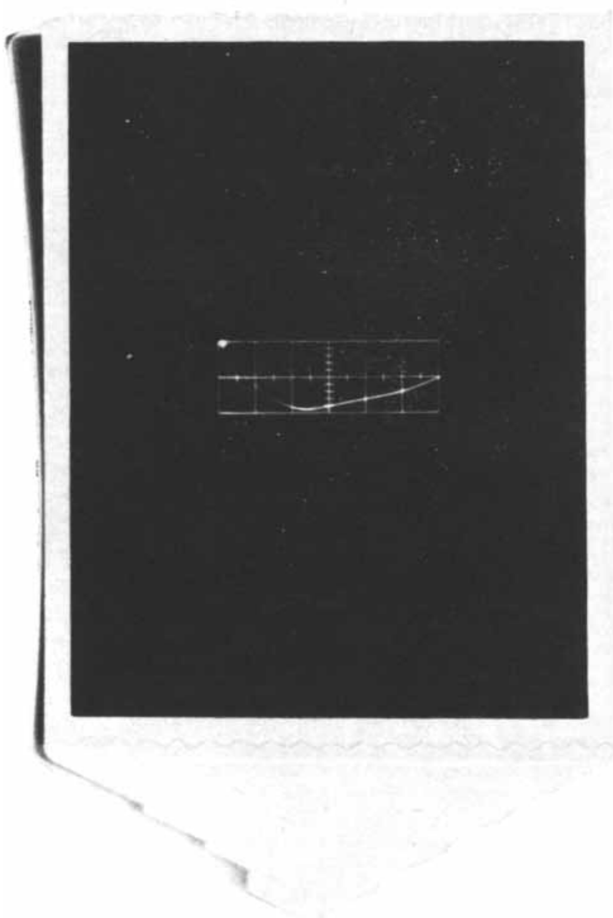
SCIENTIFIC AMERICAN

PYGMIES IN THE FOREST

FIFTY CENTS

January 1963



Established 1845 **SCIENTIFIC AMERICAN** January 1963 Volume 208 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a hunting party of Pygmies in the Ituri Forest of the Congo (see "The Lesson of the Pygmies," page 28). The Pygmy in the shadow at the far left carries a bow; the Pygmy behind him, a metal-tipped spear and, draped over his shoulders, a long hunting net.

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Cover photograph by Colin M. Turnbull

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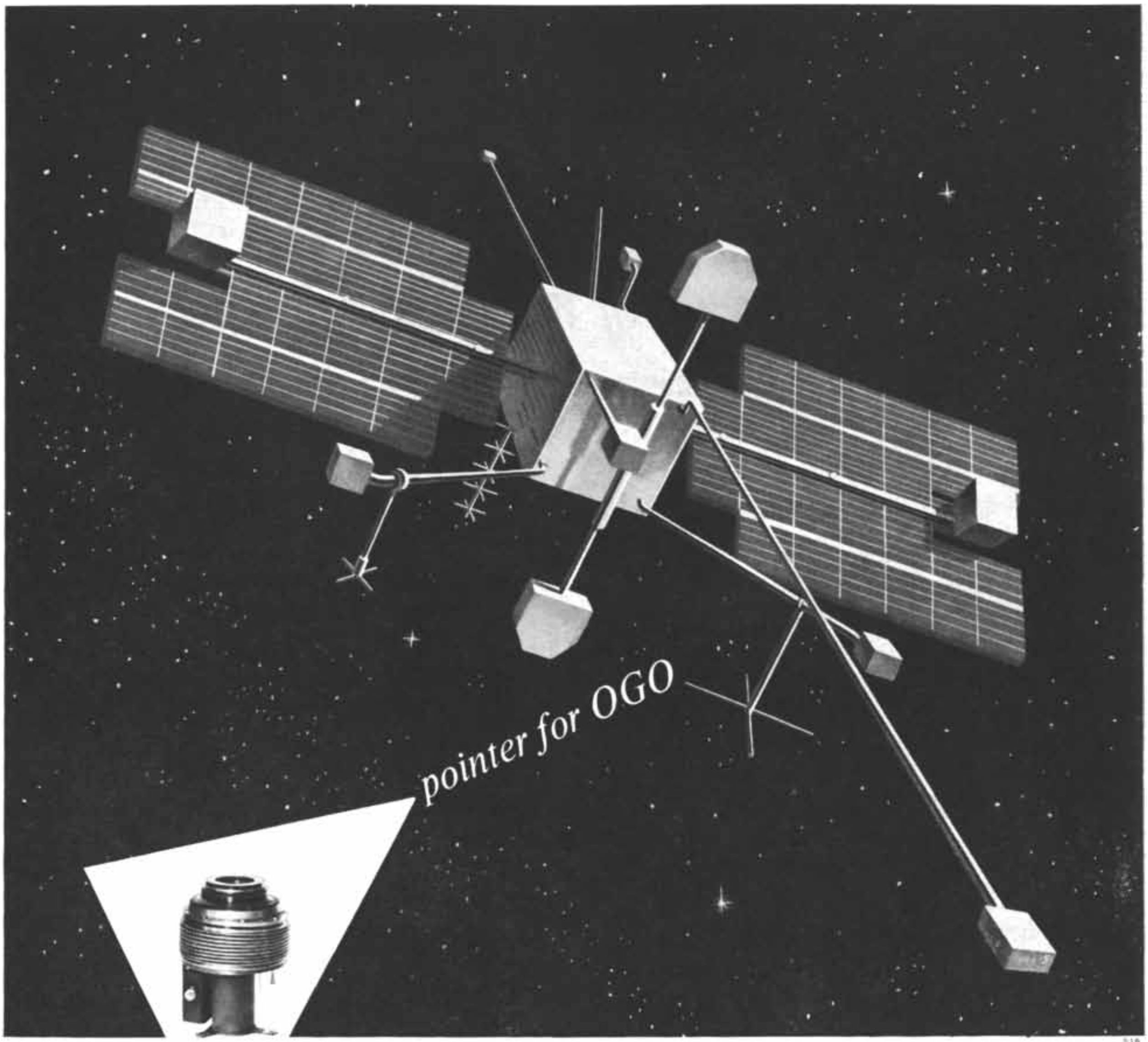

Once in orbit, OGO (NASA's Orbiting Geophysical Observatory) must orient scientific equipment in three directions. Some of its experimental packages must line up perpendicular to the sun's rays. Other experiments must turn to face the earth. Another group must seek a line parallel to OGO's own orbital plane. STL engineers and scientists have produced a hermetically sealed drive mechanism to help solve these orientation requirements. Two mechanisms are used in OGO's attitude control system. One rotates solar arrays in continuous orientation with the sun; a second keeps experiment packages fixed in desired position with respect to the orbital plane. The drive mechanism (shown above) is hermetically sealed to permit use of a conventional high-speed servo-motor without the usual problems of gear lubrication. It does its work by wabble or twist motion at a rate of one degree per second with a final gear reduction of about 24,000 to 1. STL's many projects include building OGO spacecraft for NASA's Goddard Space Flight Center, building spacecraft for Air Force-ARPA, and continuing Systems Management for the Air Force's Atlas, Titan and Minuteman programs. These activities create immediate openings in fields such as: Space Physics, Radar Systems, Applied Mathematics, Space Communications, Antennas and Microwaves, Analog Computers, Computer Design, Digital Computers, Guidance and Navigation, Electromechanical Devices, Engineering Mechanics, Propulsion Systems, Materials Research. For Southern California or Cape Canaveral positions, write Dr. R. C. Potter, One Space Park, Dept. J-1, Redondo Beach, California or P. O. Box 4277, Patrick AFB, Florida. STL is an equal opportunity employer.

