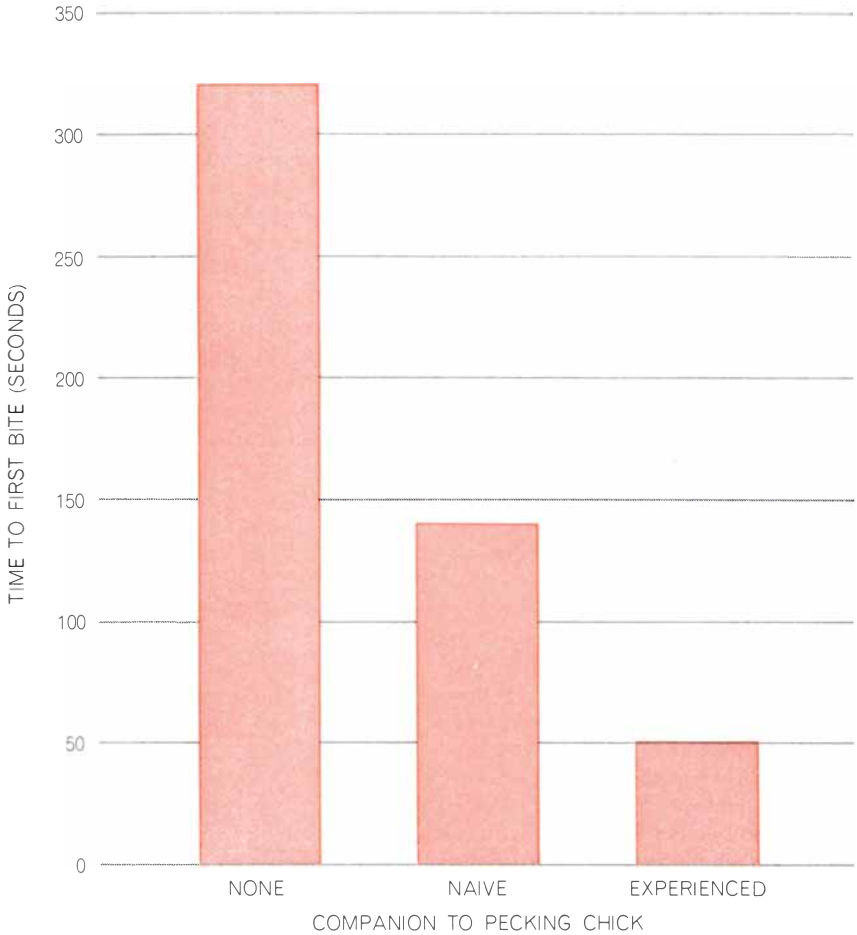
If the newly hatched chick does not initially recognize food, must it rely on trial-and-error searching to get its first bite and thereby initiate the rapid learning? Observation and experiment show that several mechanisms exist to help accelerate the first discovery of food. Recall that if a chick does not peck at food, the parent picks the food up in its beak. Quite often, in first feedings I have seen from a blind, the chick continues to peck at the parent's beak after the parent has regurgitated food onto the floor of the nest. Eventually the parent picks the food up and the chick strikes it during a peck at the bill. The observation suggests that the poor pecking accuracy of newly hatched chicks may be adaptive, ensuring that the chick at least occasionally misses the parent's bill and strikes the food instead.

Another mechanism to assist the rapid learning of what food is involves the siblings in the nest. A chick will often peck at the white bill tip of another chick. In an ordinary clutch of three eggs the chicks hatch at intervals of about 12 hours, so that the older chicks have already been fed by the time a younger one appears. If a younger chick pecks at the bill of an older one while the older one is pecking at food, which it now recognizes, the younger chick's peck will probably also strike the food. Observation from a blind has shown that the first bite of food does come about in this way at times.

We tested the recognition of food with three groups of incubator-reared herring gull chicks. In one control group each chick was put alone into the small box with food; each chick in the two experimental groups had a companion. In one group the companion was equally naïve about food, and in the other group the companion had eaten earlier in the box. The results showed that the solitary chicks took the longest time to find food. The chicks with equally naïve companions took the next-longest time, and the



RECORD OF RESPONSES by herring gull chicks to various models shows changes as the chicks grow older. The model at top left is of a herring gull's head; the one at top right is of a laughing gull's. At bottom are two models of the herring gull; the one at left has the red spot in its normal place, and in the one at right it is on the forehead of the model.



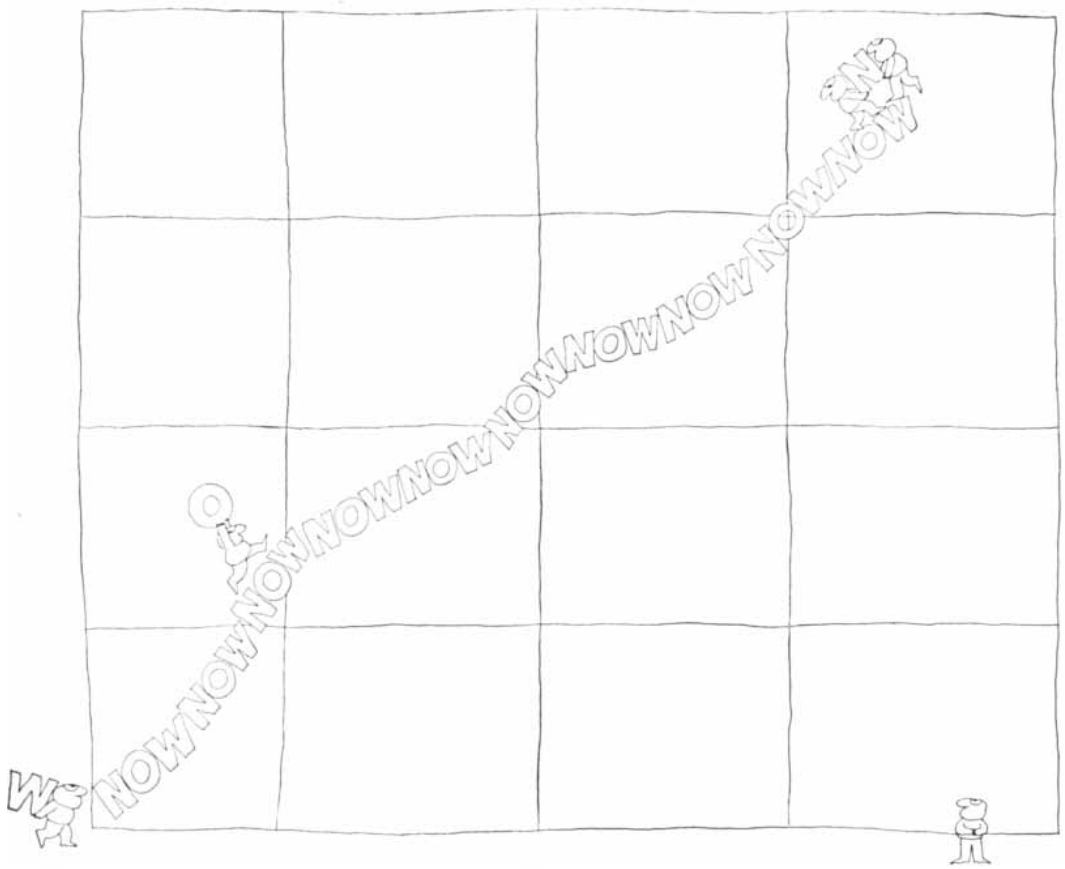
NEWLY HATCHED CHICKS were tested for speed in finding their first bite of food with and without another chick. The time was longest when the chick had no companion, shorter when the companion was equally naïve and shortest with a companion experienced in finding food. The test demonstrated that social interaction helps chicks learn to recognize food.

chicks with experienced companions took the least time [*see illustration above*].

These differences cannot be accounted for merely on the basis of increased exploratory trial-and-error pecking by the newly hatched chicks with companions, because the companion's bill actually diverted pecks from exploration. The naïve companion did cause the newly hatched chick to move about more in the box and therefore to find food more quickly than the solitary chicks did. The experienced companion must have had a further effect, inasmuch as each naïve chick in this group first discovered food when it was pecking at the bill of its companion while the companion was pecking at food.

We can now summarize the developmental picture yielded by our investigation. The newly hatched gull chick begins life with a clumsily coordinated, poorly aimed peck motivated by hunger and elicited by simple stimulus properties of shape and movement provided only by a parent or sibling. The chick cannot recognize food, but by aiming at the bills of its relatives and missing it strikes food and rapidly learns to recognize it. As a result of the reward embodied in the food, the chick comes to learn the visual characteristics of the parent. Through practice in pecking its aim and depth perception improve steadily. The chick also learns to rotate its head when begging from the parent, and thus its begging peck and feeding peck become differentiated.

The picture strongly suggests that the normal development of other instincts entails a component of learning. It is necessary only that the learning process be highly alike in all members of the species for a stereotyped, species-common behavioral pattern to emerge. The example of the gulls also shows clearly that behavior cannot meaningfully be separated into unlearned and learned components, nor can a certain percentage of the behavior be attributed to learning. Behavioral development is a mosaic created by continuing interaction of the developing organism and its environment.



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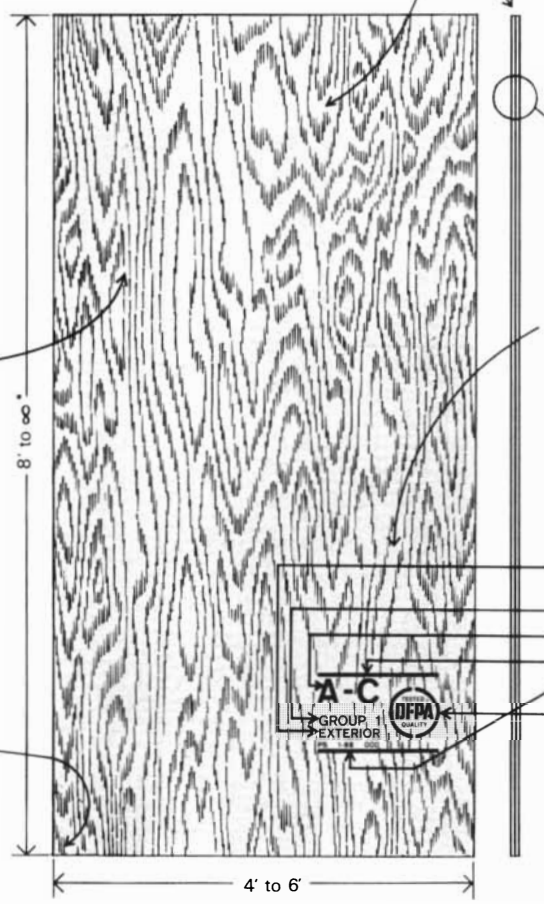

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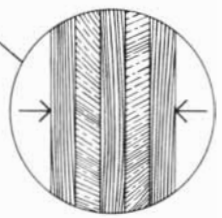

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The Peculiar Distribution of First Digits

In numbers that appear in tables of constants, lists of street addresses and similar tabulations the first digit of the number is 1 almost three times more often than one would expect. Why?

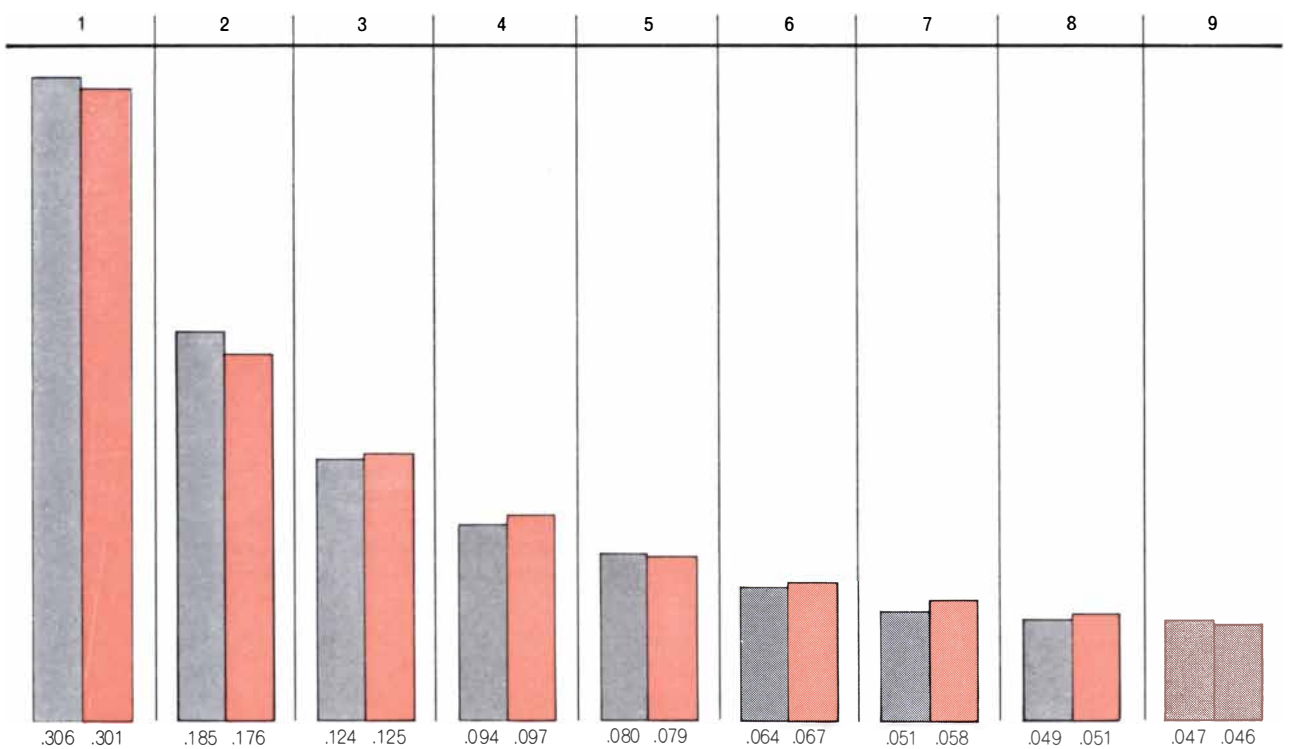
by Ralph A. Raimi

The earliest paper on the subject of this article seems to be one published by the physicist Frank Benford in 1938, and he says the observation was an old one even then: Tables of logarithms in libraries tend to be dirtier at the beginning than at the end. The first few pages show more wear than the next few, and so on to a relatively fresh last few pages.

In a bad novel this might be expected, each borrower having abandoned the book when he could stand no more, but why should students of science and engineering (say) use the earlier pages of a book of logarithms more than the later pages? Obviously because they must have more occasion to calculate with numbers beginning with 1 than with 2, and so on up to 9.

The numbers people look up in logarithm tables (or used to 30 years ago, before the era of digital computers) are the entries one finds in scientific or statistical tables, such as *Handbook of Chemistry and Physics* or *The World Almanac*. Benford investigated 20 such tables, among them the surface area of 335 rivers, the specific heat and molecular weight of thousands of chemical compounds, even the street addresses of the first 342 persons listed in *American Men of Science*. He classified more than 20,000 entries according to their first digits (regardless of decimal-point position, which does not affect the place of an entry in a logarithm table) and tabulated their frequencies in the nine divisions [*see illustration below*].

For example, Benford found that the first digit 1 appeared with frequency .306. Under the naïve hypothesis that each of the nine possible first digits appears equally often, this frequency should be .111, as should all the others.



FREQUENCIES OF FIRST DIGITS (*top*) **in 20 kinds of tables examined by the physicist Frank Benford are given here by the gray bars and the numbers under them. More than 30 percent of the numbers began with 1 and less than 5 percent with 9. Benford proposed a law to describe these frequencies: The probability that a random decimal begins with the digit p is $\log (p+1) - \log p$. The frequencies according to Benford's law are given by the colored bars and the numbers under them. Logarithms are to base 10.**

The first digit 9, on the other hand, had a frequency of only .047. If students looking up logarithms in a nine-page logarithm table made their calculations using numbers drawn randomly from the 20,000 entries Benford catalogued, the first page of that logarithm table would be more than six times as dirty as the last!

The Benford frequencies are immediately suggestive to anyone who has ever used a slide rule: they are very close to the proportionate lengths of the nine major divisions of the *C* and *D* scales on the rule [*see upper illustration below*]. All slide rule markings are laid out according to the rule that the distance from the left index to the mark for x is equal to $\log_{10} x$ (given unit length for the slide rule and disregarding the position of the decimal point in x). Thus the length of the second major division, the interval from 2 to 3, is $\log 3 - \log 2 = .477 - .301 = .176$. (All the logarithms in this article are to the base 10.) This is fairly close to Benford's frequency of numbers beginning with the digit 2; such numbers are of course found in this interval of the slide rule.

When I first learned to use a slide rule, I thought there was some injustice in the divisions' being of unequal length. Numbers beginning with 9 were hard to mark off because of the compression of the later part of the scale. Now (assuming that Benford's law is correct) I see that there is justice after all: the numbers I look up most often are in fact positioned where the scale is most widespread and perspicuous. Not only do the *C* and *D* scales multiply and divide for me, they also exhibit their markings in an optimal range of visibilities.

In his 1938 paper Benford offered a general "law of anomalous numbers": The probability that a random decimal begins with the digit p is $\log (p + 1) - \log p$. His use of the word "anomalous" is connected with the notion of randomness invoked by this statement. Analysis of his raw data showed that certain tables were in better agreement with the law than others. The street addresses and river areas worked very well indeed, but some systematic tables (such as a list of square roots) and closely knit tables (such as specific heats) did not. Square roots in ascending order do not quite seem random, and specific heats cluster pretty close around 1. Benford decided that his law should not apply to such numbers, of which we can predict something, but rather to "those outlaw numbers that are without known relationship." Hence the term "anomalous numbers."

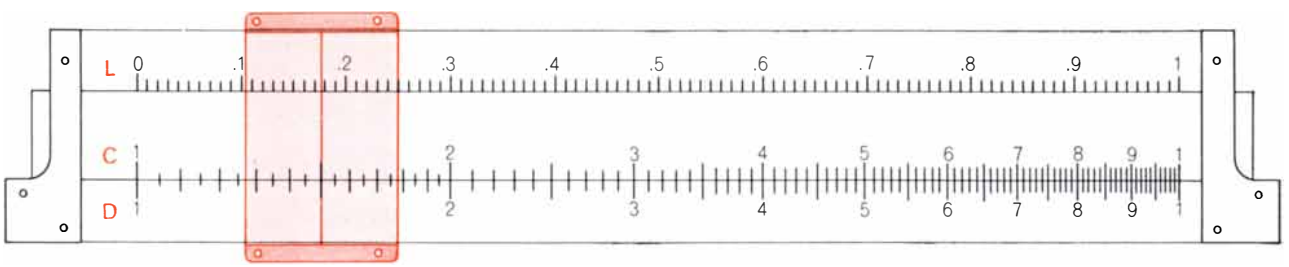
Benford gave a sweeping "explanation" of his law: he declared it nothing less than a law of nature. For this he had ample precedent in earlier laws of a logarithmic sort. For example, Fechner's law states that the response to a psychological stimulus such as optical brightness varies as the logarithm of the stimulus. Population growth (unhindered) is exponential; this is the inverse of a logarithm law. One could as well say that time varies as the logarithm of population size.

Nature, says Benford, apparently counts exponentially—by powers, 2, 4, 8, 16,... rather than 1, 2, 3, 4,.... Orders of magnitude are a greater part of the conversation of scientists than the linear scale of magnitudes themselves. "There is a tendency," says Benford, "for the step between sizes to be equal to a fixed fraction of the last preceding phenomenon or event."

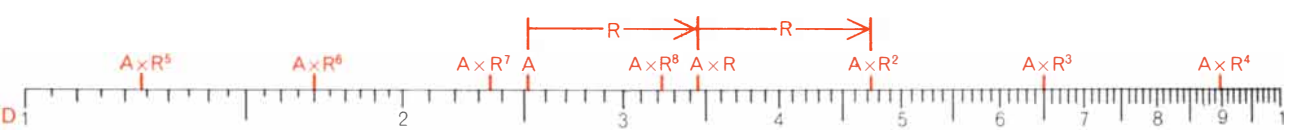
This implies that measurements of successive events form a geometric series $A, A \times R, A \times R^2, A \times R^3, \ldots$ (R stands for ratio.) The step between successive events is $A \times R^n - A \times R^{n-1} = A \times R^{n-1} \times (R - 1)$, which is the fraction $R - 1$ of the preceding measurement $A \times R^{n-1}$.

If this geometric sequence is plotted on a slide rule [*see lower illustration below*], it will appear equally spaced, because each new multiplication by R moves the point by the same distance (to the right if R is greater than 1, to the left if R is less than 1). Even where the next term runs "off the end," as between $A \times R^5$ and $A \times R^6$ in the illustration, the total distance around the bend is the same as the preceding shift.

A better picture of the geometric sequence is given on a circular slide rule, which is nothing but the *C* and *D* scales bent into a circle with the ends identified [*see illustration on opposite page*].