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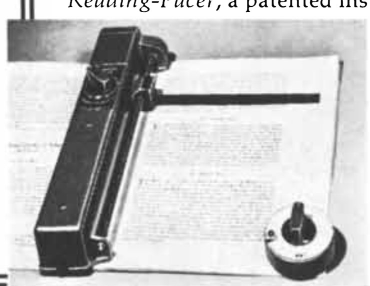

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>
> **SECOND,** that slow reading is as common among those with high IQs as among lesser brows.

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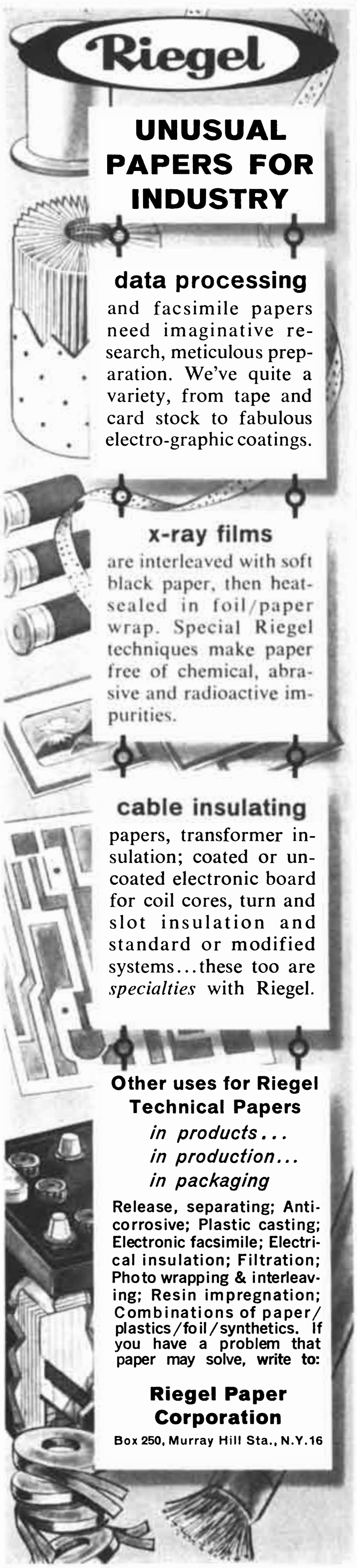


LETTERS

Sirs:

The following is in regard to Problem 8 in your department "Mathematical Games" for October, 1962. [Editor's note: The problem was to insert a minimum number of plus or minus signs between the nine digits, in ascending or descending order, to make the expression equal 100.]

Consider that between *each* pair of digits there is a "symbol." The symbol can have any one of three values: plus, minus or "null." Since there are eight such symbols, there is a total of 3^8, or 6,561, possible expressions for a given sequence of digits. In view of the relatively small number of possibilities, I was surprised to read that the problems were still open. Consequently I decided to write a computer program to test each combination, select those expressions that were equal to 100 and arrange the solutions according to the number of plus or minus signs in each. The results are shown below. As you can see, Henry Ernest Dudeney was right: his solution

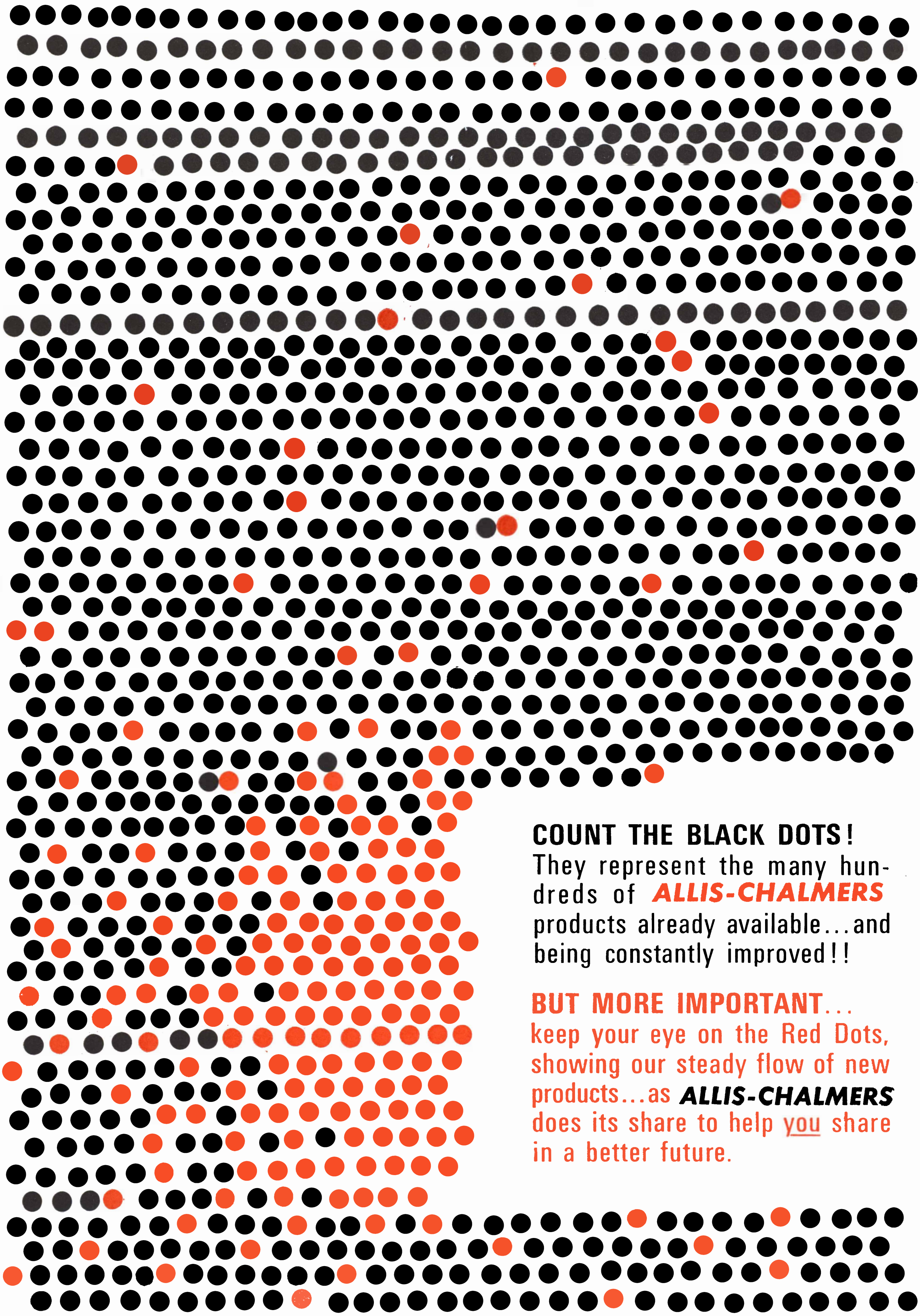
SOLUTIONS FOR ASCENDING SEQUENCE

SOLUTION	NUMBER OF PLUS OR MINUS SIGNS
123-45-67+89 =100	3
123+4-5+67-89 =100	4
123+45-67+8-9 =100	4
123-4-5-6-7+8-9 =100	6
12-3-4+5-6+7+89 =100	6
12+3+4+5-6-7+89 =100	6
1+23-4+5+6+78-9 =100	6
1+2+34-5+67-8+9 =100	6
12+3-4+5+67+8+9 =100	6
1+23-4+56+7+8+9 =100	6
1+2+3-4+5+6+78+9=100	7

SOLUTIONS FOR DESCENDING SEQUENCE

SOLUTION	NUMBER OF PLUS OR MINUS SIGNS
98-76+54+3+21 =100	4
9-8+76+54-32+1 =100	5
98-7-6-5-4+3+21 =100	6
9-8+7+65-4+32-1 =100	6
9-8+76-5+4+3+21 =100	6
98-7+6+5+4-3-2-1=100	7
98+7-6+5-4+3-2-1=100	7
98+7+6-5-4-3+2-1=100	7
98+7-6+5-4-3+2+1=100	7
98-7+6+5-4+3-2+1=100	7
98-7+6-5+4+3+2-1=100	7
98+7-6-5+4+3-2+1=100	7
98-7-6+5+4+3+2+1=100	7
9+8+76+5+4-3+2-1=100	7
9+8+76+5-4+3+2+1=100	7

A computer's solution of two problems in "Mathematical Games"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worldwide electronics and telecommunications **ITT** for the ascending problem is the simplest. I think it is curious that, although there are more solutions for the descending problem, none of them is as simple as the simplest for the ascending problem.

The problem was solved on a Philco 211 computer at Willow Grove, Pa., in 48 seconds.

MARK RESNICK

Norristown, Pa.

Sirs:

The term "kinins" has for some time been applied by our group and other workers in plant physiology and growth-regulator mechanics to the group of substituted purine derivatives promoting kinetin-like responses in plant tissues. In the August 1962 issue of *Scientific American* H. O. J. Collier published an article entitled "Kinins." The article dealt with polypeptides that possess hormonal activity in animal tissue.

Thus we have two identical words in the literature that refer to vastly different chemical entities. For this reason we suggest that in the future the plant kinins be called "phytokinins" to avoid much confusion.

R. R. DEDOLPH
S. H. WITTWER
D. C. MACLEAN

Michigan State University
East Lansing, Mich.

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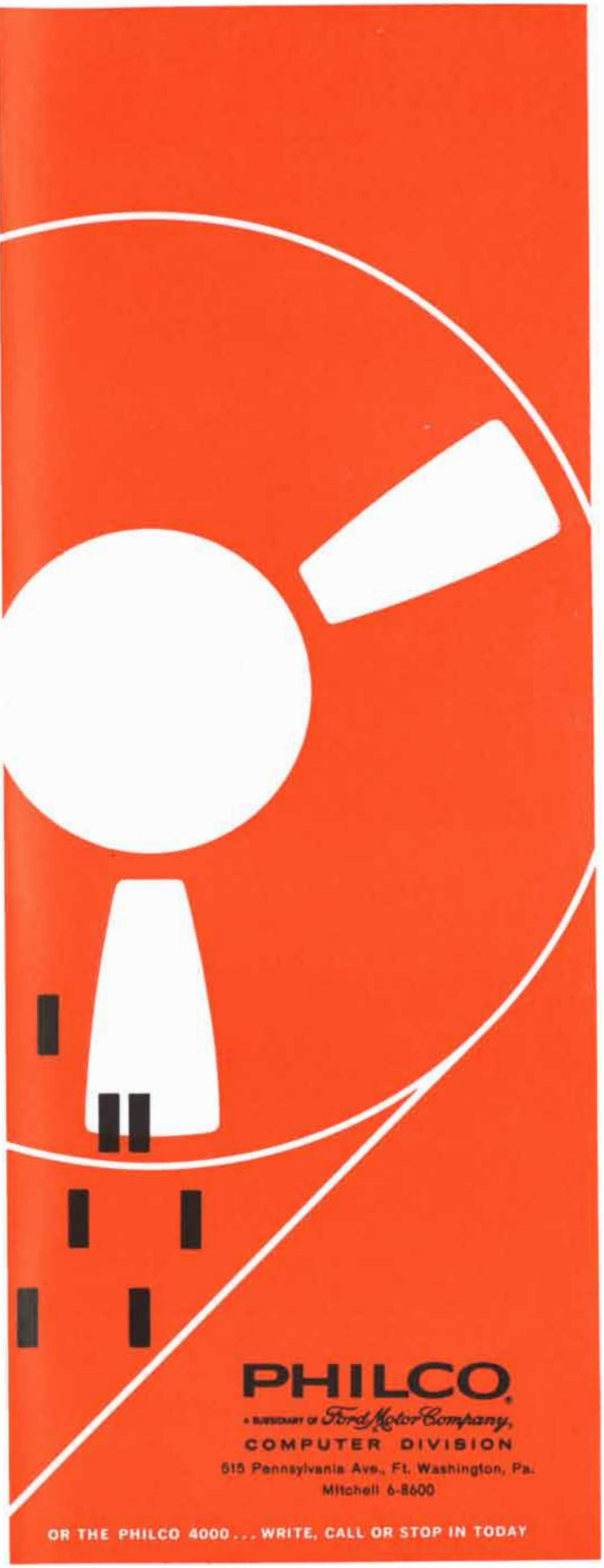


50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JANUARY, 1913: "It would appear that radium has landed geologists and biologists in a difficulty greater than that from which it was hoped it would deliver them. There is radium in the earth, and radium in disintegrating gives out heat. Therefore a once molten globe will cool down more slowly than if it contained no such independent source of heat. Lord Kelvin's calculations were made on the supposition that there was no source of heat except what the earth possessed as a molten globe. Hence we are at liberty to extend the time that has elapsed since the earth became the possible theater of geological change to 500,000,000, 1,000,000,000, or even more years ago. Radium has given us a blank cheque on the bank of time. But when the actual calculations were made as to how much radium known to exist in the outer shell of the earth would effect its cooling, this was found to be too great. It would, in fact, *raise* the temperature of the earth a fraction of a degree annually."

"Although the Berlin scientist Dr. Korn is having good success in sending photographs by wire between stations located at Paris, Berlin and Monte Carlo for use in press work, he wishes to apply his method over a much longer distance. He expects to take up the question of operating on the Atlantic cable and is confident that he will be able to send photographs across the ocean. He is also considering the matter of coming to America in order to apply the system to a line between New York and San Francisco."

"Most productive of all agricultural years in this country has been 1912, declares the 16th annual report of the Secretary of Agriculture, recently made public. The earth has produced its greatest annual dividend. The man behind the plow has filled the nation's larder, crammed the storehouses and will send liberal supplies to foreign countries. The total crop value is so far above that of 1911 and of any preceding year that the total production of farm wealth is the highest yet reached by half a billion dollars. Based on the census items of wealth production on farms, the grand total for 1912 is estimated to be $9,532,000,000."

Scientific American.

JANUARY, 1863: "The celebrated *Monitor,* whose fame is world-wide, has, we regret to say, met an adversary to whose strength and prowess she was obliged to succumb. She sprang a leak and foundered at sea off Cape Hatteras, on the 31st ultimo, with all her officers and crew on board; out of the whole number 32 perished. She was at the time in tow of the gunboat *Rhode Island;* a portion of this latter ship's crew were also lost, as the dispatches say, in endeavoring to rescue their comrades from the sinking battery. The *Monitor* made the first part of her voyage in safety. When she was off Cape Hatteras, the gale was so light that Commodore Bankhead thought it useless to run for Hatteras Inlet, then about 15 miles distant. The wind, however, increased as the night advanced, until it became a perfect storm. The sea ran very high, at times passing over the turret. The *Monitor* now began to leak, but the pumps freed her. The storm still increasing, the leak also gained, until it became a serious matter. The pumps threw overboard about 3,000 gallons of water per minute, but in spite of all, the water gained on the crew. The *Monitor* was last seen about two o'clock A.M., about a mile and a quarter distant; just before the moon vanished she was seen laboring in the trough of the waves; afterward, for a brief time, her lights were visible when suddenly they disappeared wholly, and it was known that the little battery, whose name and fame were household words, was gone forever."