SLIDE RULE is suggestive of Benford's law. The Benford frequencies are close to the proportionate lengths of the nine major divisions of the *C* and *D* scales. The *C* and *D* scale markings for a number x have a distance from the left equal to $\log x$. The position of the decimal point in x is "disregarded"; more accurately, the number x is multiplied by that power of 10 which reduces it to between 1 and 10, and the distance to the marking is the logarithm of the reduced number. Thus $\log 15 = 1.176$ but $\log 1.5 = .176$ (*position of colored vertical line on slide*), yet 1.5, 15 and 150 are all marked off at the same point. The *L* scale actually measures the fractional part ("mantissa") of the corresponding number on the *C* and *D* scales, whether or not that number has been reduced. This leads to ambiguity only in the position of the decimal point in the result of a multiplication, which is affected by adding lengths.



GEOMETRIC SEQUENCE (according to Benford, nature's way of counting) is marked off on a slide rule scale. Measurements of successive events form the sequence $A, A \times R, A \times R^2$ and so on. (R stands for ratio.) When sequence is plotted on slide rule, it is equally spaced because each new multiplication by R moves point same distance (to right if R is greater than 1 and to left if it is less).

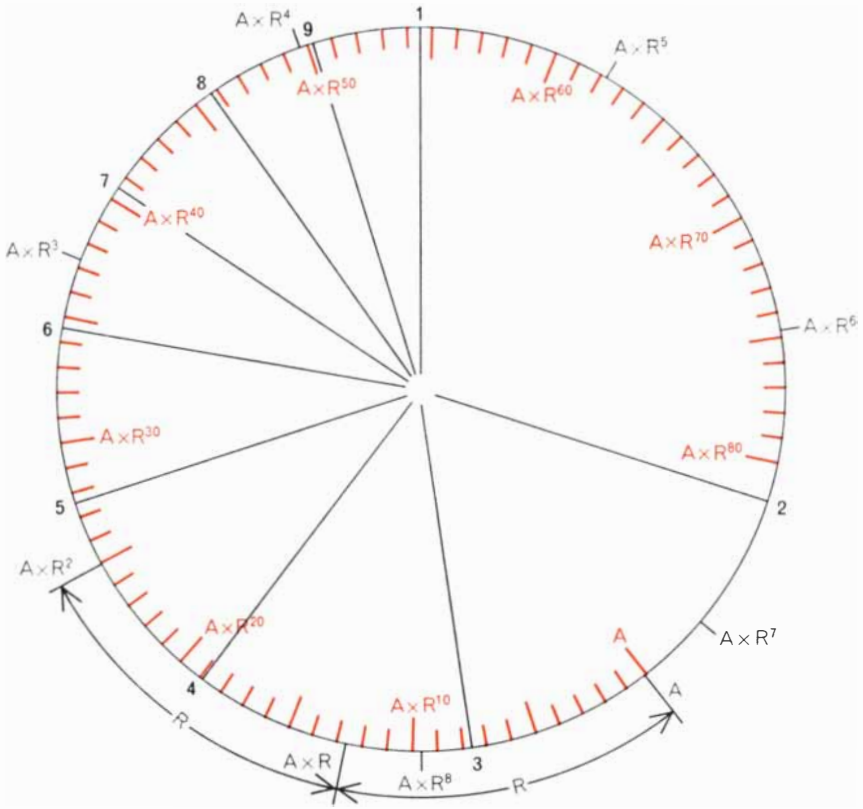
Then a shift "to the right" becomes a clockwise shift, and there is no jumping backward.

From the circular slide rule diagram it is not hard to visualize a proof of the fact that almost all geometric sequences carried far enough tend to obey Benford's law. Suppose first that R is close to 1, so that the terms A, $A \times R$, $A \times R^2$, ... are very closely spaced going around the circular rule. If enough terms are used to cover the circle just once, their equal spacing implies that the fraction of them in each major division is close to proportional to the length of that division (Benford's law). If the sequence is extended to go around one and a half times, there will be twice as many points between 3 and 4 as before but no more between 1 and 2 than before. The approximation is spoiled. If enough terms are used to go around the circle a few million times, however, the proportionality is not much disturbed by the possibility that the last revolution goes only partway.

Even so, the law is not quite proved. One of two things will happen. The pattern of points may be reentrant. This will happen if R is a rational power of 10, say $R = 10^{4/91}$. In this case the pattern will recur after 91 terms, because $A \times R^{91} = A \times (10^{4/91})^{91} = A \times 10^4$. $A \times 10^4$ is marked on the same spot as A was but four revolutions later on. Whatever approximation to the logarithm law the first 91 terms exhibit (and it can only be approximate, although it is fairly good, because there are only a finite number of terms), this approximation will never be improved by adding more terms.

On the other hand, R may not be a rational power of 10. In this case the pattern will never recur; successive points will forever filter in between the points marked on previous revolutions. It seems intuitively evident that the pattern, ultimately becoming as finely meshed as one pleases, will give ever closer approximations to Benford's law, but the proof of this is a fairly subtle theorem of number theory. Nonrecurrence of the pattern does not immediately imply that it approaches equal density in the vicinity of every point on the scale.

Yet the truth is that even when R is large, provided that R is not a rational power of 10 giving a reentrant pattern, the sequence will ultimately become as nearly equally dense as you please in all parts of the scale. From this theorem Benford's law follows for "almost all" infinite geometric sequences, the exceptions being those with ratio R equal to a rational power of 10.



CIRCULAR SLIDE RULE shows equal spacing of the geometric sequence better because sequence can continue beyond the "end" of the rule. Divisions of the rule are the radial lines in black. The other divisions are concerned with a proof that almost all geometric sequences, if carried far enough, obey Benford's law. This proof is explained in the text.

That, of course, makes plenty of exceptions. In what sense are the irrtational powers of 10 "almost all" the powers of 10? From the point of view of modern measure theory the answer is "The Lebesgue measure of the rational numbers is zero," a technical statement whose intuitive content is this: If you choose a real number at random among all real numbers, the probability that you have chosen a rational number is zero.

It is worth noticing, apart from such technicalities, that even if R is a rational power of 10, the denominator of that power is more likely to be large than small, and the resulting pattern fairly fine-meshed, even though reentrant. Thus Benford's law is approximately true even for most of the exceptional cases.

It is easy, using a desk calculator, to verify the logarithm law for some simple geometric sequences, because only the earlier digits of the successive computations need to be saved as one goes along. A desk-top digital computer is even better. The number of terms needed for the sequence 1, 2, 4, 8, 16, 32, ... to give a good result is startlingly small. Carried out to 100 terms, the distribution by first digits is 30, 17, 13, 10, 7, 7, 6, 5, 5. In this sequence $R = 2$, an irrational power of 10. When the ratio $R = 10^{1/2}$ is used instead, nothing like the logarithm law appears; the sequence $10^{1/2}$, 10, $10^{3/2}$, 10^2, ... gives a pattern of just two points recurring forever. When R is close to $10^{1/2}$, say $R = 3.16228$, the first-digit distribution in the sequence R, R^2, R^3, ... does not begin to resemble the logarithm law until millions of terms are included, but in the long run even this sequence falls into place.

If, then, nature tends to count in geometric sequences, the logarithm law is a natural consequence for first digits in tables of such measurements. The above proof, however, already tends to cast doubt on one of Benford's ideas: that the law applies only to "anomalous" numbers. What can be less "outlaw" than a rigid geometric sequence? Secondly, Benford has only shifted the burden of the problem to another ground: *Why* should nature count by geometric steps? To assume that nature does so is practically the same as announcing the first-digit law itself, since the mathematical

n	A_n	B_n
1	1	1.00
2	1/2	.75
3	1/3	.61
4	1/4	.52
5	1/5	.46
6	1/6	.41
7	1/7	.37
8	1/8	.34
9	1/9	.31
10	2/10	.30
11	3/11	.30
12	4/12	.30
13	5/13	.31
14	6/14	.32
15	7/15	.33
16	8/16	.34
17	9/17	.35
18	10/18	.36
19	11/19	.37
20	11/20	.38
21	11/21	.38
22	11/22	.39
23	11/23	.39
24	11/24	.40
25	11/25	.40
26	11/26	.40
27	11/27	.40
28	11/28	.40
29 ↓ 99	11/29 ↓ 11/99	.40 ↓ .28
100	12/100	.28
101 ↓ 199	13/101 ↓ 111/199	28 ↓ .32
200	111/200	.32
201 ↓ 999	111/201 ↓ 111/999	.33 ↓ .27
1,000	112/1,000	.27
1,001 ↓	113/1,001 ↓	.26 ↓

NUMERICAL EXPLANATION of Benford's law is suggested by a game: Choose a number from 1 to n (*first column*). Then the probability that the first digit is 1 is A_n (*second column*) and average of first n entries in middle column is B_n (*third column*).

consequences of the geometric-ratio assumption follow so swiftly and easily.

Following the publication of Benford's law a number of papers appeared that explicitly or implicitly deny that the first-digit phenomenon is a law of nature. Instead, these papers argue, it is a property of the number system itself, a property of man's manner of counting. The same law would hold in any imaginable or unimaginable universe, not just ours. Among the authors of such papers have been the physicists Wendell Furry, Henry Hurwitz and Samuel Goudsmit and the statistician Roger S. Pinkham. (I myself recently published an article on a mathematical aspect of the problem in *The American Mathematical Monthly*, and I was surprised to find that more requests for reprints came from chemists and engineers than from mathematicians.)

One of the "numerical" explanations is given by Mrs. B. J. Flehinger of IBM. The positive integers, says Mrs. Flehinger, are what we want to look at, because the position of the decimal point is irrelevant to the problem of first digits. Suppressing the decimal points and signs (plus or minus), every table ever written appears as a list of positive integers. The question can then be posed: What is the probability that a positive integer has first digit p? To simplify the discussion here, we shall concentrate on the problem when $p = 1$.

Now we have a game. Choose a number from 1 to infinity; what is the probability that its first digit is 1? It is a strange game. We are more used to games that begin "Choose a number from 1 to 15." In this game the answer is easy, under the assumption that all 15 choices are equally likely. The probability is 7/15, because 1, 10, 11, 12, 13, 14 and 15 begin with 1 and the others do not.

Suppose we play this easy game for each of the first n integers. We can make a list of the answers in the successive cases. Call them A_n [*see illustration at left*]. Thus A_7 is 7/15 as calculated above, $A_1 = 1$, $A_2 = 1/2$ and so on. These probabilities keep changing; they rise for a while (as between 10 and 19) when a string of numbers with the first digit 1 comes along; then they fall (as between 2 and 9, or 20 and 99) in a string of the other kind.

We can graph this rise and fall [*see upper illustration on opposite page*]. The horizontal scale is distorted to allow several oscillations to be shown. The maximal probabilities appear at the end of a string of "successes," at 199, 1,999 and so on, and the minimal probabilities occur when $n = 9, 99, 999, \ldots$. Except for the horizontal scale, each rise and fall very much resembles its predecessor. The successive maxima are close to 1/2, and the minima are close to 1/9.

If the graph did not continually oscillate but instead tended to level out toward a horizontal line—a limiting value—we would be justified in saying that in the long run the probability of choosing a number ("from 1 to infinity") with the first digit 1 is that limit. It is clear, however, that there is no such limit.

We can say *something*, however, according to Mrs. Flehinger. Whatever n we choose, A_n is at least 1/9 and is often much higher, up to 1/2. On the average the probability that the first digit is 1 is somewhere between 1/9 and 1/2. But where?

What Mrs. Flehinger did was to show that in a certain technical sense the average height of the graph is log 2. This is Benford's law for first digit 1. There is no obvious way to get the average height of a graph of infinite extent, unless it straightens out. You can, however, take the average height from 1 to 10, for example, and call it B_{10}, or from 1 to 100 and call it B_{100}, and so on [*see lower illustration on opposite page*]. If as n approaches infinity, B_n tends toward some limiting value, that value could well be called the average height of our graph.

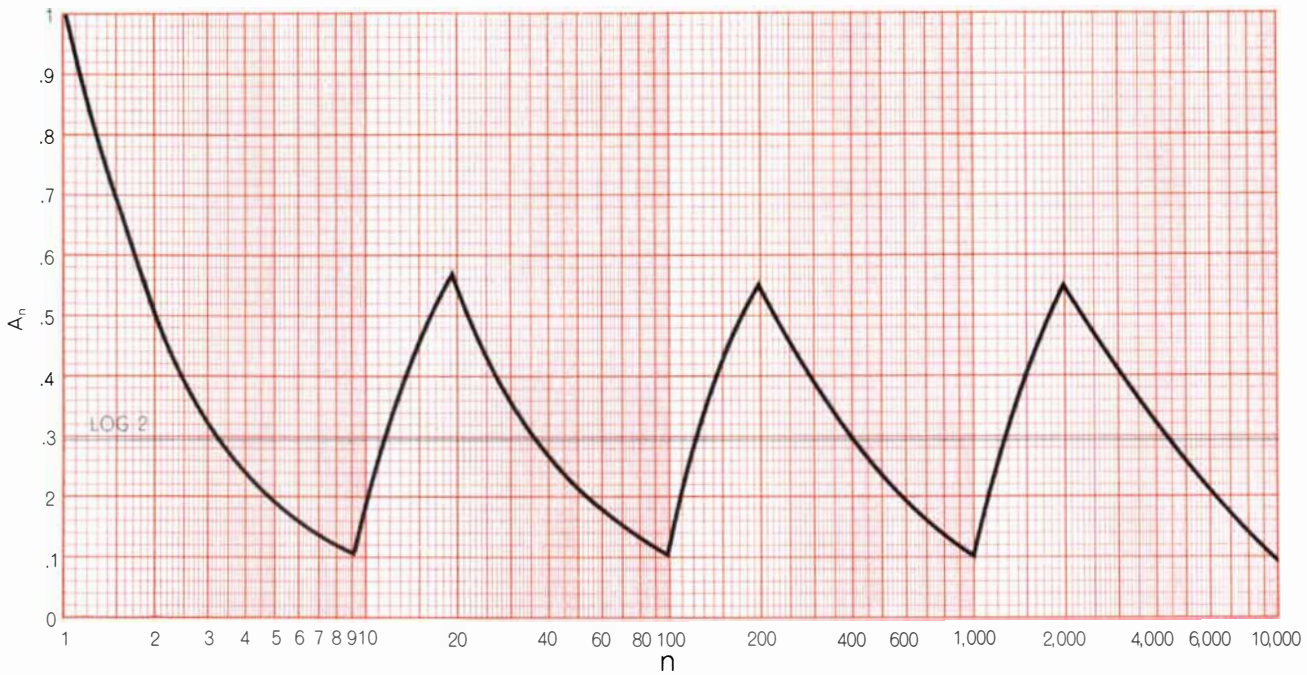
Alas, B_n also tends to oscillate indefinitely above and below the value log 2 (= .301), although the variations are smaller than in the graph for A_n. Mrs. Flehinger shows finally that if the same procedure is applied again and again, giving an infinite sequence of graphs, each one a plot of the average height from 1 to n of the preceding graph, the sequence of graphs tends (for large n) to become close to a horizontal straight line whose height is precisely log 2.

This calculation gives a rather satisfying explanation of why, out of 1,000 randomly chosen street addresses (from *American Men of Science*, say), about 301 should begin with the digit 1. Every scientist lives on some street, after all. If his street has n addresses on it all together, the probability that *his* address begins with 1 is A_n. A thousand scientists, on 1,000 streets, give rise to 1,000 probabilities A_n (various values of n, of course, since the streets have different lengths). The overall probability of first digit 1 will be something like the average of these 1,000 probabilities A_n. That means the average of 1,000 randomly chosen heights from the upper graph on the opposite page, and this in turn

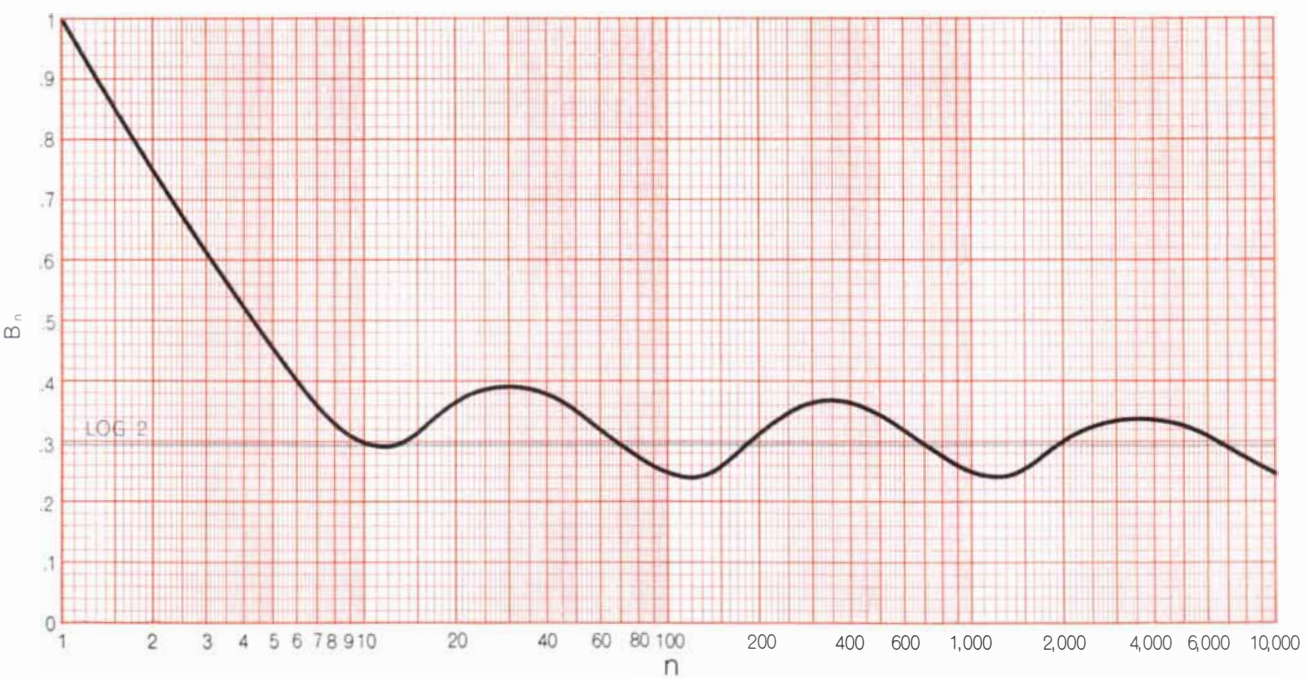
should be something like the "average height" of that graph.

Unfortunately the argument is a bit circular, because Mrs. Flehinger's method of averaging, although it is fairly natural, is by no means the only method. Mathematics knows of many summability methods (as they are called) for such graphs, and most of them do not give the answer log 2. From a logical point of view Mrs. Flehinger's choice of an averaging method amounts to a hypothesis about probabilities in the real world of scientists' houses, a hypothesis that goes beyond the bounds of an analysis of the number system alone. Benford's notion that the logarithm law is rooted in nature, not man, is not yet refuted by the Flehinger calculation.

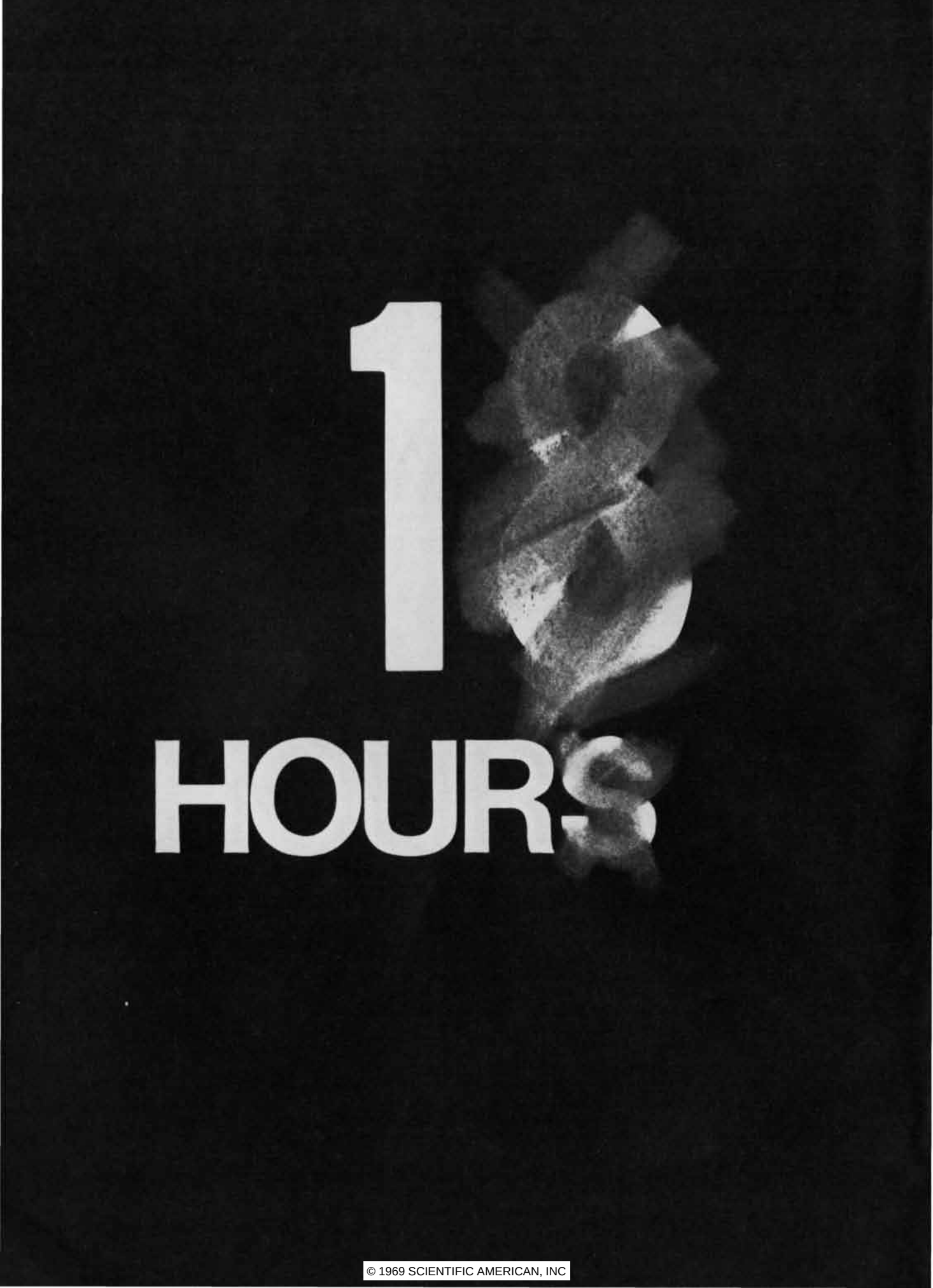
Still another mechanism has been proposed to account for Benford's law. It has to do with the obvious fact that the nature of the universe cannot depend on the choice of units of measurement used by men. Consider a table giving the surface area of 335 rivers, as Benford did. Benford's paper does not tell us whether his areas were given in acres, square miles, square meters or some other unit. The same list of rivers would produce a different numerical table for each choice of unit; should all the tables obey the logarithm law? Benford's



PROBABILITY that the first digit is 1 in the first n integers (*second column in the table on the opposite page*) is plotted in this curve. Curve rises and falls because frequency of first 1's in numbers between 1 and 20, say, is greater than that between 1 and 10.



AVERAGE of the first n probabilities (*column at right on opposite page*) is similarly plotted. The average of the probabilities up to and including A_4, for example, is $1/4\ (1 + 1/2 + 1/3 + 1/4) = .52$, that is, a fourth of the added probabilities A_1, A_2, A_3 and A_4.



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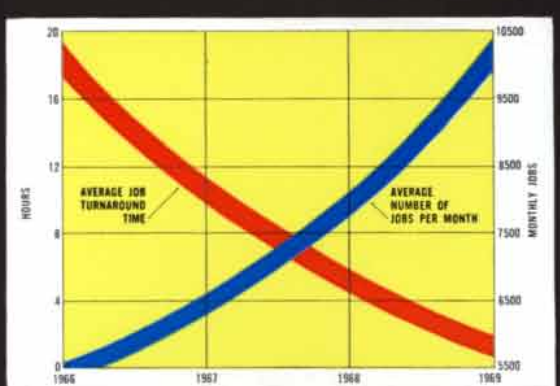

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	Original Entry	3x Entry	6x Entry	9x Entry	12x Entry
	10	30	60	90	120
	15	45	90	135	180
	20	60	120	180	240
	25	75	150	225	300
	30	90	180	270	360
	35	105	210	315	420
	40	120	240	360	480
	45	135	270	405	540
	50	150	300	450	600
	55	165	330	495	660
	60	180	360	540	720
	65	195	390	585	780
	70	210	420	630	840
	75	225	450	675	900
	80	240	480	720	960
	85	255	510	765	1,020
	90	270	540	810	1,080
	95	285	570	855	1,140
1	2	7	3	2	5
2	2	6	3	2	1
3	2	1	4	2	2
4	2	1	3	3	2
5	2	0	3	2	1
6	2	1	1	2	2
7	2	1	0	2	2
8	2	0	0	2	1
9	2	1	1	1	2

BENFORD'S LAW IS NOT OBEYED by the first column of numbers at top. In the other columns at top the numbers in the first column are scaled up by four different factors. The columns at bottom count the first digits in each of the columns above them. The fact that the first-digit counts are different indicates that the original column is not scale-invariant.

	Original Entry	3x Entry	6x Entry	9x Entry	12x Entry
	11	33	66	99	132
	12	36	72	108	144
	14	42	84	126	168
	16	48	96	144	192
	18	54	108	162	216
	19	57	114	171	228
	22	66	132	198	264
	25	75	150	225	300
	28	84	168	252	336
	33	99	198	297	396
	37	111	222	333	444
	43	129	258	387	516
	47	141	282	423	564
	55	165	330	495	660
	65	195	390	585	780
	75	225	450	675	900
	85	255	510	765	1,020
	95	285	570	855	1,140
1	6	5	6	6	6
2	3	3	3	3	3
3	2	2	2	2	3
4	2	2	1	2	1
5	1	2	2	1	2
6	1	1	1	1	1
7	1	1	1	1	1
8	1	1	1	1	0
9	1	1	1	1	1

BENFORD'S LAW IS ROUGHLY OBEYED by first column of numbers in this table. Numbers in first column are scaled up by same four factors as in table at top of page. The fact that first-digit counts are very nearly alike indicates that first column is scale-invariant.

list did. Suppose his list was given in acres. What was so special about this unit of area? Is it possible that Benford's law holds only in America and the British Commonwealth?

Roger Pinkham, although a professor at Rutgers University, rejected such ethnocentrism in favor of a kind of relativity theory. He was willing to assume that there is *some* law of first digits, indeed some distribution governing all the numbers in all the tables in this and all other worlds. That is a big assumption, but not as big as Benford's hypothesis that all these tables are made up of a lot of geometric sequences. Then, said Pinkham, let us suppose the distribution of all these numbers by first digits remains the same when we rescale all these tables by inventing some new system of units. This amounts to multiplying everything in a given table by a certain constant—the conversion factor. If the frequencies of the nine first digits stay the same, no matter what conversion factor is used, then Pinkham was able to prove mathematically that these frequencies had to be those of Benford's law. No other would do.

It is pleasant to while away an hour or two with a slide rule or desk calculator, verifying Pinkham's theorem, approximately at least. In the top illustration at the left a list of 18 equally spaced numbers is given: 10, 15, 20, 25, ..., 90, 95. It emphatically does not obey Benford's law. Each of the nine possible first digits appears twice. This list is multiplied by the conversion factors 3, 6, 9 and 12—just a sample—and the distribution of first digits is given for each of the five resulting lists. For some of the factors the distribution changes radically.

On the other hand, in the bottom illustration at the left a list of 18 numbers is given that obeys Benford's law about as closely as so short a list can. Again the scaling factors 3, 6, 9 and 12 are used, but in every case the resulting distribution of first digits is much like the original. Anyone who thinks these lists or scaling factors are rigged to produce such a contrast is invited to try his own, preferably using original lists of 100 or so well-scattered numbers rather than 18.

Pinkham's theorem, in brief, asserts that tables with scale-invariant distributions of first digits must be tables that obey Benford's law. The proof is a sophisticated argument in probability theory, and it can only be given when the theorem itself is stated in a more precise way, because *finite* tables can only

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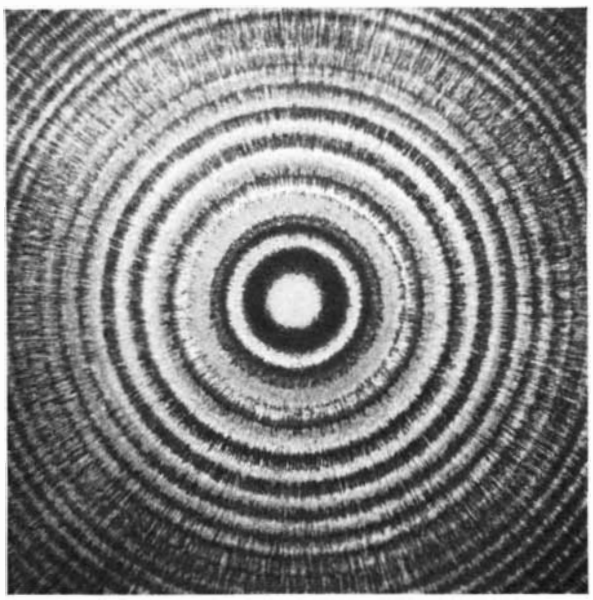

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approximately obey the law, and notions of infinity and continuity must inevitably creep into a genuine proof.

What Pinkham's theorem, as stated, leaves open is the question of whether or not there *are* any tables that are scale-invariant in their first-digit behavior. We know the answer to this one. A very long geometric sequence (usually) obeys the logarithm law. Multiplying such a sequence by a scale factor still keeps the result a geometric sequence, still therefore obeying Benford's law. Thus long geometric sequences are examples of scale-invariant tables.

The final question left open by Pinkham's theorem is the scientific one: Why should nature provide us with scale-invariant tables at all? It is conceivable to have a universe in which the tables do not obey the logarithm law, or any other law of first digits for that matter. Perhaps, in fact, there is no such law, and we have been deluded by the relatively few observations we have been able to make! If there is in fact no first-digit law, then there is no reason to invoke scale-invariance for that law, and Pinkham's entire argument goes up in a puff of mathematical formalism.

Finally, what can scale-invariance possibly have to do with the street addresses of a list of scientists? Addresses, and many other tables, are artifacts of man, not nature, and have nothing to do even with the British or metric systems.

Street addresses not only fail to fall under Pinkham's theorem, they also do not seem to have much to do with Benford's original postulation of nature's tendency to count by geometric sequences. It is possible that Benford's law applies to one class of natural phenomena whereas Mrs. Flehinger's averaging device applies to a totally different class of things, and that it is only accident that gives a logarithm law in both cases.

Thus all the explanations of the law of anomalous numbers so far given seem each to lack something of finality. Not enough is yet understood to enable us even to decide on the truth or falsity of the concluding remark in Benford's original paper: "The theory of anomalous numbers is really the theory of phenomena and events, and the *numbers* but play the poor part of lifeless symbols for living things."

A poetic thought, perhaps to be expected from a physicist such as Benford, and yet challenged by the physicist Goudsmit, who argued that it was "merely the result of our way of writing numbers." Since that time statisticians and mathematicians have also had their say, but the answer remains obscure.

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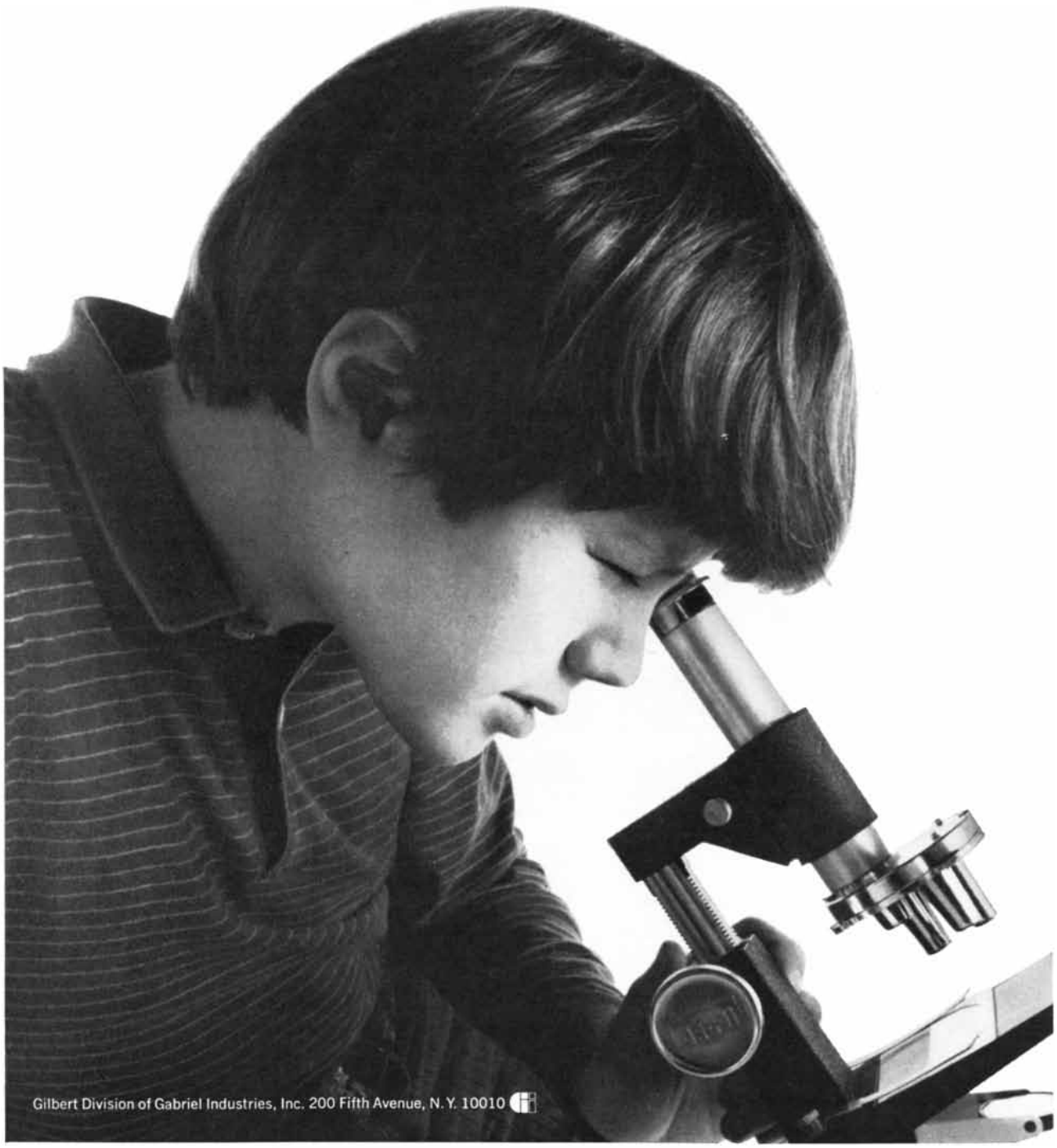

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MATHEMATICAL GAMES

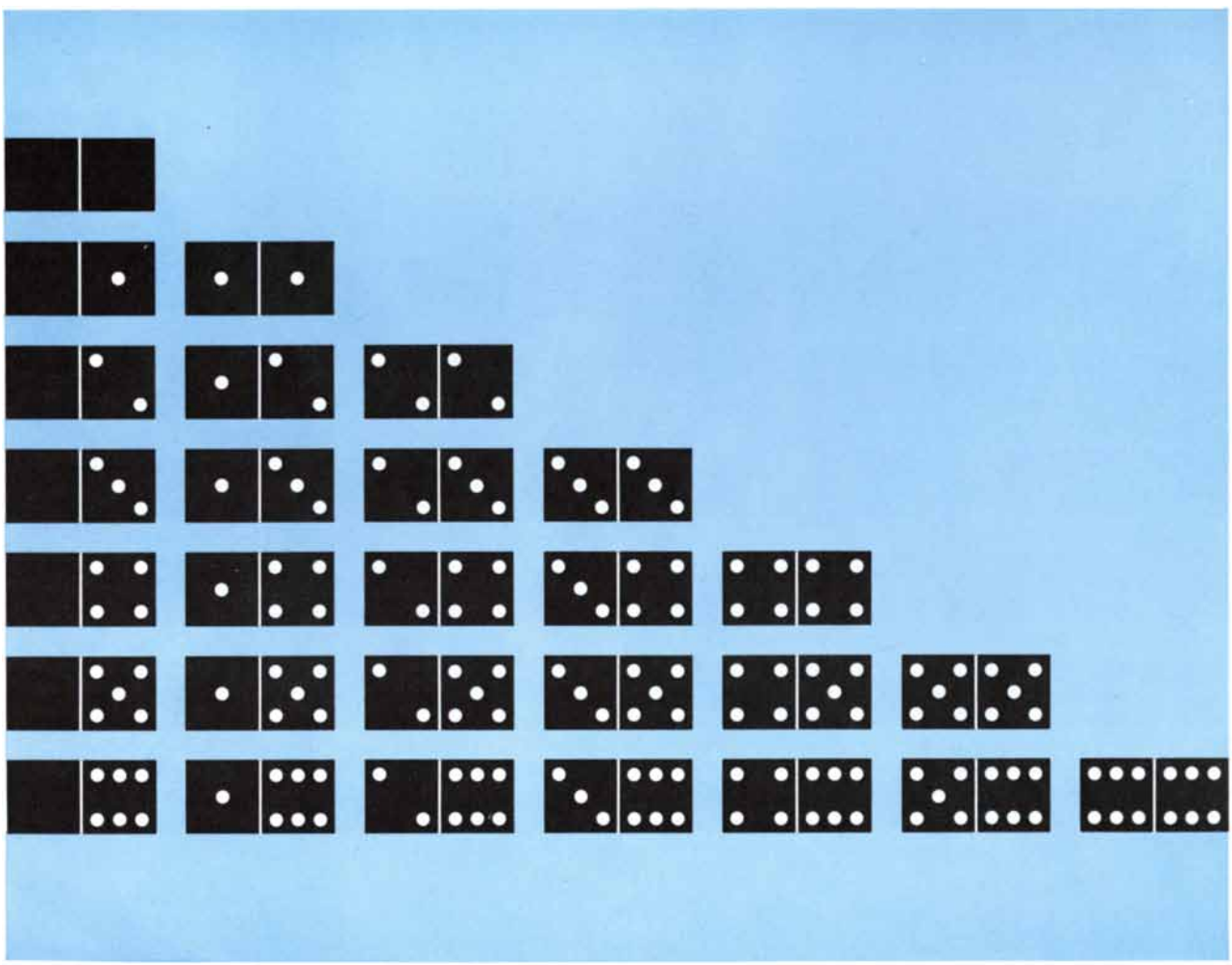
A handful of combinatorial problems based on dominoes

by Martin Gardner

Surprisingly little seems to be known about the early history of dominoes. There are no references to them in Western literature before the middle of the 18th century, when domino games were first played in Italy and France. Later they spread over Europe and to England and America. The standard Western set of dominoes has always consisted of 28 tiles that display all possible pairs of digits from 0 through 6 [*see illustration below*]. Each digit appears eight times in the set. Larger sets that run from the "doublet" 0–0 (two blank squares) to 9–9 (55 tiles in all) or to 12–12 (91 tiles) have occasionally been sold to accommodate larger numbers of players. The tiles are usually black with sunken white spots. They may have been called dominoes because of their resemblance to the black domino half-mask worn in masquerades.

No one knows whether European dominoes were invented independently or copied from the Chinese. In any case they were popular in China for centuries before they became known in Europe. Chinese dominoes, called *kwat p'ai*, have no blanks. A set includes every pair combination from 1–1 through 6–6 (21 tiles), but 11 tiles are duplicated, making 32 in all. As on Chinese dice, the ace and the 4 have red spots. All other spots are white (or black if the tiles are white) except on the 6–6, where three spots on one side of each 6 are red. (Korean dominoes are the same except that the ace is much larger than the other spots.) Each tile has a colorful Chinese name: 6–6 is "heaven," 1–1 is "earth," 5–5 is "plum flower," 6–5 is "tiger's head" and so on.