"In 1857 the iron-works in America amounted to 121 anthracite furnaces, 500 charcoal and coke furnaces, 300 forges and 210 rolling mills; and the entire production of iron was about 783,000 tuns, a decrease over the previous year of 73,235 tuns. In 1859 there were only eight States of the Union destitute of iron-works. The remaining 25 were employing 560 furnaces, 389 forges, 210 rolling mills; in all, 1,159 producing 840,000 tuns. The activity of the iron manufactories in Pennsylvania continued during the first part of 1860,

What was Bell Telephone Laboratories doing on Monday, October 1, 1962?

Murray Hill Laboratory, N. J. The search continued for new materials exhibiting superconductivity. Some of these materials have been used to produce very strong magnetic fields with the expenditure of very little electrical energy.

Allentown Laboratory, Pa. We were working with engineers of Western Electric, manufacturing unit of the Bell System, on the manufacture of long-life electron tubes for a new deep sea cable system.

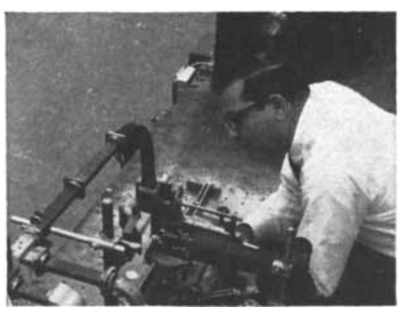
Merrimack Valley Laboratory, Mass. We were increasing the capabilities of a new microwave system designed for low-cost telephone and television communications over distances up to 200 miles. This system is based on advances in solid state technology.

Holmdel Laboratory, N. J. We were developing an electronic switching system using new solid state devices. It will bring telephone customers a whole new range of services.

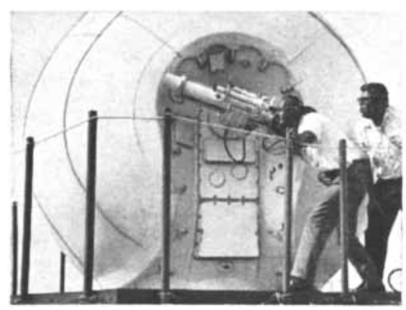
Indianapolis Laboratory, Ind. We were perfecting improved automatic dialer telephones. One model will permit the customer himself to record 50 frequently called names and numbers and then dial by simply selecting a name and pressing a button.

New York Laboratory, N. Y. We were studying the performance of a new data set which converts teletypewriter pulses into tones for transmission over regular voice circuits. Transmitting teletypewriter messages over voice circuits was introduced on August 31, 1962.

Whippany Laboratory, N. J. We were evaluating new radar technology for the NIKE-ZEUS anti-missile missile system under development for the Army. Significant improvements are further tested at four other ZEUS test sites ranging halfway around the world.



Crawford Hill Laboratory, N. J. We were experimenting with the microwave modulation of light from a helium-neon gaseous optical maser. Modulated light may someday be used to carry large volumes of information.



Cape Canaveral, Fla. We were preparing for the 102nd successful use of Bell Laboratories-developed Radio Command Guidance System. On July 10, it was used in the NASA launching of the Bell System's Telstar. This guidance system was originally developed for the Air Force and is operational on the Titan I ICBM.

These were some of the highlights of one day. Engineers and scientists at Bell Laboratories work in every field that can benefit communications and further improve Bell System services. Their inquiries range from atomic physics to new telephone sets, from the tiny transistor to transcontinental radio systems, from the ocean floor to outer space.

BELL TELEPHONE LABORATORIES

World center of communications research and development but since October of that year it has of course experienced a severe check. Many of the mills that had stopped work through the secession movement have again resumed active operations, especially those devoted to the rolling of plates. The demand on them for Government iron-plated vessels has been greater than the capacity of such mills to supply."

"Bayard Taylor, the celebrated traveler, thus sums up the result of modern discoveries :—'Within the past 25 years all the principal features of the geography of our own vast interior regions have been accurately determined; the great fields of Central Asia have been traveled in various directions from Bokhara and Oxus to the Chinese Wall; the half-known river systems of South America have been explored and surveyed; the icy continent around the southern pole has been discovered; the Northwest Passage—the *ignis fatuus* of nearly two centuries—has been at last found; the Dead Sea is stripped of its fabulous terrors; the source of the Niger is no longer a myth, and the sublime secret of the Nile is almost wrested from its keeping; the Mountains of the Moon, sought for 2,000 years, have been beheld by a Caucasian eye; an English steamer has ascended the Chadda to the frontiers of Bornou; Leichard and Stuart have penetrated the wilderness of Australia; the Russians have descended from Irkoutsk to the mouth of the Amoor; the antiquated walls of Chinese prejudice have been cracked and are fast tumbling down, and the canvas screens that surround Japan have been cut by the sharp edge of American enterprise. Such are the principal results of modern exploration. What quarter of a century can exhibit such a list of achievements?' "

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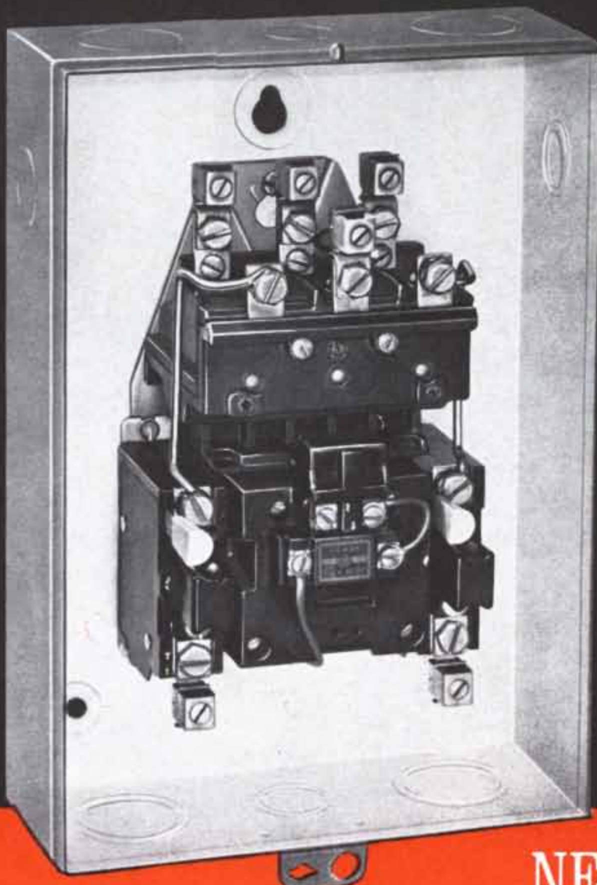
"The Treasury Department has decided that the measure of a tun, in making assesments for the internal revenue, shall be 2,240 pounds, in all cases, under the excise law, unless the contrary is specified."