Chinese dominoes are frequently made of cardboard rather than of such material as wood, ivory and ebony and are then handled like playing cards. As in the West, many different games are played with the pieces. The most popular Western games are described in any



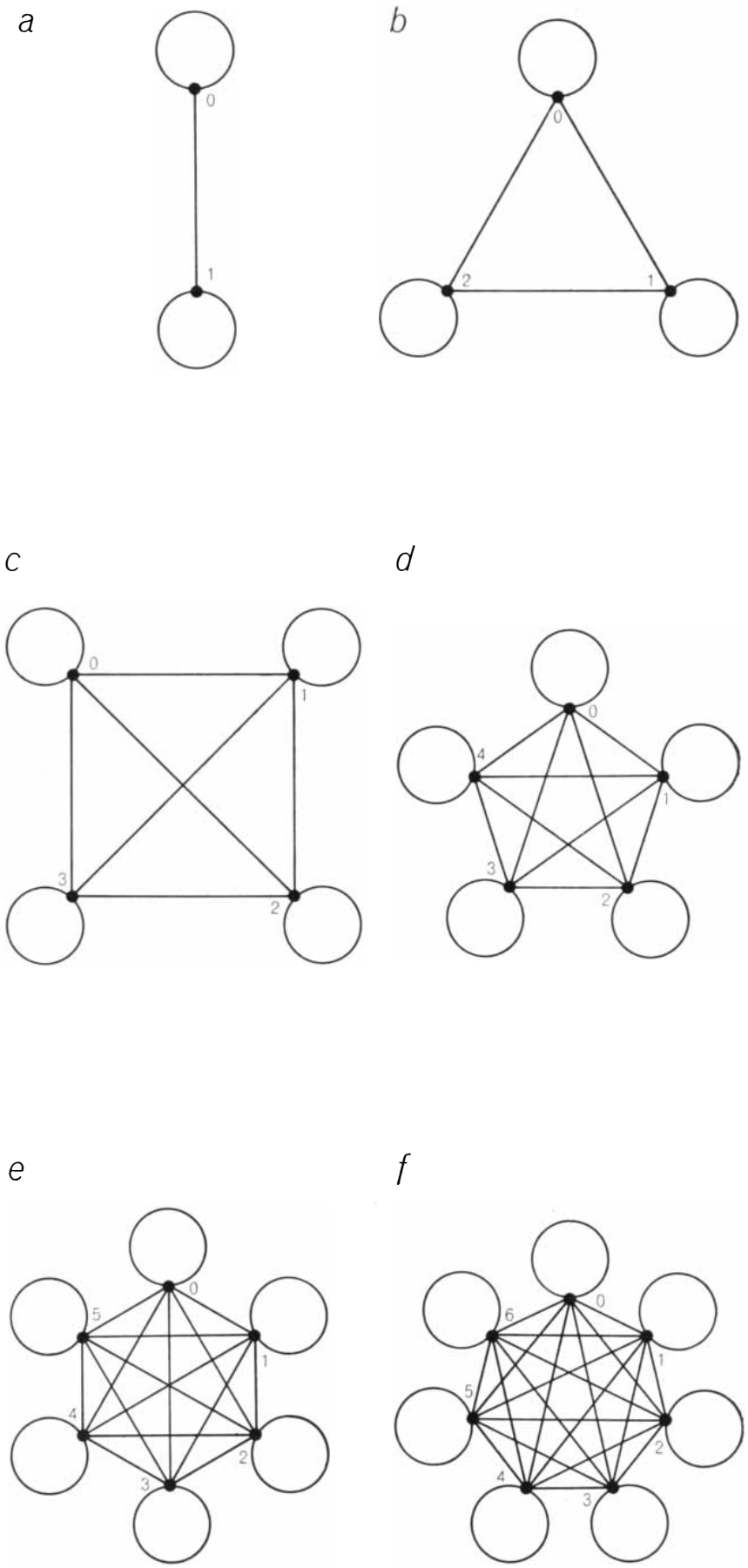
The standard set of 28 Western dominoes

modern "Hoyle." For Chinese and Korean games the best reference is Stewart Culin's *Games of the Orient,* an 1895 book reprinted by Charles Tuttle in 1958. Japan has no native dominoes but domino games are sometimes played with Western sets. (According to the *Encyclopaedia Britannica,* bone sets of 60 to 148 pieces are used by certain Eskimo tribes for frantic gambling contests in which players occasionally stake and lose their wives.)

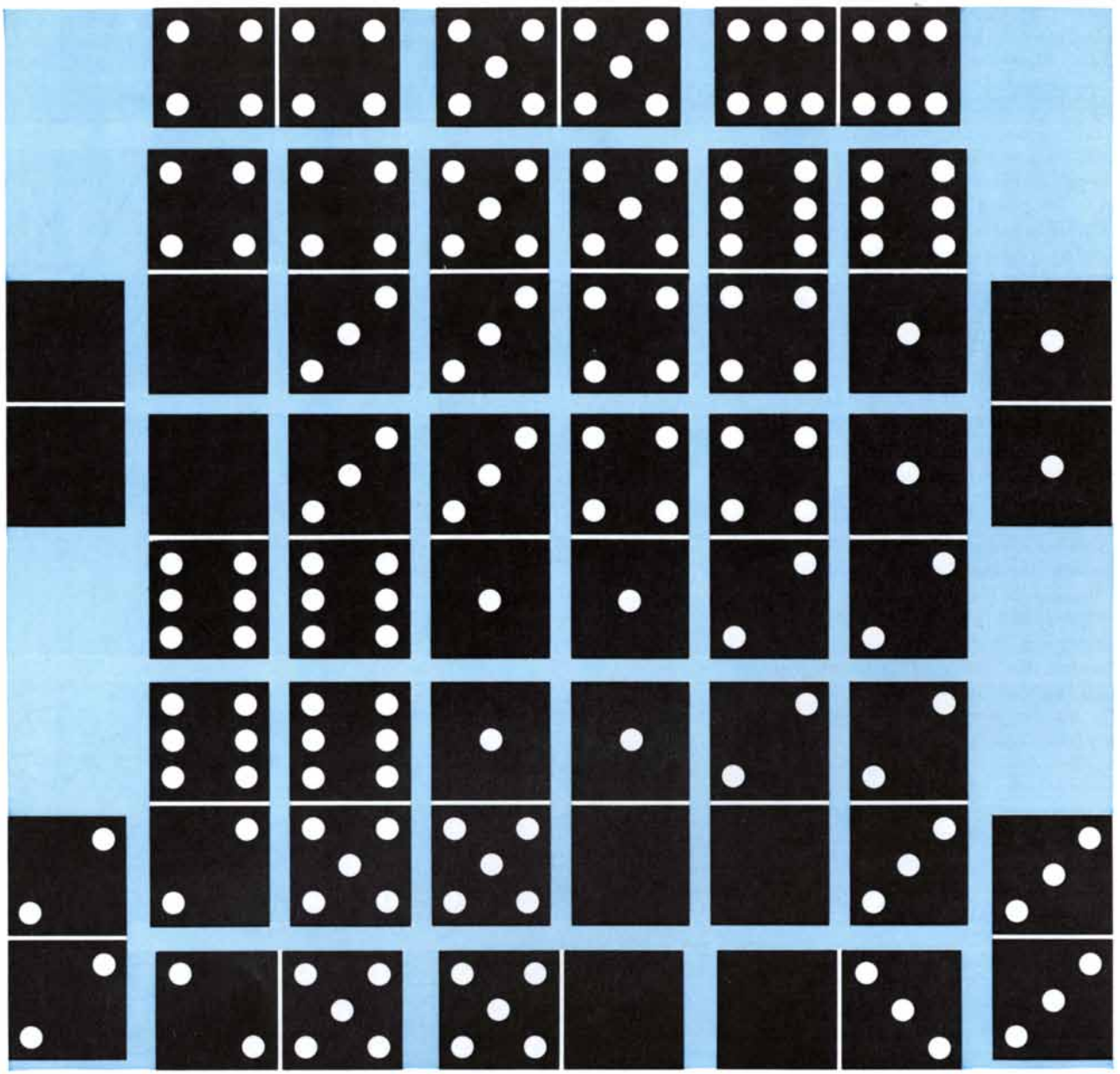
One of the oldest combinatorial problems involving dominoes is determining the number of ways in which a complete set of Western dominoes can be arranged in a straight row in accordance with the familiar playing rule that touching ends must match. (A set is complete if it contains all pairs from 0–0 through *n–n.*) The problem is interesting because it translates directly into a problem of graph-tracing [*see illustration at right*]. Ignoring the trivial set of one domino, 0–0, consider the simplest complete set: 0–0, 0–1, 1–1 [*a*]. The line from 0 to 1 corresponds to the 0–1 tile. The circles, showing that each digit is paired with itself, indicate the doublets in the set. The number of ways the three tiles can be arranged in a row is the same as the number of ways the simple graph can be traversed by a single path that does not go over any line twice. Obviously there are only two such paths, one a reverse of the other. These two (0–0, 0–1, 1–1, and its reversal) are the only two ways the tiles can be placed in a row with touching ends matching.

The problem is less trivial with the next-largest set of six tiles from 0–0 through 2–2. Its triangular graph [*b*] also has a unique path (and its reversal), but now the path must return to its starting spot. This means that the corresponding chain of dominoes is a closed ring: 0–0, 0–1, 1–1, 1–2, 2–2, 2–0. Think of the two ends as joined: 2–0, 0–0. Since the ring can be broken at six places to form a row, there are six different solutions, or 12 if reversals are counted as different.

The complete set of 10 dominoes (0–0 through 3–3) takes an unexpected turn [*c*]. All four vertexes are odd, that is, an odd number of lines meet at each. (The center crossing point of the two diagonals is not considered a vertex.) An old graph-tracing rule, first given by Leonhard Euler in his famous 1736 analysis of the problem of traversing the seven bridges of Königsberg, is that a graph can be traced by one path, without going over any line twice, if and only if all vertexes are even, or if there are exactly



Graphs for solving the row problem with complete sets of dominoes



A sample quadrille

two odd vertexes. In the first case the path is always closed, ending where it began. In the second case the path must begin at one odd vertex and end at the other. Since we have here four odd vertexes, there is no single path that will trace the entire graph and therefore no way the 10 dominoes can form a row. An equivalent impossibility proof is to note that every digit appears five times in the complete set. Because each digit must appear *within* the row an even number of times—a result of the end-matching rule—it must appear once at one end of the row. There are four digits, but a row has only two ends, and so a single row is impossible. The best we can do is to traverse the graph with two unjoined paths, which correspond to two separate rows of tiles.

The "complete graph" for five spots, with circles added to join each spot to itself, corresponds to the complete set of 15 tiles, 0–0 through 4–4 [*d*]. Since all vertexes are even, a closed path can be drawn. (As on all such graphs, crossing points inside the polygon are not vertexes.) Counting the number of such paths, each of which can be broken at 15 places to make an open chain, is a moderately complicated task. Henry Ernest Dudeney, answering this problem in his *Amusements in Mathematics* (Problem 283), points out that the pentagonal graph, aside from its circles, can be traversed in 264 ways, each of which gives a ring of dominoes. (For example, the path that starts 3024... yields the ring that starts 3–0, 0–2, 2–4, ...) The five doublets can be inserted into each ring in $2^5 = 32$ ways, making $264 \times 32 = 8{,}448$ different rings. Each ring can be broken at 15 places; therefore we multiply 8,448 by 15 to get 126,720 different row arrangements, including reversals.

The hexagonal graph for six spots [*e*] has six odd vertexes. Consequently the complete set of 21 dominoes, 0–0 through 5–5, cannot be arranged in one row. The best we can achieve is three

separate rows. The standard set of 28 dominoes, 0–0 through 6–6, has a heptagonal graph [*f*]. Note that 28 is the second perfect number (equal to the sum of its divisors). All perfect numbers are triangular (sums of successive numbers), and it takes only a glance at the illustration on page 122 to see that every triangular number is the number of tiles in a complete set. All vertexes on the heptagonal graph are even, and therefore closed paths can be drawn. It turns out that there are 7,959,229,931,520 such paths! This is the number of ways, including reversals, that the 28 dominoes can be arranged in a row. For all complete sets, with the exception of the set whose highest number is 1, a single row can be formed if and only if the highest number is even.

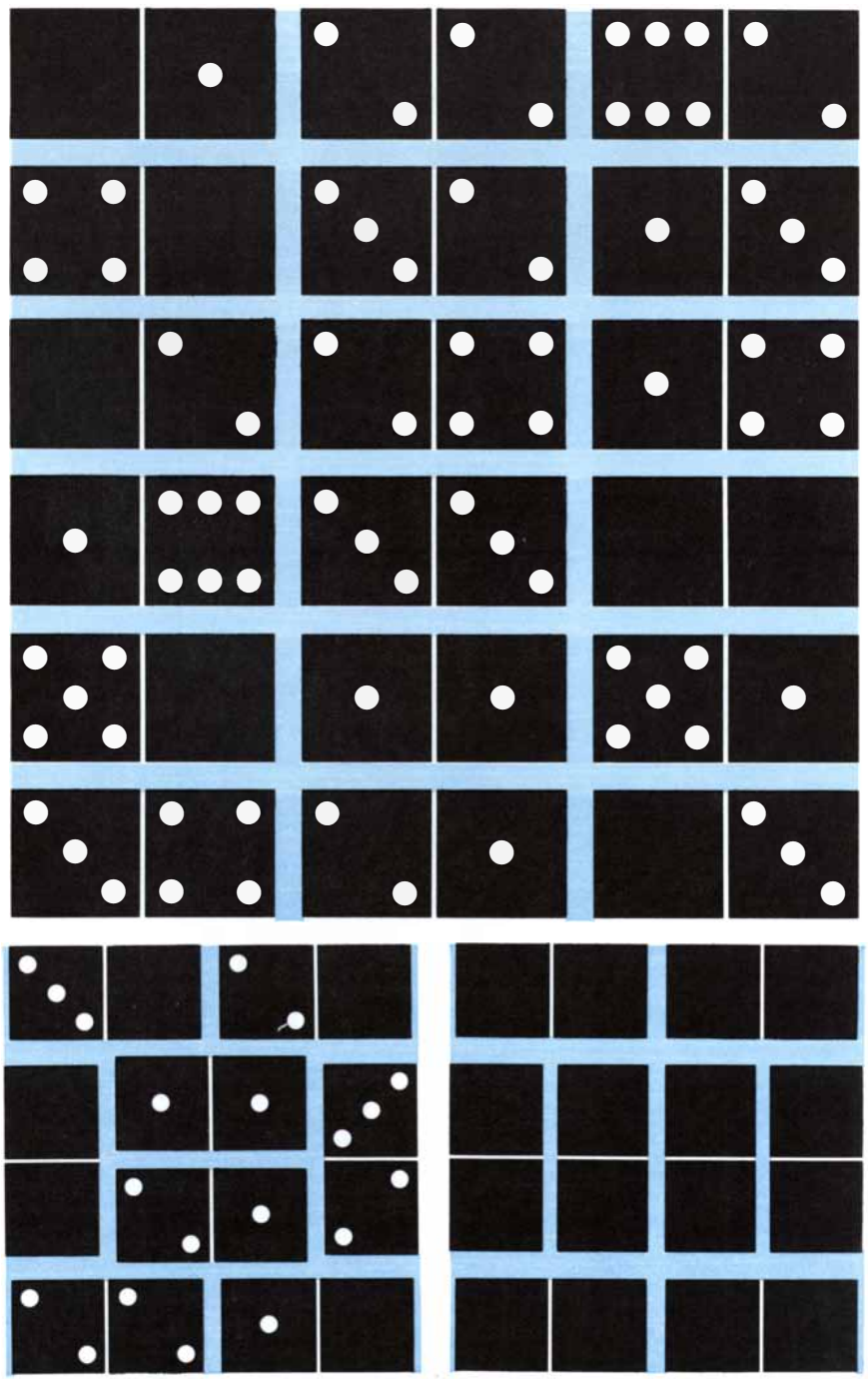
The fact that a chain of 28 dominoes must be closed is the basis of an old parlor trick. The performer secretly removes from the set any domino that is not a doublet. He leaves the room while the other players arrange all the dominoes in a single row. After this has been done the magician is able to name the two end numbers of the row without seeing the tiles. They will of course be the two numbers on the domino he removed. (If he prefers, he can predict the two numbers in advance by writing them on a piece of paper that is folded and put aside.) To repeat the trick he replaces the stolen domino in the act of shuffling the tiles and palms a different one.

Many domino problems have been proposed in which a complete set is formed into a symmetrical polygon under certain restrictions. For example, the 19th-century French mathematician Édouard Lucas, in the second volume of his *Récréations Mathématiques,* introduced what are called "quadrilles," polygons in which the standard 28 tiles are so arranged that every digit forms two sets of two-by-two squares. A quadrille from Lucas's work is shown that has a unique solution except for permutations of the digits and reflections of the entire figure [*see illustration on opposite page*]. For a recent discussion of quadrilles that gives other references see "A General Quadrille Solution," by Wade E. Philpott, in *The Mathematical Gazette* for December, 1967, pages 287–290.

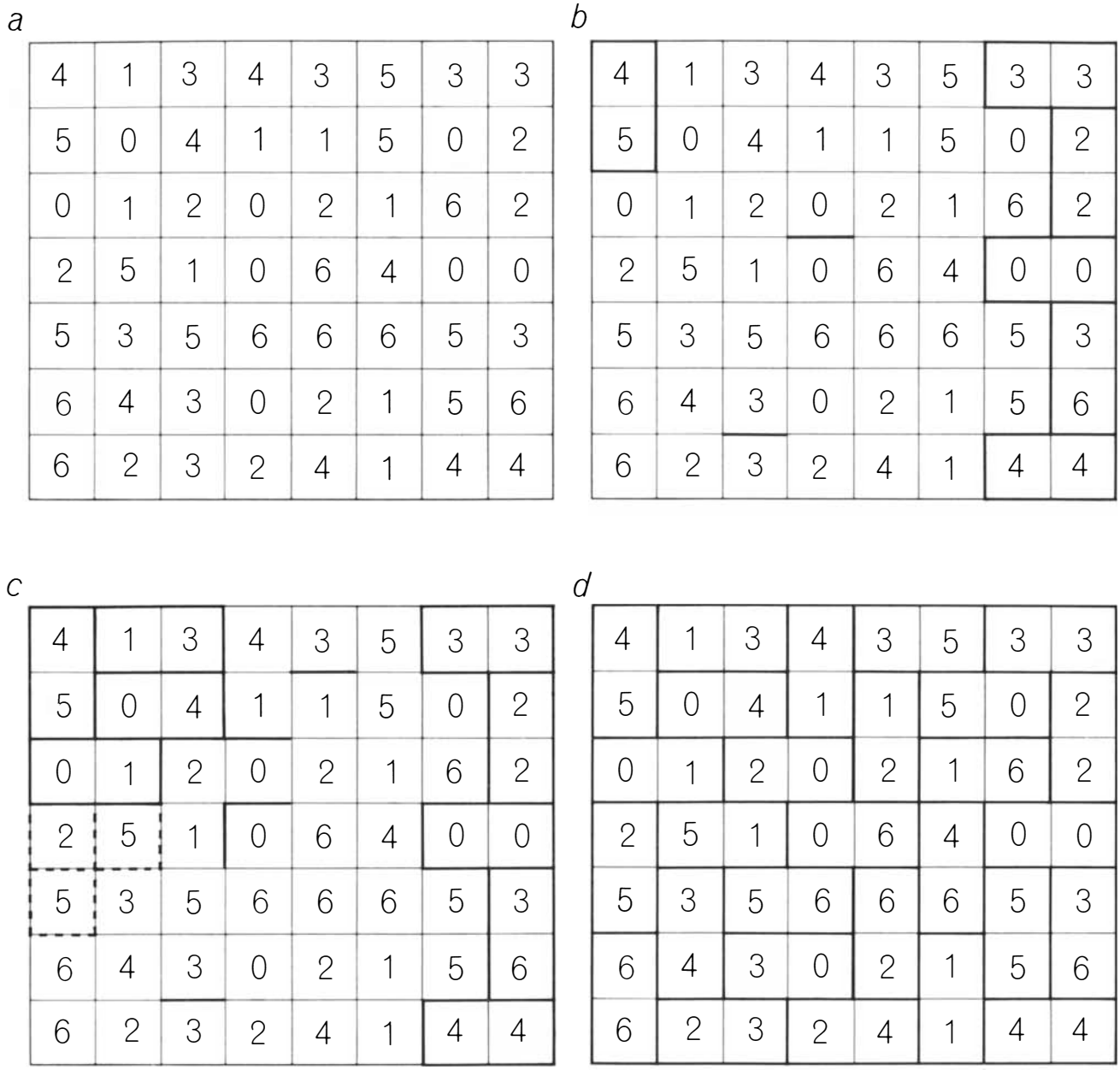
Forming magic squares with dominoes is another old recreation. A square is magic if all rows and columns and the two main diagonals have the same sum. Only squares of order 2, 4 and 6 can be made with tiles from the set of 28. (Odd-order squares contain an odd number of cells and therefore any attempt to form them with dominoes is bound to leave a hole.) A magic square of order 2 clearly is impossible; even if diagonals are disregarded, the two tiles would have to be duplicates.

An order-6 domino magic square with the lowest possible magic constant, 13 [*see square at top in illustration below*], can be changed to a square with the highest possible constant, 23, by replacing each digit with its difference from 6. The two squares are said to be "complementary" with respect to 6. To prove that 13 and 23 are minimum and maximum constants, first note that an order-6 magic square must have a total of spots that is evenly divisible by 6. Since 78 and 138 are the smallest and largest multiples of 6 that can be the sum of the spots on 18 dominoes, it follows that $78/6 = 13$ and $138/6 = 23$ are the smallest and largest possible constants.

The smallest and largest constants for an order-4 magic square formed with eight dominoes from the standard set are $20/4 = 5$ and $76/4 = 19$. If one starts



Domino magic squares



Solving a domino grid problem

with a square with a constant of 5 [*at bottom left in illustration*], replacing each digit with its difference from 6 produces a magic square with the maximum constant, 19. Order-4 domino magic squares are possible with any constant from 5 through 19. Can the reader find eight dominoes from the standard set that will fit the blank pattern [*at bottom right in illustration*] to produce a magic square that adds to 10 along all rows and columns and the two main diagonals? Two solutions will be given next month.

An intriguing puzzle game with dominoes comes to me by way of Lech Pijanowski, a film critic in Warsaw who also writes a weekly newspaper column on games of mental skill and is the author of an excellent 360-page book on board games, *Podroże W Krainie Gier* (*Journey into the Land of Games*), published this year in Warsaw. Any number can play but we shall assume that there are only two players. Each does as follows. While his opponent is out of the room he shuffles the 28 face-down tiles of a standard set and then forms them randomly into a seven-by-eight rectangle. The tiles are turned over and their digits copied on a grid without showing the domino pattern. (It is a good plan to make a second copy, showing the pattern, to prove later that such a pattern does indeed exist.) The patternless grids are exchanged and the first player to find a way of forming it with dominoes is the winner. Since many arrangements of digits on a seven-by-eight grid have more than one solution, it is not necessary to discover the original pattern—just a pattern that will produce the grid.

Given a patternless grid [*see "a" in illustration above*], how does one go about finding a solution? Pijanowski suggests first listing all 28 domino pairs, then searching the grid for pairs that can be at only one spot. In this case 4–5, 2–2, 3–6 and 4–4 must be where they are shown in *b*. To prevent holes the 0–0 and 3–3 can immediately be added. Because this prevents the 0–0 and 3–3

from appearing elsewhere, the two small bars are drawn to show that a domino cannot cross either bar.

The 2–5 tile must be either horizontal or vertical as indicated by the broken lines [*c*]. In either case 0–1 must go in the spot shown, from which 1–3 and 0–4 follow to avoid duplicating 0–1. More bars can now be added. Proceeding in this way it is not hard to find the unique solution shown in *d*.

The reader is urged to test his prowess on the slightly more difficult grid shown at the left in the illustration at the right. It too has only one solution. If successful, the reader may feel sufficiently confident to tackle the extremely difficult grid shown at the right in the illustration. The two grids were supplied by Pijanowski. The second has at least two patterns. Solutions for both grids will be given next month.

2	3	3	1	6	6	0	4
5	2	3	0	4	6	1	1
1	4	6	1	3	3	0	1
1	0	2	5	6	6	3	2
5	5	2	0	5	4	4	5
5	5	1	3	2	0	0	3
4	4	4	0	2	2	6	6

6	5	1	1	3	5	3	3
2	4	1	4	3	2	2	4
1	2	5	0	0	2	1	1
6	1	0	0	0	0	6	3
6	5	4	0	0	1	6	2
5	2	4	6	3	3	6	4
4	2	4	3	5	5	5	6

Two domino grid problems

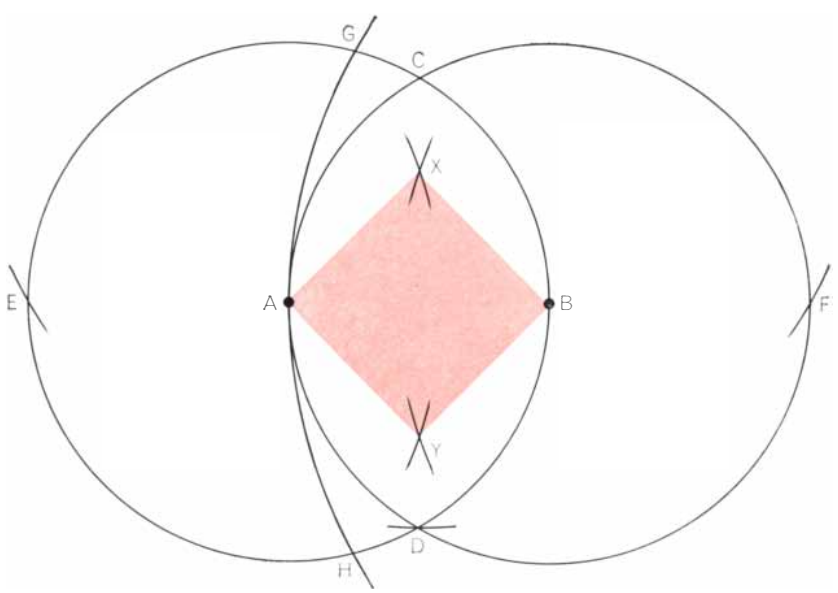
Last month's problem was to determine how a certain pattern for Sidney Sackson's induction game was ordered. The answer: Starting at the upper left-hand cell and spiraling clockwise to the center, there is first one symbol, then two symbols, then three, then four, then the same order of symbols is repeated in sets of five, six, seven and eight.

A large number of readers noticed that Mascheroni's compass-only method of constructing a point midway between two points, given in September, can be reduced by one step. Referring to the illustration on page 240 of the September issue, the distance between the intersections of the two circles clearly is equal to *CE,* therefore point *E* can be found without the intermediate step of finding point *D*. This procedure, as many readers pointed out, automatically lowers by one the number of arcs required to bisect a line segment, to find the four corners of a square inscribed in a given circle ("Napoleon's problem") and, given adjacent corners of a square, to find the other two corners.

The problem of finding the other two corners of a square when given two diagonally opposite corners—a problem answered with nine arcs in October—reduces to eight arcs by adopting the procedure just described. However, Roger D. Coleman, Charles W. Eliason, Oscar O. Kuentz, William Mathison and David Kerr, Claude Raifaizen, Royes Salmon and two 17-year-old Frenchmen working together, Michel Beigbeder and Claude Mabile, discovered a beautiful six-arc solution [*see illustration at right*]. *A* and *B* are the given corners. After drawing the two circles through these two points, open the compass to *CD* and with *C* as center draw arc *EDF*. With *F* as center and *AF* as radius, draw arc *GAH*. With *E* and *F* as centers and *EG* as radius, draw the two arcs intersecting at *X* and *Y*. It is not hard to prove that *AXBY* are the corners of the desired square. As far as I know this is the first publication of a six-arc solution to the ancient problem. If any reader knows of a prior publication, I should be pleased to have the reference.

In the July column on match recreations I erred in saying that no draw is possible in the commercial game of Twixt. Numerous readers informed me that the rules of Twixt do permit a draw, and that John F. Nash's well-known proof of a first-player-win in Hex can be extended to prove that the first player can either win or draw in Twixt if he plays rationally. The same extended proof applies to the match game of Hit-and-Run, given in July, as well as to games of ticktacktoe, in spaces of any dimension, provided that a draw is possible. If no draw is possible, as in two-by-two and three-by-three-by-three ticktacktoe, Nash's proof of first-player-win applies.

It is not hard to find a draw on the four-by-four-by-four ticktacktoe board. In 1962 Alfred W. Hales was the first to discover a drawn position on the order-4 hypercube. Nash's proof and its extension to certain types of game in which draws can occur do not provide, of course, any strategy by which the first player can either win, or win or draw, nor does it indicate the conditions under which the second player can always force a draw, as he can, for example, on the traditional three-by-three ticktacktoe board.



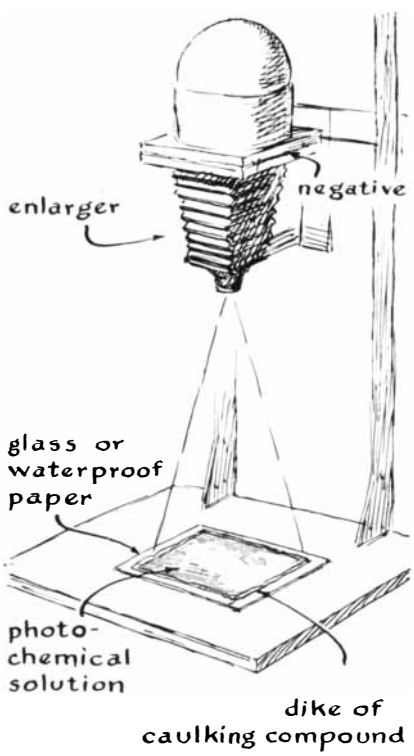
A six-arc solution to a Mascheroni problem

THE AMATEUR SCIENTIST

How to make photographs in polymer and build a sensitive pressure gauge

Conducted by C. L. Stong

To make a reinforced plastic that will last for thousands of years, soak a strip of linen in oil of lavender that contains Syrian asphalt and let the fabric dry in the sun. Light will cause chemical bonds to form between adjacent molecules of the tar, converting the sticky mass into a durable solid. The reaction would be regarded by organic chemists as an example of photocrosslinking, but to the artisans of ancient Egypt it was merely a way to make good mummy wrappings. Syrian asphalt, which is also known as bitumen of Judea, is a naturally occurring mineral tar of high molecular weight that, according to the Bible, was used for caulking both Noah's ark and the rush basket of the infant Moses.



Arrangement for exposing monomer

Other experiments can be made with the material. For example, in 1824 Joseph Nicéphore Niepce, a French physicist and amateur Egyptologist, coated a glass plate with the same mixture of oil and tar and exposed it to a brightly lighted scene with a camera obscura that he constructed according to the design of Leonardo da Vinci. When Niepce subsequently washed the plate with oil of lavender, the unexposed tar dissolved but the light-struck portions, which were photocrosslinked, adhered to the glass, forming an image of the scene. The plastic film served as a lithographic surface for greasy inks, thus yielding the first permanent photograph.

Photocrosslinking has subsequently become a highly developed branch of photochemistry, as has photopolymerization: the use of light for triggering chemical chain reactions in which the small molecules of certain liquids join end to end to form the giant molecules of solid plastic. In both phenomena light causes fluids to solidify. An innovator in the field of photopolymerization and photocrosslinking is Gerald Oster, professor of biophysics at the Mount Sinai School of Medicine of the University of the City of New York. He has recently developed several new chemical systems that demonstrate both effects. One of his systems enables the amateur to make a finished photograph of grainless texture in less than a second. Oster explains how the new materials work and describes a few of the many experiments that can be made with them:

"All plastics consist of very large molecules that are made up of smaller molecules repetitively joined together. The small units are known as monomers (*mono*, meaning one, plus *meros*, meaning part) and the large ones as polymers (many parts). Molecules consisting of two small units are called dimers and those consisting of three units trimers. Most common polymer materials, such as polyethylene and Lucite, are made by heating monomer together with a catalyst. The reaction proceeds slowly. Several hours may pass before the monomers are fully linked.

"It turns out, however, that light can trigger almost instantaneous chain reactions in certain organic fluids, with the result that the fluids solidify in less than a second. If you expose a solution of this kind to light passed through a photographic transparency, you get a three-dimensional image in plastic. You can stop the reaction at any time by turning off the light. The resulting photograph can be fixed (made insensitive to light) by washing off the unreacted monomer. The image forms during the exposure and so requires no chemical development as in ordinary photography.

"The effect is nicely demonstrated by monomer in the form of a water solution of calcium acrylate. This material is prepared by neutralizing acrylic acid with calcium hydroxide. The neutralizing procedure is a bit tricky, because heat that is liberated as the chemicals combine must be removed by controlled cooling to maintain the compound at a constant temperature. Moreover, the acid is toxic prior to its reaction with the alkali. For these reasons the amateur is advised to buy the monomer ready-made. It is available, along with other chemicals and materials that are required for the experiment, from the Edmund Scientific Co., 101 East Gloucester Pike, Barrington, N.J. 08007.

"Calcium acrylate monomer is made into polymer by a combination of both photopolymerization and photocrosslinking. In effect units of monomer, each roughly in the shape of a *T*, are fastened together to form a ladder-like structure by chemical 'nails.' The crossbars of the *T*'s are joined end to end to form the sides of the ladders. This is an example of polymerization. The rungs of the ladders—the crosslinks—are atoms of calcium.

"The 'nails' are electrons supplied by another chemical, triethanolamine, which must be mixed with the calci-

um acrylate solution. Triethanolamine is known as an electron donor, but it must be forced to make its donations. The necessary force is derived by means of a third chemical, a dye that must also be added to the solution. The dye absorbs energy in the form of light. Dyes of various colors can be used, but a convenient one for making experiments indoors is methylene blue, which absorbs red light, the color emitted most strongly by incandescent lamps.

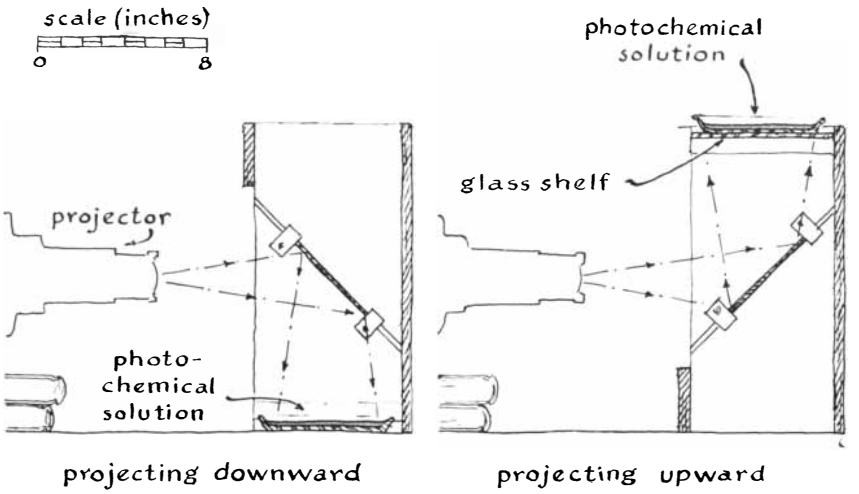
"For the initial experiment put about 20 milliliters of monomer solution in a transparent container such as a cup made of clear plastic, add two drops of triethanolamine and two drops of methylene blue and swirl the container to mix the solutions. Hold the container a few inches from an incandescent lamp. Within seconds the clear blue mixture will become cloudy on the side that faces the lamp and will change into an opaque, blue-white film attached to the wall of the container. The film is a plastic: polycalcium acrylate. It will continue to grow in thickness as the dye absorbs light; within seconds it will fill the container with solid polymer. The mass can be dissolved by adding a mild acid. The resulting fluid is a solution of polyacrylic acid.

"The reaction has several steps. When the dye acquires energy by absorbing light, it exerts an electrical force on a neighboring molecule of triethanolamine and thereby attracts an electron to itself. The dye is now in an electron-rich condition. It carries a charge, is highly reactive chemically and is called a free radical. The free radical attaches itself to a monomer and thereby makes the monomer a free radical. This free radical in turn attaches itself to a neighboring monomer. Now we have a dimer. Again, the free radical makes the dimer a free radical that reacts with still another neighboring monomer to make a trimer radical, and so on. In other words, we have a chain reaction. Similar chain reactions occur throughout the solution, but the majority of them are triggered in regions where the light is brightest. The action stops when two growing chains come together and unite.

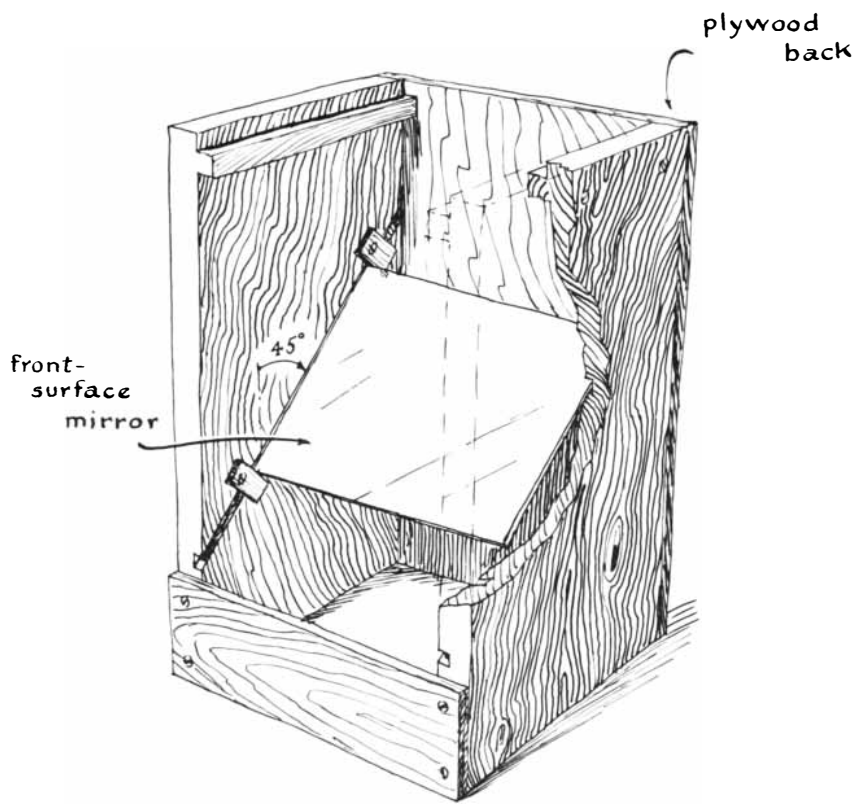
"Under appropriate conditions the dye will in time reject the electron and revert to its normal state, as can be demonstrated by experiment. Place five or 10 milliliters of triethanolamine in a test tube and to the clear fluid add a drop or two of methylene blue. Expose the mixture to an incandescent lamp or to sunlight. Within 20 seconds or so, depending on the intensity of the light, the bright blue solution will become as clear as water. Molecules of dye have now absorbed electrons; as chemists would say, the dye is reduced.

"The reduced dye can also be oxidized. Darken the test tube for a minute or two by putting it in your pocket or even in the shade. As oxygen from the air diffuses into the solution the dye loses its borrowed electron and the blue color returns. You can speed the recovery by shaking the container. The experiment can be repeated several times until the triethanolamine is exhausted.

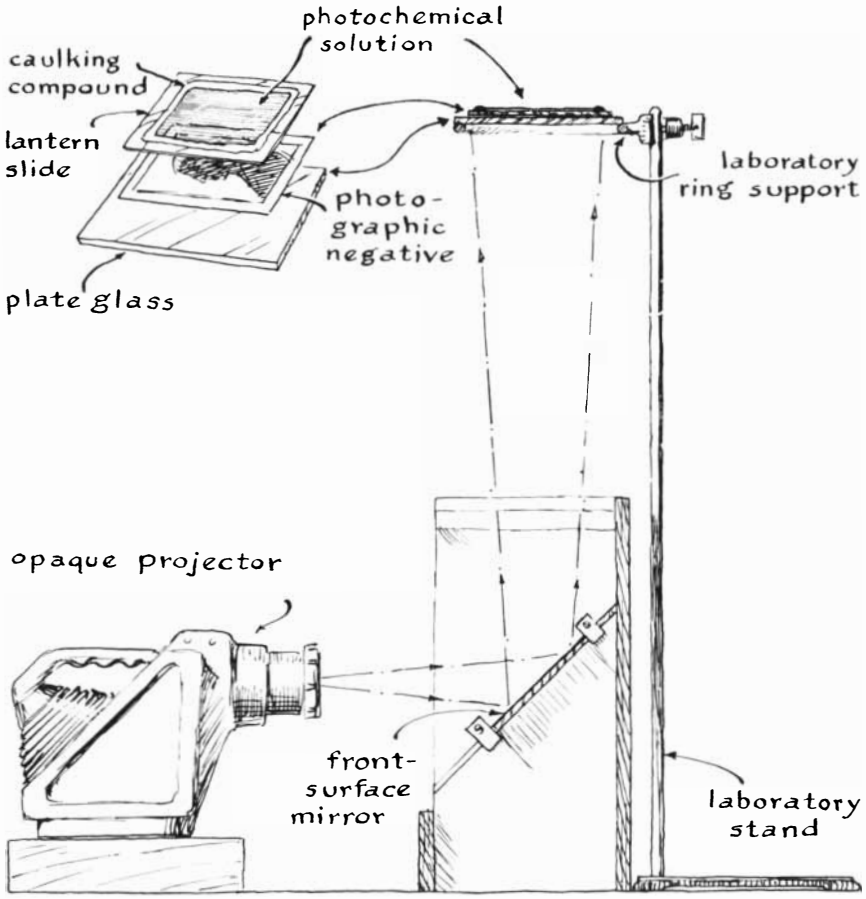
"Both original photographs and prints can be made with the monomer mixture. Prints are easier to make. Coat a glass plate with solution and project an image onto the coating. A film of plastic that varies in thickness with the intensity of the light in the image will form on and adhere to the glass. The resulting picture will appear to be either a photographic positive or a negative, depending on how



Gerald Oster's design for vertical projections made with a front-surface mirror



Fixture for supporting the mirror at an angle



Apparatus for making a contact print

you light it. For example, if you made the exposure with a negative transparency, the plastic film can be projected on a screen as a positive image. Highlights in the original scene become dark areas on the negative that shields the plastic from the light. In these areas the plastic is thin, and so it transmits projected light to the screen. Conversely, dark areas in the original scene are represented by thick areas of plastic that absorb light and result in dark areas on the screen. On the other hand, the plastic, when it is examined by reflected light against a dark background, appears to be a photographic negative. Thick regions of plastic reflect blue-white light, whereas the dark background appears through thin regions. Hence highlights in the original scene appear as shadows and vice versa.