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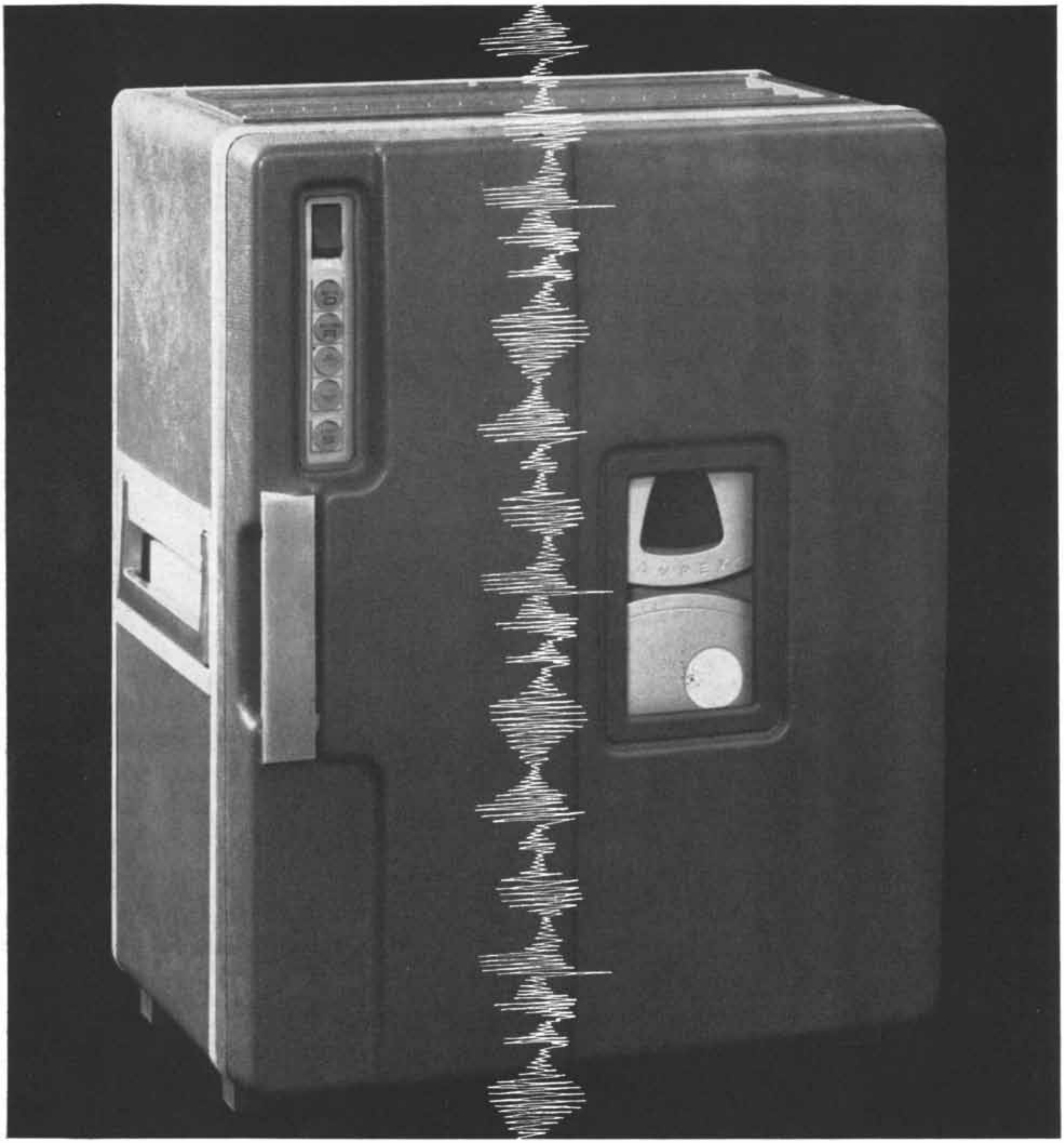

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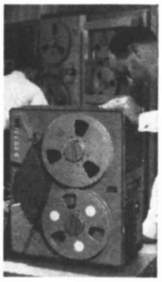

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		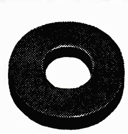		
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INDIANA GENERAL

THE AUTHORS

COLIN M. TURNBULL ("The Lesson of the Pygmies") is assistant curator of African ethnology at the American Museum of Natural History. Turnbull's entrance into anthropology resulted indirectly from his interest in philosophy and music. After taking a degree in philosophy and politics at the University of Oxford, Turnbull spent two years at the University of London studying Hindi and Sanskrit and another two years on a research fellowship at Banaras Hindu University in India. He returned to England by way of Africa, spending most of his time in the Congo, where he stayed for several months in the home of Patrick Putnam, an American anthropologist who had settled there in the 1920's. It was through Putnam that Turnbull first gained access to the Pygmies of the Ituri Forest. Already aware of the importance of music in Indian society, Turnbull was particularly struck by the role of music among the Pygmies. On a second visit in 1954 and 1955 he concluded that any understanding of the music required a thorough understanding of the whole society. A grant from the Royal Anthropological Institute made possible a third visit in 1957 and 1958. Turnbull joined the Museum of Natural History in 1959, and in 1961 he published an account of his life among the Pygmies entitled *The Forest People*.

R. D. HILL ("Resonance Particles") is professor of physics at the University of Illinois, where since 1947 he has taught and done experimental research. For the past eight years his research has been mainly in the field of high-energy nuclear physics. He was associated with the group at the Brookhaven National Laboratory that first detected in nuclear emulsions the production of tau and K mesons by the Brookhaven Cosmotron in 1954. Before going to the University of Illinois, Hill, who was born and raised in Australia, had been senior lecturer at the University of Melbourne since 1941. In the years 1939 to 1945 he was involved in radar work, first in England and later in Australia. Prior to that Hill took his D.Sc. at Melbourne in 1936, did research for a year at the University of Cambridge and worked the following year at Illinois.

R. W. HORNE ("The Structure of Viruses") is a member of the staff at the Institute of Animal Physiology in Cambridge, England. Horne, whose main interest is in developing new methods of combining electron microscopy with biochemical techniques, has since 1947 been closely associated with the development of electron microscopes and their applications. In 1958 he collaborated with Sydney Brenner of the University of Cambridge in a detailed study of the structure of the T2 virus, which infects the colon bacillus. The methods used in that study have subsequently been applied in elucidating the structure of a wide variety of viruses.

HALTON C. ARP ("The Evolution of Galaxies") is an assistant astronomer on the staff of the Mount Wilson and Palomar Observatories. He received an A.B. from Harvard University in 1949 and a Ph.D. from the California Institute of Technology in 1953, was a Carnegie Fellow at the Mount Wilson and Palomar Observatories until 1955 and a research associate at Indiana University until 1957, when he took his present job.

HENRY GILMAN and JOHN J. EISCH ("Lithium") are respectively professor of organic chemistry at Iowa State University and assistant professor of chemistry at the University of Michigan. Gilman received his B.S. from Harvard University in 1915, did graduate work at the Zürich Polytechnikum and the University of Oxford in 1916 and then returned to Harvard, where he acquired M.S. and Ph.D. degrees in 1917 and 1918. He taught for a year at the University of Illinois before joining the faculty of Iowa State, where he became a full professor in 1923. Gilman served with the Chemical Warfare Service in World War I and the Manhattan Project in World War II. He is at present a consultant to the Atomic Energy Commission, a vice-president of the American Association for the Advancement of Science and a member of the editorial boards of *The Journal of the American Chemical Society* and *The Journal of Organic Chemistry*. Eisch was graduated summa cum laude from Marquette University in 1952 and did his doctoral work under Gilman, receiving a Ph.D. in 1956. He studied for a year with Karl Ziegler at the Max Planck Institute for Coal Research in Germany and then taught at St. Louis University before going to the University of Michigan in 1959.

HANS WALLACH ("The Perception of Neutral Colors") is professor of psychology at Swarthmore College. Born and raised in Berlin, Wallach studied under Wolfgang Köhler, the founder of the Gestalt school of psychology, who was then professor of psychology at the University of Berlin. Wallach received his Ph.D. in 1935; when Köhler moved to Swarthmore the following year, Wallach went with him.

RUPERT E. BILLINGHAM and WILLYS K. SILVERS ("Skin Transplants and the Hamster") are respectively a member and an associate member of the Wistar Institute of Anatomy and Biology in Philadelphia. Billingham, who is also Wistar Professor of Zoology at the University of Pennsylvania, took a degree in zoology at the University of Oxford in 1942. After serving with the Royal Navy until 1946, Billingham returned to Oxford to begin his doctoral studies under P. B. Medawar (winner, with Sir Macfarlane Burnet, of the 1960 Nobel Prize for Physiology and Medicine). He worked with Medawar for the next 11 years (at Oxford, Birmingham University and University College London), principally on tissue transplantation and the immune reaction. Oxford awarded him D.Phil. and D.Sc. degrees in 1950 and 1957. Billingham went to Pennsylvania in the latter year and was elected to the Royal Society in 1961. Silvers, who is also a research associate in the department of dermatology of the University of Pennsylvania's School of Medicine, holds a B.A. from Johns Hopkins University and a Ph.D. from the University of Chicago.