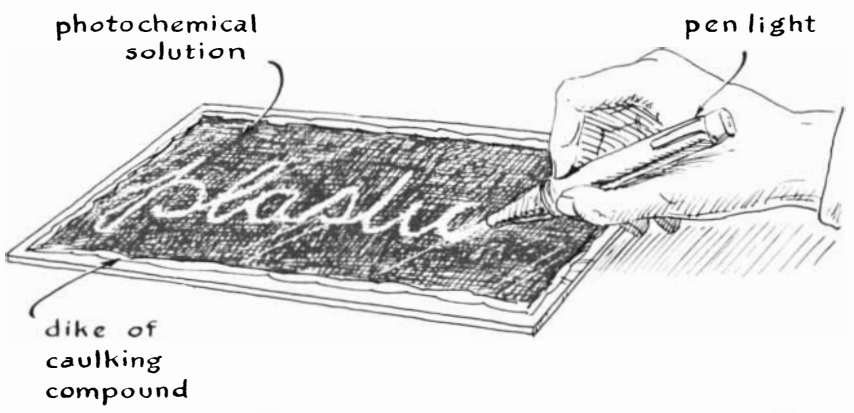
"The exposures can be made in various ways. I improvise a shallow container for holding the monomer by pressing a strip of caulking compound around the edges of a glass plate. If the glass is clean, the plastic image will adhere to the plate as a conventional photographic emulsion does.

"Before applying the caulking compound I wash the plate with a kitchen detergent, scrub the washed surface with absorbent cotton saturated with strong ammonia solution and rinse it with distilled water. After drying the glass with clean absorbent paper I apply the caulking compound. Monomer is poured onto the plate to a depth of a millimeter or two, depending on the nature of the picture. As in ordinary photography, the production of good prints is more an art than a science. The best depth of monomer to use for a given picture must be found by experiment. The results improve with practice.

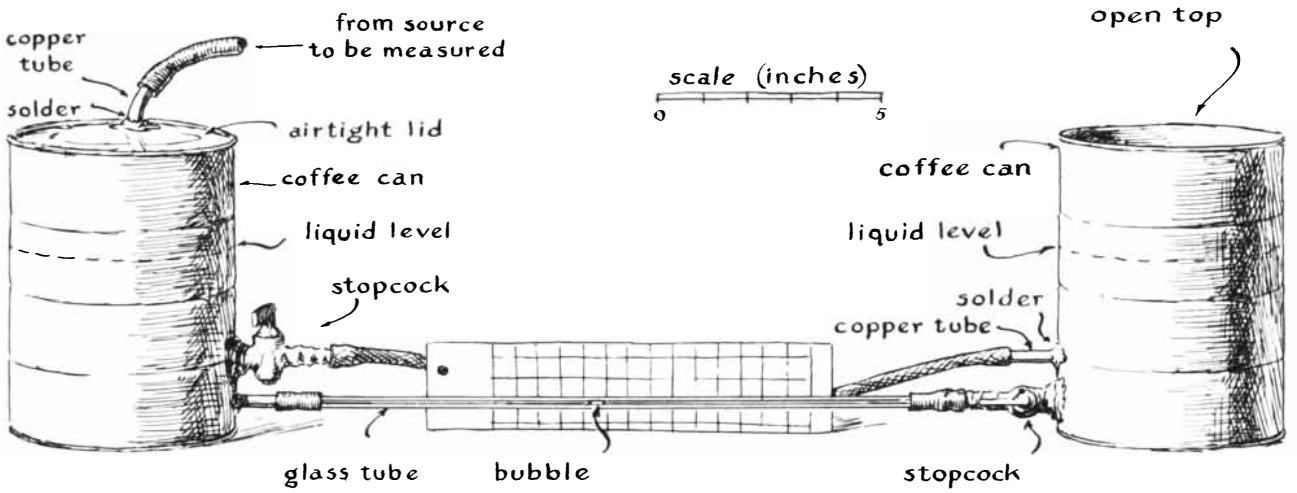
"Because the photosensitive material is a fluid, the glass plate must be kept horizontal when the exposure is made. The plate can be placed on the level base of a vertical enlarging projector, as in conventional projection printing. Polymer forms initially at the upper surface of the fluid and grows downward. It may not adhere firmly to the glass. For this reason I prefer to make exposures through the bottom of the glass by projecting the light upward with a conventional 35-millimeter projector and a mirror mounted at an angle of 45 degrees [*see top illustration on preceding page*]. An ordinary hand mirror can be used, but some light is reflected by the unsilvered front surface, which tends to cause a ghost image. Photographs of the best quality require the use of a front-surface mirror. Mirrors of this kind are available from the Edmund Scientific Co.

"Reproductions of opaque illustrations, such as printed text and halftones, can be made with an opaque projector. Light reflected by the opaque object is brought to a focus on the monomer by a projection lens. Direct prints can be made by sandwiching a negative or any other transparency between a sheet of clear glass and the plate that supports the monomer. The exposure is made through the bottom of the sandwich with projected light. Do not use a bare incandescent lamp because the scattered rays will form a fuzzy image.

"The thickness of the plastic film, and hence the density of the photographic reproduction, varies with the intensity of the light, the exposure time and the temperature of the monomer solution. The sensitivity of the solution to light depends in part on the proportions of dye and electron-donor solution. In gen-



Writing in a monomer with a penlight



Elements of the manometer designed by Kipling Adams

eral the speed of the polymerizing reaction increases, up to a point, as the proportion of dye and electron-donor solution is increased.

"For the first experiment I suggest a mixture consisting of 30 milliliters of calcium acrylate, two drops of methylene blue and four drops of triethanolamine. If this solution is exposed at room temperature by a 500-watt, 35-millimeter projector that contains a transparency of average density that is enlarged to an image approximately five inches square, polymerization will occur in the highlights within about 20 seconds, and the image will be fully developed within a minute or two. To stop the development, turn off the light. Undeveloped monomer solution can be poured into a container for reuse. I usually immerse the developed plate in a tray of distilled water in order to wash off the film of unreacted monomer, and then let the polymer dry in the air.

"The reaction can be speeded by any or all of four procedures: preexposing the monomer solution briefly to light, adding dye, adding electron-donor solution and increasing the intensity of the light. For example, you can make instant plastic by carrying out the exposure with an ordinary photographic flash lamp. Similarly, plastic will form instantly in the beam of a helium-neon laser at distances of up to 50 feet, depending on the power of the laser.

"Numerous other experiments are possible. For instance, any plastic image can be used as a printing plate. Bring the dry plastic into contact with an ink pad and transfer the adhering ink to white paper. The quality of the first print may leave something to be desired, but the prints will improve as you gain experience. Transparencies of line drawings are the easiest to reproduce with this technique.

"You can also incorporate pigments and other materials into plastic pictures. For example, moisten a tablespoon of fine, clear beach sand with monomer mixture, stir to make a thin paste, spread the paste on a glass plate and expose it to a transparency that has coarse details. After washing the polymerized material you will have a photograph in sand. The effect can be varied by substituting for the sand other substances such as powdered glass and fine beads. By polymerizing a mixture of monomer and powdered fluorescent chalk you can make pictures that glow when they are exposed to ultraviolet light. In the same way you can make a permanent record of a magnetic field by mixing iron filings with monomer, placing a horseshoe magnet against the bottom of the plate and 'freezing' the pattern with a flash of intense light.

"It is easy to prove that the mixture discussed so far responds only to red light. Cover several areas of the monomer with gelatin color filters of various hues and make the exposure through the filters. You might use red, yellow and blue filters. Polymer will appear only in the region that is exposed to light through the red filter. By the same token exposures made with color transparencies respond only to shades of red.

"Other colors can be reproduced by substituting appropriate dyes for methylene blue. For example, the monomer mixture can be made sensitive to blue by using acridine yellow and sensitive to green by substituting rose bengal for methylene blue. Rose bengal, a red dye, is a derivative of fluorescein. A print in full color can be made as a composite of three plastic films, each exposed for one of the primary colors, by means of a negative color transparency. The negative is essential because methylene blue responds to red, acridine yellow to blue and rose bengal to green—the reverse of the colors in the negative. These dyes are commonly used for staining biological materials and can be bought from distributors of chemical supplies, such as the Fisher Scientific Company, 52 Fadem Road, Springfield, N.J. 07081.

"Even better photographic reproductions can be made in transparent plastic by means of another chemical system that demonstrates photopolymerization. The photographic resolution that can be achieved with this system is limited principally by the wave nature of light and the quality of the optical system used for making the exposure. The monomer is acrylamide, a solid organic material that dissolves in water at room temperature in the proportion of about one part monomer to four parts water plus 1 percent or less of the crosslinking methylene bis acrylamide. The solution is clear and becomes sensitive to light by the addition of a small percentage of a dye, such as riboflavin. This particular dye functions both as the light absorber and as the electron donor. The polymer forms an essentially grainless, three-dimensional image that does not scatter light. After the unreacted monomer has been washed away the image has the form of a transparent plastic film. The thickness of the film varies roughly in proportion to the square root of the intensity of the light. In effect the polymer becomes a device for converting the intensity modulation of light into optical phase modulation with obvious applicability to the

production of holograms. The monomers are about as toxic as ordinary photographic chemicals, and the same precautions should be observed when working with them."

Modifications in the physical properties of many substances, including the polymerization of plastics, are accompanied either by changes in vapor pressure or by changes in volume, which can be transformed into variations in pressure by enclosing the substance in a sealed container. Substantial changes in pressure can be measured fairly accurately by a simple manometer: a *U*-shaped tube of glass containing a fluid of known density, such as water.

One arm of the tube is connected to the vessel containing gas under unknown pressure. If the gas pressure is higher than atmospheric pressure, fluid moves downward in that arm and upward in the other arm. The pressure is equal to the difference in the height of the fluid in the arms multiplied by the specific weight of the fluid. The height can be measured with reasonable accuracy to within .5 millimeter. In the case of water .5 millimeter is equal to .0014 pound per square inch.

By a simple modification of the manometer the sensitivity of the instrument can be increased by a factor of several thousand. Details of the modification are explained by Kipling Adams, who is associated with the General Radio Company in West Concord, Mass. Adams writes:

"The sensitive manometer consists of two cylindrical containers interconnected near the bottom by a pair of tubes. One of them is a capillary made of glass or clear plastic and therefore transparent. Each tube contains a stopcock. The assembly is filled with fluid. The movement of the fluid is indicated by a bubble of air trapped in the middle of the capillary.

"One cylinder is closed at the top by a gastight lid containing a pipe nipple through which the manometer is connected to the source of unknown pressure. The top of the second cylinder is exposed to the air in the room [*see illustration on preceding page*]. The principle of the device is as simple as its construction. A difference in pressure that acts on the surface of fluid in the containers causes fluid to flow through the capillary toward the container of lesser pressure, as is indicated by the movement of the bubble.

"The dimensions are not critical, but they must be known as accurately as

possible for calibrating the instrument. For instance, assume that the cylindrical containers have a diameter of five inches and that the capillary has a bore of .05 inch. If we now apply a pressure of 36 millionths of a pound per square inch to the surface of the water in the closed container, the water level will fall .005 inch and will flow through the transparent tube until the level rises an equal amount in the opposite container. (A cubic inch of water weighs about .036 pound.) The ratio of the cross-sectional area of the cylindrical containers in this example is 10,000 times the cross-sectional area of the bore of the capillary. The bubble will therefore move five inches toward the left. Hence a bubble displacement of 1/8 inch indicates a change in pressure of a millionth of a pound per square inch.

"A practical device can be made with a pair of coffee cans, two brass stopcocks, some rubber tubing and the capillary. Glass tubes with a bore of from .01 inch to several inches are available from distributors of scientific supplies. Assemble the apparatus as indicated in the accompanying illustration. Place it in operation by closing the stopcock connected to the glass tube and opening the other stopcock. Fill the cans about three-quarters full of water. When the levels have equalized, close that stopcock and open the other one. With a medicine dropper add a few drops to one reservoir until water pushes most of the air out of the glass tube. A few drops added to the second reservoir will bring the air bubble back to the center of the tube. If the reservoirs are five inches in diameter, each drop will move the bubble about 1.5 inches in a tube with a bore of .05 inch.

"The multiplying factor of 10,000 may prove to be too large for some measurements and the pressure range too small. A reduction factor of, say, 100 may be required. You can make this reduction in sensitivity by shrinking the effective diameter of the open reservoir from five inches to .5 inch. Reducing the diameter this substantially is not as difficult as it might seem. You can accomplish it by putting a nonfloating cylinder 4.741 inches in diameter in the open reservoir. This 'dividing' plug does not need to be placed concentrically in the reservoir. It will work in any position, provided that it does not block the outlet tubes and provided also that the level of the water in the reservoir does not reach the top or bottom of the plug.

"The instrument can also be used as a highly sensitive tilt indicator. The 10,000-to-1 sensitivity figure applies to the liquid levels, so that raising one reservoir from the balance position 10 millionths of an inch displaces the bubble almost 1/16 inch. To demonstrate the sensitivity of the device, place a piece of wood two feet long and two by four inches in cross section on supports two feet apart. Stand one reservoir on the center of the board and the other reservoir above one of the supports. The weight of a finger placed on the board near the center will cause the wood to bow downward about .0001 inch and will displace the bubble .5 inch!"

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A NEW YEAR GREETING

by W. H. Auden

(for Vassily Yanowsky)

EDITOR'S NOTE

The following verses were written after the poet had read "Life on the Human Skin," by Mary J. Marples (SCIENTIFIC AMERICAN, January, 1969). They were intended as a new year greeting for 1969, but it seems appropriate to present them on the eve of 1970.

On this day tradition allots
To taking stock of our lives,
My greetings to all of you, Yeasts,
Bacteria, Viruses,
Aerobics and Anaerobics:
A Very Happy New Year
To all for whom my ectoderm
Is as Middle-Earth to me.

For creatures your size I offer
A free choice of habitat,
So settle yourselves in the zone
That suits you best, in the pools
Of my pores or the tropical
Forests of armpit and crotch,
In the deserts of my forearms
Or the cool woods of my scalp.

Build colonies: I will supply
Adequate warmth and moisture,
The sebum and lipids you need,
On condition you never
Do me annoy with your presence
But behave as good guests should,
Not rioting into acne
Or athlete's foot or a boil.

Does my inner weather affect
The surfaces where you live,
Do unpredictable changes
Record my rocketing plunge
From fairs when the mind is in tift
And relevant thoughts occur
To fouls when nothing will happen
And no one calls and it rains?

I should like to think that I make
A not impossible world,
But an Eden it will not be:
My games, my purposive acts,
May become catastrophes there.
If you were religious folk,
How would your dramas justify
Unmerited suffering?

By what myths would your priests account
For the hurricanes that come
Twice every twenty-four hours
Each time I dress or undress,
When, clinging to keratin rafts,
Whole cities are swept away
To perish in space, or the Flood
That scalds to death when I bathe?

Then, sooner or later, will dawn
The Day of Apocalypse,
When my mantle suddenly turns
Too cold, too rancid for you,
Appetizing to predators
Of a fiercer sort, and I
Am stripped of excuse and nimbus,
A Past, subject to Judgment.

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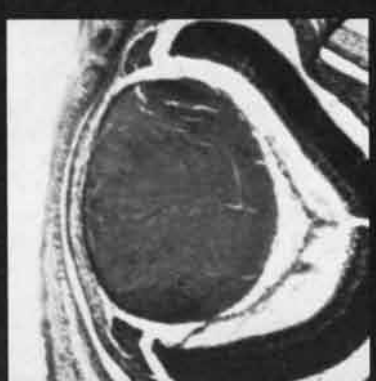

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BOOKS

Children's books about science: an annual Christmas selection

by Philip and Phylis Morrison

It occurs to us, in reflecting on our choices in this annual survey of books about science for younger readers, that children's books are where you find them. Quite a few of the books we have selected were not intended by their authors for the special audience of children at all. That is as it should be. Moreover, we believe that all but a few of these excellent books written for children will properly appeal to the general reader, particularly one who seeks an introduction to some specialized topic.

Men in the Past

BEFORE YOU CAME THIS WAY, by Byrd Baylor. Illustrated by Tom Bahti. E. P. Dutton & Co., Inc. ($4.75). Many children are tightly bound by a kind of anxiety to the culture into which they are slowly growing. Their familiar surroundings seem to them necessary, almost inevitable, whatever they are. Small American travelers are apt to demand querulously their favorite can when a fragrant bowl of real French soup steams on the table before them. Shown the Eskimo's ingenuity or high Greek art, they feel mainly pity for the absence of television or of blue jeans and zippers. It is hard to give them any appreciation of the long ago. This brief jewel of a book meets the problem in a couple of dozen poetic sentences. The words are placed on pages that reproduce simple pictographic images done on rough bark paper of warm tone. It is not only the arts of brush and word that in this book evoke the sense of the past; it is above all the precision with which the authors have understood the unvoiced question with which children approach such novelty.

"You walk down this canyon, this place of high red cliffs and turning winds and hawks that float in a far white sky and you wonder: 'Am I the first one ever to come this way?' " So the text begins, and soon, by the mastery that is the poet's and artist's alone, the book braids the reader into the long chain of human life. The explicit inspiration for the work is the American Southwest, but its impact is universal and intense.

AMERICAN ODYSSEY: THE JOURNEY OF LEWIS AND CLARK. Ingvard Henry Eide, editor and photographer. Rand McNally & Company ($14.95). Across nearly 60,000 miles this dedicated man followed the route of the young officers who carried the writ of Thomas Jefferson from the Middle Western settlements to Puget Sound. His 260 photographs in black and white give his book its somber enchantment. Selections from Lewis and Clark's frank day-by-day original journals supply the bulk of the text, and the accompanying photograph usually shows the very spot at the very season when the old expedition traveled by. Here and there we see men who look like the men they encountered when the land was the Indians'; we see mule, elk, morel; we see the long views, the still rivers, the snowy peaks, the great shiprocks in the lonely steppe of the Palouse. The novelist A. B. Guthrie, Jr., writes an introduction, commenting on the photographs: "It hardly matters that we have not seen their like before; it matters that we may not see their like again." But the land still remains, although the big dams have flooded some of it and cities and freeways hide some more; these pictures show nothing one could not have seen in 1805. The people have changed, but the look backward is not sentimental. "The Indian Nations west of the Rocky Mountains . . . amount by our estimate to 69,000 souls." The cruel future was implied even in that peaceable journey: "I saw [tattooed] on the left arm of a Squar the following letters *J. Bowman*."

Like all real explorers' material, the text is not innocent but is taken up here and there with terminal matters of death and love. Lewis and Clark spell with confident unconcern, and even President Jefferson employed the form "knolege"! Spelling is provably the skill not of the writer's trade but of the editor's.

THE QUEST FOR ARTHUR'S BRITAIN, edited by Geoffrey Ashe. Frederick A. Praeger, Publishers ($12.50). Arthur was king of a land where history, archaeology, folklore and literature meet. Was the many-layered ruin at Cadbury, south of Bristol, ever the hall of Camelot? The Round Table lives on in Disney, on Broadway and with T. H. White. Here is a fascinating and beautifully illustrated account of Arthur seen from many points of view. The myth is plainly myth, powerful with its implications as old as Stonehenge and as deep as man's desires. Now, however, we dig up fifth-century Christian Celtic hilltops held against the Saxons. No high-battlemented anachronisms, those places might yet be the authentic relics of the Arthur who was once—and shall be?—king. It is at present compelling to agree with Ashe's conclusion: Neither the skeptical literary scholars nor the romantic believers are correct, but fact lies closer to fancy than it does to that kind of scholarship which, willing to rest content with bookish evidence, decries excavation. Jewels and costume, wall and weapon and map and hilltop beacon are here attractively shown in plenty. This is not a book aimed at children, but it will become for many of them a resource and a stronghold worth the taking.

WHEN THE STONES WERE SOFT: EAST AFRICAN FIRESIDE TALES, by Eleanor B. Heady. Illustrations by Tom Feelings. Funk & Wagnalls ($3.95). Written in a cadenced prose, as they might be told by grandmother Semamingi, the best storyteller in a little village somewhere in the Rift Valley, these are 16 tales of origins and reasons: how we have the rainbow, why the baobab tree grows so strangely, and much more. The dog lives with men because he sought sponsorship one after another from the hartebeest, the elephant and the lion, each of whom in turn showed fear of man, the strongest of creatures. The cat learned even

more acutely who was feared, so the cat lives with women. (This slightly cynical tone is not borne out by the gentle, pretty housewife drawn smiling among her baskets at her house cat.) Swahili phrases add to the convincingly authentic quality of these stories.

ONE HUNDRED FAVORITE FOLKTALES, chosen by Stith Thompson. Drawings by Franz Altschuler. Indiana University Press ($12.50). Once upon a time there were ugly trolls and lovely careless princesses and generous white bears and magic whistles. The best-known of American scholars of folklore has picked 100 European tales; here they are, the unusual and the familiar, all of them substantial in that curious compact richness of the much-told tale. They stem from a dozen countries and tongues; Professor Thompson adds a tantalizingly brief remark about the distribution of each type of tale illustrated. It is delight in narrative that has kept these tales alive at least since the Bronze Age; that delight lives on here in print.