KEITH B. MATHER ("Why Do Roads Corrugate?") is associate professor of physics at the Geophysical Institute of the University of Alaska on leave from the University of Melbourne, where he lectures in physics. Born and raised in Adelaide, Australia, Mather acquired a B.Sc. in electrical engineering from the University of Adelaide in 1942 and an M.Sc. in physics there in 1944. After three years of research in nuclear physics at Washington University in St. Louis and a year at Birmingham University, he went to Ceylon in 1950 to lead the Ceylon University Cosmic Ray Expedition to the Himalayas; two years with the Australian Atomic Energy Commission were followed by a year at Mawson Station in Antarctica. He went to the University of Melbourne in 1958 and to the University of Alaska in 1961.

KENNETH E. BOULDING, who in this issue reviews Sebastian de Grazia's *Of Time, Work, and Leisure* and Hugh Dalziel Duncan's *Communication and Social Order*, is professor of economics at the University of Michigan.

GENERAL PRECISION BUILDS BOTH FACES

ON-BOARD SYSTEMS—A Librascope computer, the first designed to guide an exploratory instrument package to a soft landing on the moon, will be carried aloft inside NASA's Atlas-Centaur spacecraft. One of the smallest and lightest general-purpose digital computers available for today's space needs.

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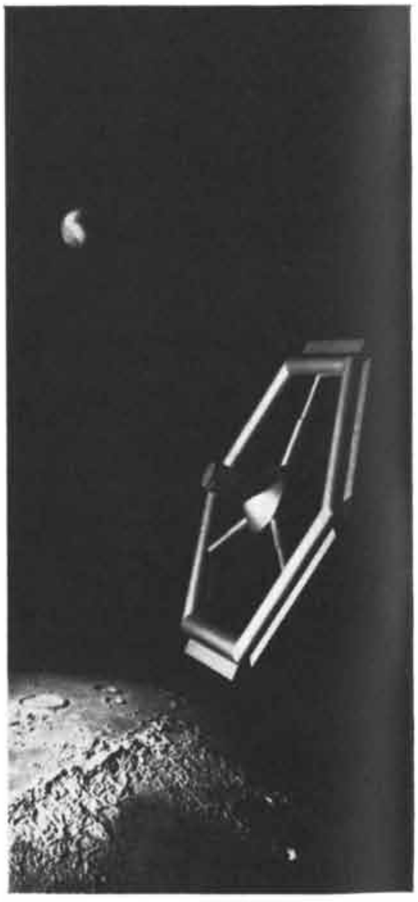
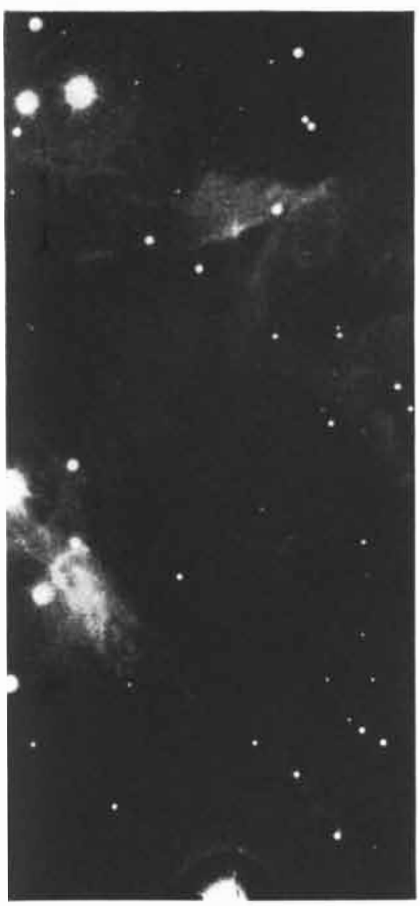
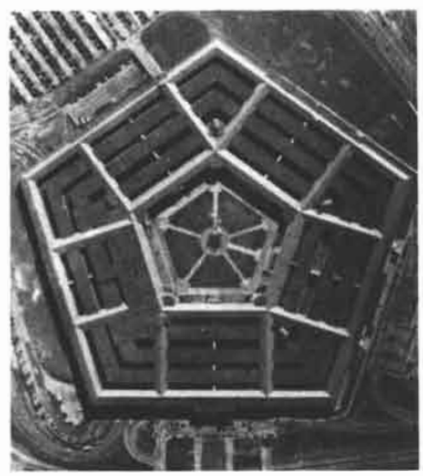


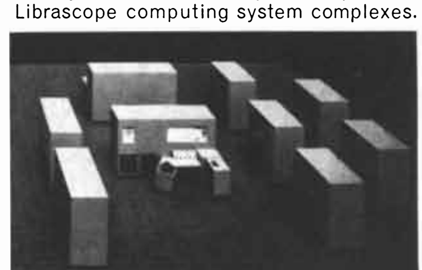
OF A SPACE-INFORMATION SYSTEM



under military and space contracts, and in integrating complex information systems. □ Other divisions of General Precision aid in furnishing the depth of experience in space-environment sensing, astro-navigation, vehicle- and ground-systems displays, and simulation-system management. □ Send for the story of Librascope's 25 years in information systems and latest work on advanced computing techniques and equipment.



GROUND-BASED SYSTEMS—From 1963 on, U.S. global strategy will be supported by this Librascope multiple-computer system, a key part of USAF's 473L command-and-control system to be installed in the Pentagon. One of the many new large-scale Librascope computing system complexes.



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From Washington—

A CLARIFICATION

that can significantly affect your future visits to the world's most important city

Few remember the original meaning of a noble word that will be dramatically clarified and redefined with the opening of The Madison in Washington, D. C., this month.

That word is "hotel". French in origin, "hotel" made its first written appearance in 1644. The literal meaning was "a town mansion", and that is what the early European hotels were: town mansions of wealthy, country-based families, privately maintained for their own uses during the brilliant Court seasons. To this day, many impressive private residences in Paris are called "hotels".

In The Madison, the word "hotel" will be restored to its original dignity and meaning.

A Long-Felt Need

The need for a luxury hotel in the great European tradition, catering to Washington's most highly placed and discerning visitors has long been recognized by a group of local businessmen, which I have the honor of heading.

We have felt that in the process of increasing their efficiency as business enterprises, the better hotels have lost much of the highly personalized flavor that distinguishes the great European hotels, and that was so importantly a part of the traditional hospitality of "Old" Washington. We believe that management by teletype from a distant management center cannot effectively satisfy the individual requirements of the individual guest, nor make him feel that he is occupying his "own" Washington town mansion.

The Madison, privately and locally owned and individually managed, is the result of our mutual determination to correct this situation and to place at the disposal of Washington's distinguished guests, an elegant "town mansion" worthy of their patronage. To this end we have pledged generously of our resources.

The Madison Atmosphere

While The Madison will be one of the world's most luxurious hotels, its atmosphere will be one of *restrained elegance*. Its opulence will be unobtrusive; there will be no glitter of chrome nor blare of unwelcome music, and there will be no garish uniforms to offend either the beholder or the wearer.

The quiet refinement and exquisite taste of The Madison's Federal period decor will be reminiscent of the gracious, unhurried correctness of living that James Madison and his wife "Dolley" brought to Washington from their stately Virginia home, Montpelier.

The Madison Service

Individual tastes and preferences of guests will be served in the European manner by a multi-lingual staff; with courtesy, dignity, quiet competence and the attentive deference that is the due of "the lord of the manor."