Biology in General

WINDOW INTO AN EGG: SEEING LIFE BEGIN, by Geraldine Lux Flanagan. William R. Scott, Inc. ($5.95). Hello, chick! The first photograph in this book shows the hero chick, bedraggled, tired, beaky, pushing apart the cracked halves of his eggshell prison. How the three weeks before that were spent in the subtle and spectacular quickening of the egg into chick life: the beating heart, the ripening of the eye, the blood-vessel roots drawing sustenance from the endowment of the yolk—all this is described with humor and accuracy in the text and is documented by photographs (principally at natural size or in slight close-up by two expert photographers, whose pictures are supplemented by embryological studies at higher magnification). It is drama beautifully told and simply written, for grade school readers. It is not merely avian embryology, either: the chick's birth drama is by implication our own. The role of fertilization is made explicit for rooster and hen, and is clearly implied for the birth of every reader. By making real and wonderful, yet not magical, the process of ontogeny, this book will mark out a quiet and clear path to self-knowledge for many a boy and girl. In both the objective and the subjective sense the author and her photographers and her biologist aides (and her son John, "expert adviser... on the child's point of view") have made a book of lasting excellence. "In about half a year this chick may itself become a parent. Good-bye, chick."

OUR NATURAL WORLD: THE LAND AND WILDLIFE OF AMERICA AS SEEN AND DESCRIBED BY WRITERS SINCE THE COUNTRY'S DISCOVERY, compiled and edited with comments by Hal Borland. With drawings by Rachel S. Horne. J. B. Lippincott Company ($10). Eighty-five excerpts, averaging some 10 pages, from writers on the land and the wildlife of our country are made into one attractive and compact volume. The pieces range from the journal of Don Juan de Oñate (written in 1601) through Davy Crockett, Mark Twain, Henry Thoreau and John Wesley Powell to Rachel Carson and the work of many living naturalists. Six poignant pages from *Harper's* of a century ago, which present the main source for the legend of Johnny Appleseed, are a high point of the selections.

DONALD AND THE ..., by Peter F. Neumeyer. Drawings by Edward Gorey. The Addison-Wesley Publishing Company, Inc. ($2.95). In the meticulous ink sketches and hand lettering of this well-known artist is told the tale of Donald, a boy who loved animals. Once he found a white worm in the garbage can, where he went with his mother, a wise lady who wore ostrich plumes and carried now a parasol, then a croquet mallet. She let him bring the pet home to his room. The rest is metamorphosis.

HIDDEN ANIMALS, by Millicent E. Selsam. Harper & Row, Publishers ($2.50). A revision of a first edition of 1947, this book does much to show why the author has such an excellent reputation as a writer of science books for young readers. The inchworm and the walking stick are all but entirely hidden in the photographs where they first appear; photographs with the animals darker than their environment provide the key overleaf. Many more cases of natural camouflage are exhibited delightfully and are discussed in a simple, sensible text.

Specific Forms of Life

SIX-LEGGED SCIENCE, by Brian Hocking. Schenkman Publishing Co., Inc. ($4.95). PLEASURE FROM INSECTS, by Michael Tweedie. Illustrations by Joyce Bee. Taplinger Publishing Company ($5.95). THE WORLD OF DRAGONFLIES AND DAMSELFLIES, by Ross E. Hutchins. Illustrated with photographs by the author. Dodd, Mead & Company ($3.75). Archaeologists and entomologists regularly seem to produce books that are superior in subject matter and form to those by authors in other scientific specialties. Here we have three quite distinct examples of very good books about insects (with a few arthropodal extensions to spiders and the like). The first book is a set of brief, graceful, informal and literary essays: on scientific curiosity, on pesticides, on insect flight, on how bees originate in the carcasses of oxen (a classical mistake based on observations of certain carrion flies) and a dozen other topics. Their lightness belies their depth; these pieces will please anyone who enjoys reading or listening. Did wasps first teach papermaking by example in old China? They certainly supplied the West with ink; the gallnut, which with iron salts makes the standard ink of Europe, is a reaction of the oak to the presence of a wasp larva. This is good reading for good readers.

The second book, by a British naturalist, is again wide in scope: it tells of spiders' weaving, of hover flies keeping altitude to the millimeter even in turbulent air, of crickets, silverfish and giant silk moths. The book is not focused, as Professor Hocking's is, on the content of entomology and the imaginative response to the science. This is rather a how-to-do-it book—how to gain pleasure from insects by looking at them, attracting them, keeping them and photographing them. Not for tyros or the impatient, it will carry the earnest a long way. Although the author is British, he has paid special attention to American readers.

The third book centers on one group of insects: the dragonflies and damselflies. As showy and delightful as butterflies and moths, these lacy-winged predators are far less familiar. Dr. Hutchins, with his own splendid photographs (mostly telephoto ones; these insects have excellent sight and are not easy to approach for close-ups), tells much about their habits and life cycle. He also devotes a chapter to their evolution, with genuine pride in the two-foot wingspread of an ancestor of the modern forms, back there in the club-moss forests of the Carboniferous. You can see a fine two-foot flying model of a modern form too. The metamorphosis of the dragonfly transforms a nymph even uglier than a hairy caterpillar into a glossy flying beauty.

THE DAY OF THE DINOSAUR, by L. Sprague de Camp and Catherine Crook de Camp. Doubleday & Company, Inc.

($6.95). The Age of Giant Mammals, by Daniel Cohen. Illustrated by James G. Teason. Dodd, Mead & Company ($4). Among grade school readers there is a large and happy cult of girls and boys who dote on dinosaurs. There has grown up a splendid literature to serve them; indeed, perhaps it called them into being. These two books, both excellent and fresh, do not quite serve the cult. *The Day of the Dinosaur,* a savory mixture of biology and history, illustrated largely with photographs of reconstructions of the living monsters from the dry bones, is for graduates of the cult—readers with teen-age skills and interests who have retained their old dragon thirst—or for some who did not join the cult in younger days and now want to try it out. Lively and intelligent, the book covers a wide range of lore and logic, from genetics and the problem of extinction to the scaling of beasts. A final imaginary safari in the Jurassic is logically planned: for the big flesh-eaters one had best carry a real elephant gun, the Continental .600 or perhaps the Holland & Holland double express .500. "But, if we could hunt dinosaurs . . . we should find ourselves in a position like that of a tribesman facing a lion with a spear." Skeptical and yet imaginative, the text lives up to the De Camp reputation.

The Age of Giant Mammals is written for younger readers; its drawings are impressive, although here and there is a hint of visual uncertainty about scale. The giant bones that stimulated many an old tale were not the bones of reptiles but of much more recent and more shallowly buried big mammals. Men have hunted such mammals and drawn them too. Somehow they do not have the good press of the big reptiles. In addition to recent giants such as the mammoth and the woolly rhinoceros there are big mammals that go back to the Cenozoic. In this book all are mustered and described in an excellent context of comparisons and of the nature of the evidence. We still wantonly hunt the biggest mammals of all—at sea. The killing of these giants ought to stop, the book argues. "The time has come to put away the slingshot—forever."

The Tiger: Its Life in the Wild, by George B. Schaller and Millicent E. Selsam. Harper & Row, Publishers ($4.95). Like house cats, tigers express friendliness by rubbing the whole side of their bodies against each other. Just before that, the tiger often blows air several times out of its mouth and nostrils, making a soft puffing sound. "If a person at a zoo makes this sound in front of the tiger cage, the cat may reply and approach the bars." Tigers, like people, can be told apart by their faces, although for tigers the markings are more distinctive than the features. Schaller came to recognize many wild tigers and learned a great deal more about them and how they lived when he spent a year with his family in a house in the midst of a tiger preserve in central India, following the animals and watching them, unarmed and quiet, from the ground or a handy tree. A brief version of his full report, this small book presents tigers in words, photographs and drawings as they are (with a few pages of the myths men have made about these beautiful and powerful animals). The text is written for children from 10 up by an experienced writer who has not overcome a certain stiffness here. The material is fascinating all the same.

Plants and Man: The Story of Our Basic Food, by H. L. Edlin. The Natural History Press ($6.95). An introduction to economic plants done with breadth and taste by an expert British agriculturist-author, this volume is illustrated with maps, photographs, old prints and color plates of flowers and foods on most of its page area. It presents the history and geography of the rise of agriculture, and its current practice as well. You can see the peanut pyramids of Kano, a marihuana plant of remarkable vigor and a succession of the beautiful heads of the chief grains, the staff of man's life and also the topic of the longest chapter. Here is an account and an old print of the wild durian, the Malaysian king of fruits; there, an array of dishes holding 16 varieties of beans. History, literature and the duties and pleasures of the kitchen surround the management of scores of useful plants. Peat-bog cutting, done by machine to fuel power stations in Ireland, is not omitted, nor are Dutch tulips. This is a rich book for reading and reference. High school age and up.

Plants That Eat Animals, by Linna Bentley. Illustrated by Colin Threadgall. McGraw-Hill Book Company ($3.50). Large detailed paintings, a few in color, sprawl across the pages of this unusual book for readers from eight up. They show the carnivorous plants bigger than life, the scale made clear by the ants or flies that are the plants' prey. Plants with snapping traps, with suction traps, with flypaper leaves or with jug-of-water traps are all described.

What brilliant design manifests itself! One tropical pitcher plant has a loose, scaly coating of wax inside at the right place. "Even a fly, which has sticky pads on its feet and can walk happily upside down, is quite helpless when it has a wax plate like a small ski stuck on each foot." The book lists a few big-city botanical gardens where you can see the plants in action.

Mathematics and Games

An Adventurer's Guide to Number Theory, by Richard Friedberg. McGraw-Hill Book Company ($5.95). "(Even after years of practice, I can't read an equation involving factorials without getting a little bit excited.)" The author is so open, perceptive and enthusiastic that one can believe this parenthetical remark. So is his book, a talkative, ingenious introduction to the theory of numbers from Eratosthenes to Gauss, using only simple algebra and induction. There is a discursive historical flavor to the work; one spread shows an alchemical laboratory, brought in by the deep remark that the fundamental theorem of arithmetic (which is neatly proved here) gives the prime numbers the place in number theory that the elements hold in chemistry.

The History of the Abacus, by J. M. Pullan. Frederick A. Praeger, Publishers ($4.95). The place-holding zero is the key to extended paper-and-pencil arithmetic. Yet the Romans must have been fast but zeroless reckoners: they used not paper but place-ruled boards on which an empty space stood for zero very nicely. The Roman numerals were employed mainly to state the results of calculation with the abacus. (The wired frame with sliding beads is only the later form of the abacus.) Indeed, the Roman numerals themselves betray their connection with the counting board in the use of half-decimal symbols, such as V, L and D, for intermediate ruled lines. Five-markers to speed up the tally count are commonplace. The present Japanese bead frame is marked by its scheme for five-tally.

All this and much more is set out in this charming monograph. The struggle to introduce into Europe the paper-and-pencil arithmetic of Arabic numbers, with its enigmatic zero and its many mental tables and rules, was a long one, won only in the 17th century. In 1348 the University of Padua required that book prices be marked "not by figures but by clear letters." The formal teaching of rules has made paper arithmetic

somewhat hateful to many; the return to a concern for understanding begins to reinstate ingenious mechanical aids, from counting board to time-sharing terminal. This book is a mine for arithmetic teachers and their teachers.

BOARD AND TABLE GAMES FROM MANY CIVILIZATIONS, by R. C. Bell. Oxford University Press (Volume I, $2.25; Volume II, $7). The first volume, reissued as a paperback after its publication in 1960, describes, illustrates and gives rules of play for 91 table games: race games such as pachisi, position games from go to noughts-and-crosses, and games with dice and dominoes. There is a somewhat tentative account of a Sumerian form of backgammon from the royal tombs of Ur. The new volume (which is a hardback) continues in the same clear and meaty style, adding another several dozen games from other lands and times and including games of manual skill such as shove-ha'penny and spellicans. Chinese spellicans, or pick-up-sticks, is played with ivory pieces carved into recognizable forms: saw, spear, trident and many another. The highest score goes for sliding out the toothed saw without disturbing any of its neighbors. There is a fine account of the counting game so common in black Africa, shown here with its boards in half-a-dozen forms of graduated subtlety. Card games (except for those that use boards as well) and chess are omitted. There is material on chips and counters, and a start on making game boards in astonishing variety. Camps, clubs, schools and families will find one or both of these volumes a treasury.

Physics

THE ATTRACTIVE UNIVERSE: GRAVITY AND THE SHAPE OF SPACE, by E. G. Valens. Photographs by Berenice Abbott. The World Publishing Company ($5.95). The beautiful stroboscopic photographs of balls falling and bouncing, projectiles colliding, pendulum bobs and revolving disks circling and swinging, bear out the clarity of the good-humored text. We see them all—ellipses, parabolas and circles —as they really are: sections of ice-cream cones! With no very advanced algebraic formalism but with continued and careful use of graphs, proportionality, diagrams and numerical examples, this experienced author manages without failure or confusion to explain fully the laws of motion and Kepler's laws, the problems of centrifugal force, satellite orbit, weight and weightlessness and, even if only by analogy in three dimensions, the metric interpretation of the gravitational force. A table weighs 20 pounds when it is weighed on the earth, we say. The author shows us that the earth itself can properly be said to weigh 20 pounds when it is weighed on that table! Here, not so far from the sun, the earth weighed against space alone is "perfectly weightless as it wheels," just like a man or a Hasselblad in orbit. This is a first-rate introductory physics text. It is certainly more palatable than any other, yet in it dynamics remains a substantial meal, no chocolate-coated sweetmeat. The younger or older reader will still have to chew on it, photographs, spoofing and all.

IN MOTION, by Alfred K. Buchanan and William G. Martin. Illustrated by William Brooks. Prentice-Hall, Inc. ($3.95). Three men watch the briefcase intently. The Spymaster, with his infrared telescope, is sure that it is speeding by him at 60 miles an hour as the train flashes past. Mr. Watcher, special agent on the train, certifies by radio that it never moved from the spot where it had been put two hours ago, whereas the conductor, walking back and forth through the train, saw it come into view and disappear again. So the tale of motion begins. In the framework of a somewhat jocular spy story, the authors write for readers in junior high school and higher grades a witty tale of the foundations of Galilean relativity and Newtonian mechanics. Into their story they weave perhaps too rich a pattern of questions and teasers, with the experiments that can answer them all—if they are conscientiously conducted and reasoned. It is certainly tempting to skip the hard parts altogether; even so, this unusual book is bound to interest and teach. If it helps young readers to grasp a tenth of what it implies, it is well worth their time.

Astronomy and Space

FOOTPRINTS ON THE MOON, by the writers and editors of the Associated Press. Manuscript by John Barbour. The Macmillan Company ($7.95). LIVING IN SPACE: THE ASTRONAUT AND HIS ENVIRONMENT, by Mitchell R. Sharpe. Doubleday & Company, Inc. ($2.45). FRONTIERS OF SPACE, by Philip Bono and Kenneth Gatland. Illustrated by John W. Wood *et al.* The Macmillan Company ($3.95). There is a flood of books about man in space. These three represent distinct approaches; each in its way stands out. *Footprints on the Moon* is the narrative record of the American space effort that has culminated as the title records. It is skillfully written from more than a decade of energetic journalism, replete with the banality, the crises, the nationalism, the breezy comment, the ironies and all the rest. Anyone who can read a newspaper can read this nontechnical chronicle, full of dialogue and event. The many large color photographs are marvelously well chosen; among others we have the Russian *Vostok* on takeoff, the chimponaut on recovery, wonderful sequences of the earth receding as the moon approaches, and that small first footstep. " 'The cost,' Kennedy said. 'That's what gets me.' "

Living in Space, a paperback, is a detailed study of life support at a popular but quantitative level. It supplies lists of requirements of pounds per day, elaborate block diagrams of Russian and American life-support systems and lots of somewhat overjazzy graphs. One learns how men prepare, how they are kept alive and well and living in orbit, how closely they are watched by their radio-linked doctors and what the medical implications are. The subject matter is more directly appealing than the cold dynamics of rocket jet and orbit, and the treatment is clear and helpful as far as it goes.

Frontiers of Space, with 80 color plates, many of them elaborate and detailed renderings of real or proposed rockets and spacecraft, looks beyond Apollo. Most of its projections are corporate dreams, unlikely to prove as accurate as the first Apollo forecasts that made up most of the first volume of this pocket-encyclopedia series. There is no clear plan to follow in the decade ahead. Indeed, the devices treated include an intercontinental troop-transport rocket, which one hopes will be fully as illusory as the Nazi antipodal bomber that is also represented. This one is for the real buffs, but they are not few.

INSIDE THE ORBIT OF THE EARTH, by Willy Ley. McGraw-Hill Book Company ($4.50). VISITORS FROM AFAR: THE COMETS, by Willy Ley. McGraw-Hill Book Company ($4.50). We shall no longer have new, cheerful and coherent books from Willy Ley. This justly admired writer of popular science, especially on astronomical and space topics, died earlier this year. These two brief examples are a worthwhile legacy. At his best in history, particularly when he follows the logical thread of an error and its uncovering, Ley presents a simple,

a short story by Ray Bradbury

The Hour Of Ghosts

It was the finest hour.

It was the most delicious hour in the day.

It was the Hour of Ghosts.

In Timothy's room, an extraordinary mist spun round, took shape.

In Ralph's room, a second phantom of incredible size and mysterious mien reared up.

In Alice's hideaway, across the hall, a third and mournful stranger wove itself from shuttling light, air, and pollens of dust.

In the parlor, below, Father enjoyed *his* Visitation.

And Mother? She moved and worked in the kitchen while the Brewing Witch leaned near upon the warm bake-oven air, pointing to spices, riffling cookbooks, advising mixtures.

You would have had to thrust out your hand to find which was real. Your fingers would have gone right through the Wise Old Thing. Your fingers would have stopped on summer flesh: the Lady of this house.

"Gosh, this is great!" cried Timothy.

"You can walk all the way round them!" said Ralph.

And this was true.

And they circled all around their Ghosts, the private electronic miracles beamed into their rooms.

"They're *real!*"

"And yet not *quite* . . ."

"Say it all again," said Alice to the bright air.

"Yes," said the boys. "Speak!"

And in Timothy's room, Marley's Ghost shook his money-box chains, grieved for his lost soul, and fixed the boy with a pale oyster eye:

"O woe is me! I wear the chains I forged in life! . . . No rest. No peace! Beware, Ebenezer Scrooge!"

While by Ralph's bed, the spectre of Blind Pew clutched a bit of paper with a dark circle inked thereon and cried:

"The Black Spot! I'm doomed!"

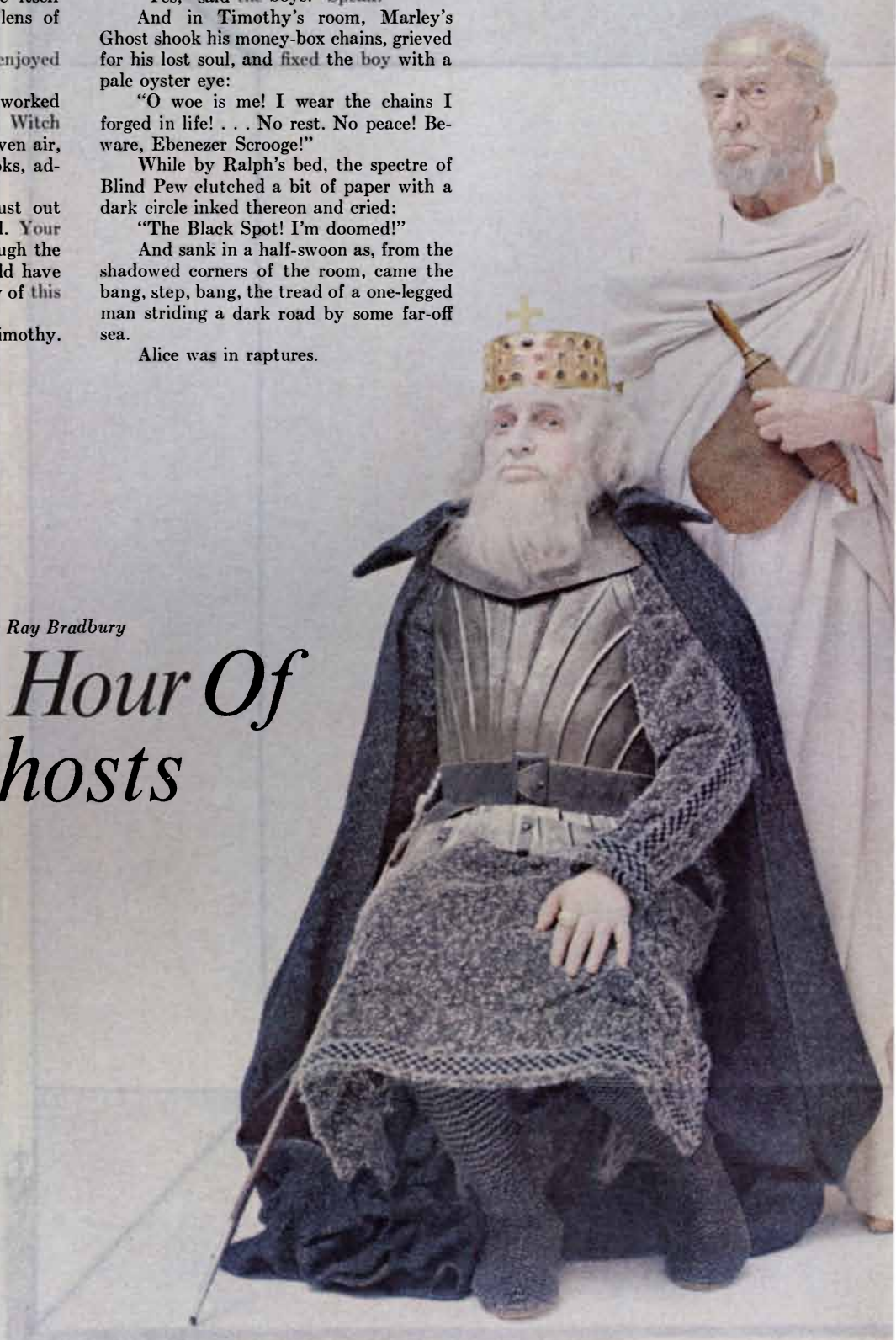
And sank in a half-swoon as, from the shadowed corners of the room, came the bang, step, bang, the tread of a one-legged man striding a dark road by some far-off sea.