The right of The Madison guest to privacy will be rigidly respected. No guest accommodation will be within sight or hearing of any delivery or service area. Rooms and suites will be shielded with the most effective sound insulation known to modern building science.

And a firm policy of *"No Conventions, No Tour Groups"* will be maintained both to protect the serenity of The Madison way of life against untoward invasion, and to assure an adequate supply of accommodations to regular patrons in all seasons.

The service of food and drink in The Madison will be in the great and lavish European tradition. It is our aim to make *The Montpelier Restaurant,* off the main lobby, a mecca for connoisseurs of Continental formal dining and the adjacent *Montpelier Lounge* the most elegant gathering place for Washington gentlemen and their ladies. *The Retreat,* a bit of transplanted Old England, will be sacred to males; *La Provence,* a bright and gay dining room authentically French provincial in decor, will serve, informally, delicious meals at modest prices, and the flagstone terraced, protected sidewalk cafe will be known, appropriately, as *Coin de Paris*—in truth, "a corner of Paris."

A Pledge

It is our determination to maintain, in The Madison, the highest standards observed in the most meticulous private homes, so that you and our other perceptive guests will accept The Madison as *your own Washington town mansion,* and know that in it, you are indeed "the lord of the manor."

Marshall B. Coyne
President

THE MADISON *Washington's Correct Address*

NOTE: Our Managing Director has prepared a special indoctrination booklet for The Madison staff members. In this, the basic philosophy and the facilities of The Madison are detailed. If you would like a copy of this interesting, behind the scenes booklet, we shall be happy to forward one to you. Please address your request (preferably on your letterhead) to: Hans Sternik, Managing Director, The Madison, Fifteenth and M Streets, N.W., Washington 5, D. C.

Established 1845 SCIENTIFIC AMERICAN January 1963 Volume 208 Number 1

The Lesson of the Pygmies

It has long been assumed that these inhabitants of the African rain forest had adapted to a kind of serfdom in villages. The discovery that they have not has implications for the problems of Africa today

by Colin M. Turnbull

In the welter of change and crisis confronting the lives of the peoples of Africa it would seem difficult to work up concern for the fate of the 40,000 Pygmies who inhabit the rain forests in the northeastern corner of the Congo. The very word "pygmy" is a term of derogation. According to early explorers and contemporary anthropologists, the Pygmies have no culture of their own—not even a language. They became submerged, it is said, in the village customs and beliefs of the Bantu and Sudanic herdsmen—cultivators who occupied the periphery of the forest and reduced them to a kind of serfdom some centuries ago. By the testimony of colonial administrators and tourists they are a scurvy lot: thievish, dirty and shrouded with an aura of impish deviltry. Such reports reflect in part the sentiments of the village tribes; in many villages the Pygmies are regarded as not quite people.

To argue that the Pygmies are people—even to show that they maintain to this day the integrity of an ancient culture—will not avert or temper the fate that is in prospect for them. The opening of the rain forests of Central Africa to exploitation threatens to extinguish them as a people. The Pygmies are, in truth, *bamiki nde ndura:* children of the forest. Away from the villages they are hunters and food gatherers. The forest provides them with everything they need, generally in abundance, and enables them to lead an egalitarian, co-operative and leisured existence to which evil, in the sense of interpersonal malevolence, is so foreign that they have no word for it. After centuries of contact with the "more advanced" cultures of the villages and in spite of all appearances, their acculturation to any other mode of life remains almost nil. They have fooled the anthropologists as they have fooled the villagers. For this reason if for no other, the Pygmies deserve the concerned attention of the world outside. Their success should make us pause to reconsider the depth of acculturation that we have taken for granted as existing elsewhere, as industrial civilization has made its inexorable conquest of the earth.

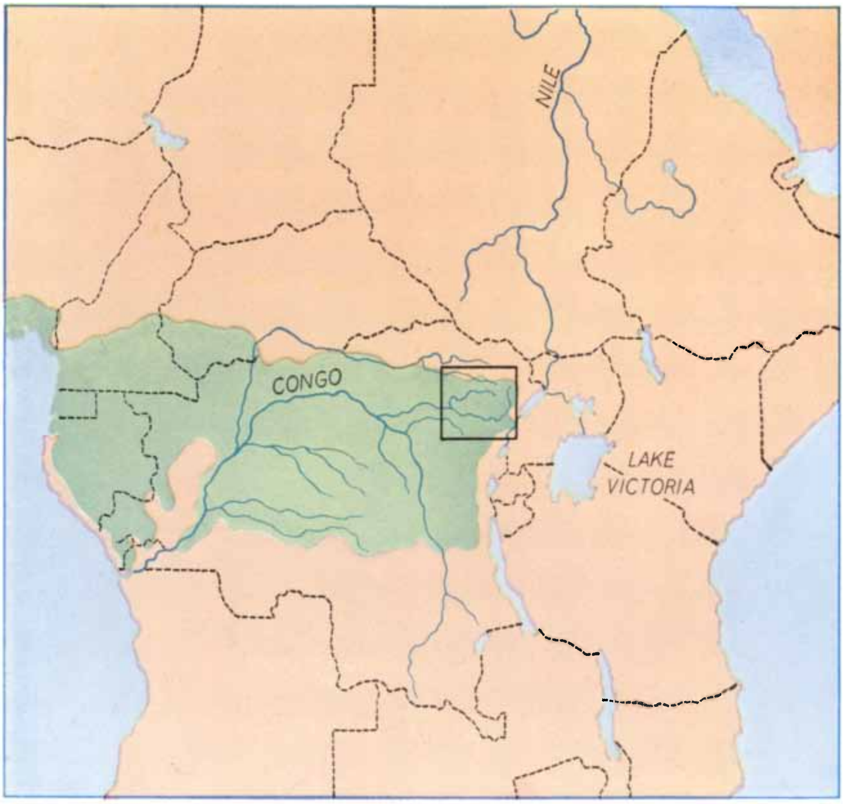
The reason for the prevailing erroneous picture of the Pygmies is now clear. It has hitherto been generally impossible to have access to them except through the offices of the village headman, who would call the local Pygmies in from the forest to be interviewed. To all appearances they lived in some sort of symbiosis, if not serfdom, with the village people, subject to both the secular and the religious authority of the village. The fact that Pygmy boys undergo the village ritual of initiation in a relation of subservience to village boys was cited as evidence of ritual dependence, and it has been held that the Pygmies are economically dependent on the villages for metal and for plantation foods, presumably needed to supplement the meat they hunt in the forest. The few investigators who got away from the villages did not manage to do so without an escort of villagers, acting as porters or guides. Even in the forest the presence of a single villager transforms the context as far as the Pygmies are concerned; therefore all such observations were still basically of Pygmies in the village, not in their natural habitat.

My own initial impression was just as erroneous. By good fortune my contact with the Pygmies circumvented the village and was established from the outset on a basis that identified me with the world of the forest. Seeing them almost exclusively in the context of the forest, I saw a picture diametrically opposed to the one generally drawn. Instead of dependence, I saw at first independence of the village, a complete lack of acculturation—in fact, little contact of any kind. It was only after two additional stays in the Ituri Forest, the home ground of the Congo Pygmies, that I was able to put the two contradictory pictures of their life together and to see the whole. It turned out that neither is wrong; each is right in its particular context. The relation of the Pygmies to the villagers is a stroke of adaptation that has served their survival and even their convenience without apparent compromise of the integrity of their forest-nurtured culture.