Alice was in raptures.

Her Ghost, a young woman, hair blowing in the wind, tapped at a snow-blind window and called a wild man's name:

"Heathcliff!"

And swiftly, in the midst of the air, a door swung wide on the winter's night. A man, answering, plunged out and vanished away from Wuthering Heights, lost in blizzards of white that fell to touch the bedroom floor and melt without trace.



"Holograms," whispered Timothy. "Telecommunications. All done with laser light and extra special machines. . ."

"Don't!" said Ralph, younger but wiser. "I mustn't know that. I just want to *see!* Ghosts are the greatest things ever. After Blind Pew I got King Tut and the Phantom Rickshaw and—heck! why not *now!?*"

He stabbed a button. The laser light rewove its tapestry. Blind Pew unraveled and fled, pursued by a one-legged tattoo.

Out of moorland fogs, in a crack of lightning and a drizzle of rain, a Hound with fiery eyes rose up and bayed.

"Good old Hound," said Ralph. "Good old Baskervilles!"

In the parlor, the ghost of Hamlet's father mourned:

"List. O List! Hamlet . . . remember *me!*"

"One cup of cooking sherry," said the Cooking Ghost, the computerized memory of how to work well between oven and table. "Two . . ."

"Much obliged," said Mother, and touched a switch.

The Kitchen Ghost, obedient to lightning, vanished.

"Dinner!" called Mother, in the hall.

"You," said Timothy-like-Scrooge, "are nothing but a blot of mustard, a fragment of under-done potato . . ."

At which old Marley collapsed upon his bones with a final despairing cry, and was no more.

"Come back at eight!" said Ralph.

And the Hound hid deep in the moorlands grass of the carpet.

"Oh, such lovely Ghosts." Alice wept as the figures of Heathcliff and his love ran away through the walls.

At Elsinore, dawn lit the parlor airs. Hamlet's Father withdrew. And the father of *this* house stood up and went to dinner.

As did all the real children, drawn by a real mother with real food.

The hour of Ghosts was done.

The dusk of laser Visitations was through.

But night lay fresh ahead. And waiting in their rooms, after homework, after studies, other spectres stood alert. The Ghosts of Christmas Past, Present, Future abided in the walls. The Phantom Signalman beckoned his spirit lantern at the top of the stairs. The house was indeed Haunted. . . .

"I've taken the liberty," said Father, "of inviting Plato and Aristotle to dinner . . ."

"They talk too much!" said Ralph.

But suddenly, the two old men were there, gently, at their elbows.

"How goes the Republic?" asked Tim.

"Well . . ." And Plato told him, sweetly, fine, and true.

And even Ralph was astounded after awhile and sat up, blinked, and said, "That *last*. Tell it again."

And Plato told.

And it was *almost* as good as Blind Pew and the whine and bark of the far Hound on the moors . . . .

• • •

Are these the Ghosts of Christmas Future?

Yes.

Not so far off across the sill of Tomorrow, three-dimensional holograms will 'visit' your house.

These friendly Phantoms, invited in through your telecommunications system, will delight, edify, and educate. Or, if Mum's the Word, be still, as you wish.

These are such stuffs as dreams are made of.

Built upon the very fabric of light and air in any room. View them from north-south-east-west. Walk around them. They'll have as many sides as you have angles.

Watch for these friendly spirits.

Ray Bradbury

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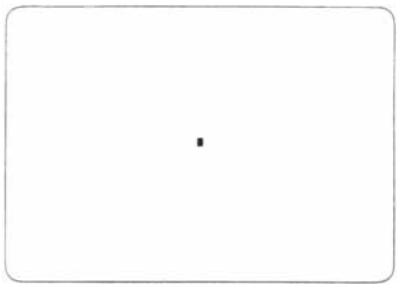
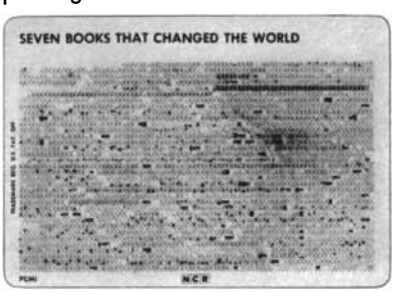


don't brush it off—it's knowledge

Good things come in small packages.

This "flyspeck" is actually a page of valuable research material, packaged for instant retrieval.



Today's information explosion has made library management tougher than ever. The problems of book acquisition, budget allocations and shrinking shelf space are growing with the ever-increasing demand for vast amounts of source material. Much of it is unavailable, out-of-print and very expensive.

We felt it was time for a new approach.

An NCR development—the PCMI* Library Information System—now makes it possible to store a comprehensive collection of the world's most meaningful books at less than $1.50 each. A 4" x 6" PCMI Ultramicrofiche stores about 3,000 pages of valuable text, the equivalent of seven to ten books. The PCMI Reader, as simple to operate as a portable television set, restores each page to larger than original size, in sharp focus. The PCMI Reader/Printer instantly delivers quality page reproductions at the touch of a button.

NCR offers the PCMI Library Information System in a low-cost subscription service; starting with large meaningful collections and building upon them year by year.

Initial PCMI Collections include: Science and Technology, Social Science, American Civilization, Literature-Humanities, Government Publications.

Other collections, such as those relating to Law, Medicine, Religion, Physics and Chemistry, are in development.

Now every library—regardless of size, locale or budget—can function as an active, full-fledged research center. As a space age library should.

For further details, contact: The National Cash Register Company, PCMI Library Information System, IPD Dept. "E," Main & K Streets, Dayton, Ohio 45409.

*Trademark Reg. U.S. Pat. Off. See a PCMI demonstration at Booth 143 at the Modern Language Association Convention, Denver, Colorado, December 27-29.

clear, well-illustrated story of the motions and nature of comets. Halley and his great discovery of periodicity are at the focus of the tale; the unmanned mission to a comet that lies ahead a decade or so caps it. *Inside the Orbit of the Earth* (which is illustrated with line drawings only) is the account of what we know of Mercury, Venus and the zodiacal light and of what was mistakenly reported about other sun-hugging planets over the centuries. The space-probe results of 1967 are included. The story of the false satellite of Venus, which was sometimes the reflection of the image of Venus from eye to eyepiece and sometimes a background star, gives us a fine example of Ley, making clarity and human warmth out of the slow self-correction process that is science. It is not likely that the nature and the origin of comets are quite as clear yet as Ley makes them out to be. The writing is simple but not elegant, on the level of a quick-reading magazine story.

Technology

ELECTROSTATICS: EXPLORING, CONTROLLING AND USING STATIC ELECTRICITY, by A. D. Moore. Anchor Books, Doubleday & Company, Inc. ($1.45). SIMPLE WORKING MODELS OF HISTORIC MACHINES (EASILY MADE BY THE READER), by Aubrey F. Burstall. The M.I.T. Press ($3.95). These two books, unlike most of what is in print, appeal as much to the reader's hands as to his mind. The first is an engaging and chatty paperback account of modern electrostatics—a technology of Plexiglas and epoxy—that centers around a family of electrostatic generators. They are modern versions of the famous Wimshurst machine, small enough so that skillful and energetic high school students can understand, build and improve on them. The essential theory is given, with a real feeling for engineering design and development. A modern Leyden jar can be built in minutes around a polyethylene freezer container. Don't scorn its small capacity: "Wait until you take a poke from . . . a 150 pF capacitator. . . . It would not harm you, but it certainly will keep you interested." The book will too, even if you do not build a machine. One hopes the volume will generate quite a lot of sparks, and a white flicker on a good many television screens. (Safety, by the way, is an explicit and quantitative concern of this experienced author.)

The second book is an equally inviting work, although the subtitle may be overenthusiastic. (The author had the help of technicians in the workshops of the mechanical engineering department of a large English university.) The pages present succinct descriptions, drawings and photographs of about three dozen marvelous gadgets from the heroic history of technology, all realized as working models. There is no attempt to follow scale, materials or finish in authentic detail; the aim is to abstract and exhibit the "particular go" of each machine. Most of the devices are to be made at the woodworker's bench, with some sheet-metal, plastic, rope or hardboard parts. A number call for machined metal gearing that is beyond amateur skills; one can criticize the absence of much effort here to help young people take advantage of the rich marketplace of manufactured parts in our technological era. The book is nonetheless a pleasure and a challenge. Who would not like to see working models of the device used to generate screw threads without copying any existing thread; of the Chinese spoon-tilt hammer, an automatic water-power scheme still familiar in Japanese gardens, or of the Cornish man-engine, a vertical moving belt of miners, forerunner of the mine hoist?

THEY LIVE BY THE WIND, by Wendell P. Bradley. Alfred A. Knopf ($7.95). THE GRAND BANKS, by Bern Keating. Photographs by Dan Guravich. Rand McNally & Company ($9.95). The first of these two books bears the subtitle The Lore and Romance of the Last Sailing Workboats: the Grand Banks Schooners, the Square-Rigged Training Ships, the Chesapeake Oysterboats, the Fishing Sloops of the Bahamas. After that there is not much need for a review, although one might object that there are plenty of sailing junks working the Asian seas. Bradley, whose untimely death ended his own oyster dredging in 1967, was a champion yachtsman. He tells the story of these sailing ships, large and small, and of their men from aboard ship and not at second hand, with passion for the beauty and the utter benignity of silent, smokeless, economical sailing. There can be no doubt that the sailor's hard life knows beauty, and that most busy sailors love to race. The auxiliary engine and the radar antenna have ruined that life, Bradley felt. There is a case here against the machine, all right. Yet the sweating oarsmen must also have railed at the effortless speed of the brainy fellows who first set rude sail to boats long ago.

The Grand Banks is a journalist's lively history, with beautiful color photo-

graphs and an up-to-date account of Newfoundland and the throngs of fish around it. The men of sunny Portugal who work in the cod fleet spend 16 hours a day tending line in the mist in one-man dories, "each one the home of a Portuguese fisherman for more than half of his life." The Russians now fish the Banks industrially with factory ships, relief crews, doctors, movies and libraries. Maybe we Westerners will no longer be able to afford the big fish fillets, and will begin to fish as men now fish the China Sea, with small-mesh nets taking everything for sardines and meal. But maybe the Newfie will survive and "fish his own banks again when the industrial wonders have long since run home."

THE STEAM CARS OF THE STANLEY TWINS, by Robert B. Jackson. Henry Z. Walck, Inc. ($3.75). F. E. and F. O. Stanley, with identical bushy black beards and dressed exactly alike in long black overcoats and black derby hats, hissed in their first steamer all the way from Newton, Mass., to Cambridge. This small book is the skillfully written story of these men and their cars, a tale meant for grade school readers. Stanley Steamers held the world land speed record until Barney Oldfield beat them in his Blitzen Benz in 1910. The racing Stanley Bug crashed on a beach speedway at around 150 m.p.h. or even faster; the intrepid driver, who had survived the crash, recalled 50 years later that he was "doing 197 when he hit the hollows." The Stanley was safe, in spite of rumors. It was fast and nimble as a sports car, but it was also noisy, thirsty, smelly and slow to start. Up-to-date steam cars have been made, and they might come back. A delightful piece of nostalgia, a good deal stranger than most fiction.

CONTACT!: THE STORY OF THE EARLY BIRDS, by Henry Serrano Villard. Thomas Y. Crowell Company ($10). *Contact!* is a chronicle of the first years of flight, told as an account of the men and women in those flying machines by an author who has added historical scholarship to his own recollections. The book is substantial, unsentimental, warm and accurate. Here are the years from Kitty Hawk to the outbreak of the war in Europe, the years when first flights spanned the nations from Denmark to France by 1906 and got as far as China and Madagascar by 1911. Here is T. O. M. Sopwith sitting in his famous Camel, at once jaunty and boyishly sullen, and Alberto Santos-Dumont, the first pilot of Europe, in his floppy panama. That sensitive pioneer took his own life after his state of Saõ Paulo in 1932 dropped bombs on other Brazilians. They were magnificent men in those flying machines; this book is worthy of their stature. School libraries note.

ARCHITECTURE: A BOOK OF PROJECTS FOR YOUNG ADULTS, written and illustrated by Forrest Wilson. Reinhold Book Corporation ($6.95). Experiments in statics are put together in a brilliant introduction to the principles of architecture, ancient and modern. Lump-sugar masonry yields the corbel and the arch, the flying buttress and the catenary. The principles of modular design are set out in a paper game devised by Le Corbusier. Then modern materials are introduced: balsa, paper, glue, toothpicks and thread. Out of these there arise warped-shell roofs like Nervi's, beams reinforced with prestressed rubber bands, paper space frames and folded plates—like anybody's airline terminal. Finally there are subtler tasks: using light and texture to express purpose and mood, to comment on form and material. Teen-agers who want to construct and teachers who work with younger children will find here many enticing projects. This thin book promises to become an architectural classic.

SAFE BIND, SAFE FIND: THE STORY OF LOCKS, BOLTS AND BARS, by Garry Hogg. Criterion Books ($3.50). The familiar Yale lock has a cylinder held by a set of split pin tumblers. If any pin is raised either too far or not far enough, the split will not be aligned with the cylinder surface and the bolt cannot be drawn. Such "double-acting" locks are not new, although since its invention a century ago the Yale has dominated the world of household locks. Egyptian bolts had single-acting pin tumblers 4,000 years ago, although the keys were carved out of wood and were a couple of feet long. This book, very British in allusion, recounts with pleasure the history of the ingenious little machines that are locks as a long-lasting and dramatic conflict between "the unpickable lock" and "the invincible lockpicker." The 1851 triumph of A. C. Hobbs, locksmith of New York City, over the until then unconquered locks of the best designers of London is a dramatic episode that is recounted and explained. The combination lock is Chinese in origin; the ultimate lock is the genuinely unpickable time lock. It takes high explosive! Fort Knox, as it is described here, is even stronger. The photographs and old draw-

Give them this day their daily bread.

Think of the last time that *you* were hungry. Really hungry. Was it because dinner was late? Or because you missed a lunch?

Can you imagine what it is to go through life never knowing what it is like *not* to be hungry? Subsisting day after day on a few greens around noon... and some pinto beans in the evening? Nothing more. Nothing different. And not even enough of that.

It sounds incredible. And it is incredible. Because it's taking place right now... in the midst of the good life so many of us are now living in America.

But walk down the back roads of most any Mississippi Delta town and you'll see tenant farmers, field hands, seasonal workers ... and their children ... with stomachs bloated, eyes dulled, feet swollen, arms and legs matchstick thin.

The irony is that they aren't starving at a rate dramatic enough to arouse the indignation of the nation and the world. Otherwise something would have already been done.

One of the programs that is aiding many of these families is the federally sponsored Food Stamp Plan. Under this plan a needy family can convert a 50¢ food stamp into as much as $12.00 worth of food. The problem is getting that 50¢, because many families have *no* income at all.

The NAACP Special Contribution Fund has begun a nationwide drive to help thousands survive. If you can do with one less "dinner out" this month, the money can mean a month's supply of meat, milk, and bread for a family of five. Just $10.00 buys up to $240.00 in food stamps.

If you would like to contribute to this fund, please send your tax-deductible check, for as little or as much as you can, to the NAACP Mississippi Emergency Relief Fund.

Thank you. And may *your* next meal be a little more enjoyable.

NAACP MISSISSIPPI EMERGENCY RELIEF, DEPT. SS1, BOX 121, RADIO CITY STA., NEW YORK, N.Y. 10019
(A project of the NAACP Special Contribution Fund—tax-deductible arm of the National Association for the Advancement of Colored People.)

ings are interesting, but better diagrams would have helped to clarify the descriptions of cunning mechanisms.

TRAIN WRECKS: A PICTORIAL HISTORY OF ACCIDENTS ON THE MAIN LINE, by Robert C. Reed. Superior Publishing Company ($12.95). Mostly by its period engravings and photographs, this book shows the story of railroad accidents in the U.S. from the disaster near Secaucus, N.J., in 1853 up to a diesel head-on on the Southern a few years ago. Although sudden death is implied, and is even manifest in a few photographs, the overall impression is more one of grotesque piles of iron forgings than of human suffering. There are many pictures of children clambering over the outlandish wreckage; parents will understand. One burst superheater looks like the entrails of some dragon, slain and scorned on the Southern Pacific right-of-way.

MOTORS AND ENGINES AND HOW THEY WORK, by Harvey Weiss. Thomas Y. Crowell Company ($4.50). With effective informal line drawings and a text simple enough for sixth-graders, the author tells how wind, water, steam and sand can run engines, some of them large and some of them small enough for the reader to build for himself. Workable recipes for an electric motor, an electromagnet and a buzzer are here too.

Guides and Handbooks

FIELD GUIDE TO SNOW CRYSTALS, by Edward R. LaChapelle. University of Washington Press ($6.50 hardbound, $2.95 paperbound). The mineral we call water forms splendid crystals wherever and whenever there is snow. Armed with a good hand lens and this small book crammed with photographs, the collector can add snowstorms to the list of fascinating natural history collections. Unlike the classic works of snow-crystal photographs, this small guide shows and classifies not only the perfect and the unusual crystals but also the broken, clumped, overgrown or half-evaporated flakes of real life, both as they fall and as they lie on the ground. Rime, graupel and hoarfrost are here too. The work is adult and fully technical, aimed at snow rangers, but it is clear enough to help any young person trying to understand "what he actually sees and how the snow got that way."

GEM HUNTER'S GUIDE, by Russell P. MacFall. Thomas Y. Crowell Company ($5.95). "The complete handbook for the amateur collector of gem minerals," the fourth edition of this book professes to be. It pretty nearly is, too. Color photographs, a key, a long list of museums and state guides, and then two-thirds of its pocket-sized pages are devoted to a state-by-state list and mapping of locations. The diamonds and pearls of the U.S. receive special treatment. (Our Kimberley is near Murfreesboro, Ark.; our pearl hunters take mussels from the Wabash and the Tennessee.)

WHAT WOOD IS THAT?: A MANUAL OF WOOD IDENTIFICATION, with 40 actual wood samples and 79 illustrations, by Herbert L. Edlin. The Viking Press ($7.95). Wood is still the most widely used construction material we have. Plywood, veneer, bent wood, wood turned and molded is all around us in house and furniture. This agreeably written book opens up the recognition of wood in the style of a first-class field guide. The general background of the utilization of wood (the Pacific Northwest remains the world's greatest source of timber), the multiple keys for recognition and the carefully presented examples of its use add up to a book unique in the English language, a fresh chance to look with insight at the beautiful and the commonplace.

SEASHELLS OF NORTH AMERICA, by R. Tucker Abbott. Illustrated by George F. Sandström. Golden Press ($3.95). Pocket-sized, paperbound, dense and handsome, this is a model field guide. There are more than 800 species described, most of them illustrated in color. There are an expert and interesting general account of the biology of mollusks, and many hints for collectors of any literate age and for mere strollers on the beach. Egg cases and other developmental stages are not neglected in this workable, handy, fairly priced book.

THE MODEL AIRCRAFT HANDBOOK, revised by Howard G. McEntee. Thomas Y. Crowell Company ($6.95). An updated version of an old favorite, this handbook is a basic introduction to all forms of the hobby. It is a guide to planning and to construction, although not to original design, and it points the way to the associations of modelers, the large specialized literature and the widely distributed kits and parts. The book includes balsa techniques, and it starts the reader off toward gliders, rubber-band engines, piston engines, "high power" two-ounce jets, and even a little way toward rocketry.

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