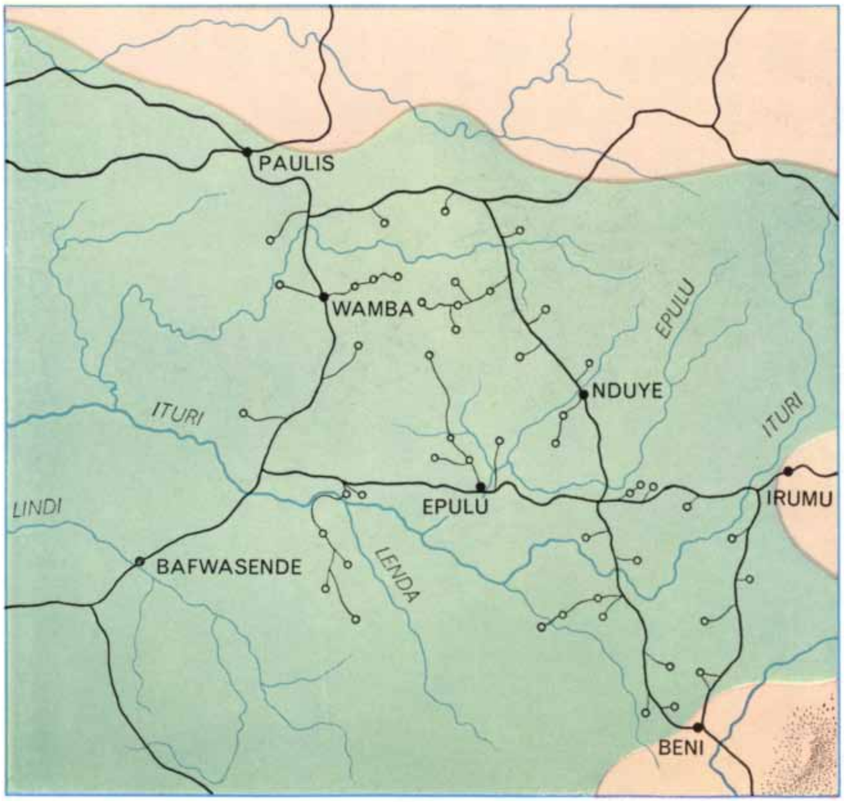
The BaMbuti, as the Pygmies of the Ituri Forest are known to themselves and to their neighbors, may be the original inhabitants of the great stretch of rain forest that reaches from the Atlantic

PYGMY WOMEN and children rest in the shade of the forest while the men collect honey from nearby trees. The women often accompany the men on honey-gathering and hunting expeditions, but they do not take part in the final stages of these activities.

PYGMY MEN remove from one of their vine nets a small forest antelope they have caught and killed. One edge of the net, which the men and older boys set up, can be seen at lower left center. The women served as beaters to drive the animal into the net.



ITURI FOREST inhabited by the Pygmies occupies an area of roughly 50,000 square miles in the northeastern corner of the tropical rain forest of the Congo, in Central Africa.



DETAIL MAP OF THE ITURI FOREST shows the Pygmy camps visited by the author (*small open circles*), villages (*black dots*) and various rivers (*blue lines*). The camps are connected by forest paths (*thin black lines*), the villages by roads (*heavy black lines*).

coast right across Central Africa to the open grassland country on the far side of the chain of great lakes that divides the Congo from East Africa. Their origin, along with that of Negrito peoples elsewhere in the world, is lost in the prehistoric past. Most Pygmies have unmistakable features other than height (they average less than four and a half feet) that distinguish them from Negroes. They are well muscled, usually sway-backed and have legs that are short in proportion to their torsos. Their faces, with wide-set eyes and flat, broad noses, have a characteristically alert expression, direct and unafraid, as keen as the attitude of the body, which is always poised to move with speed and agility at a moment's notice. They do not envy their neighbors, who jeer at them for their puny stature; in the enclosure of the forest, where life may depend on the ability to move swiftly and silently, the taller Negroes are as clumsy as elephants. For his part the Pygmy hunter wins his spurs by killing an elephant, which he does by running underneath the animal and piercing its bladder with a succession of quick jabs from a short-shafted spear.

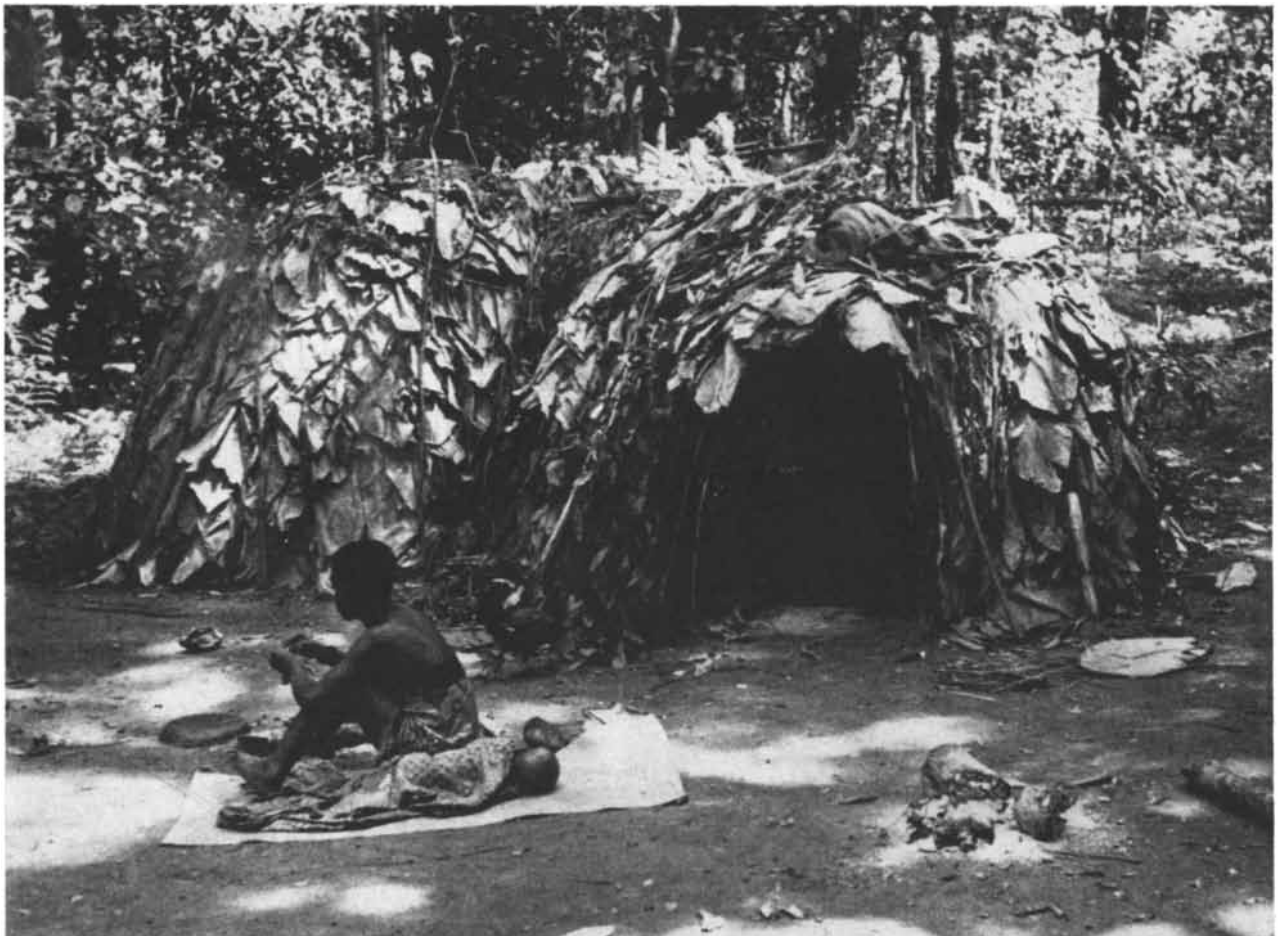
A BaMbuti hunting band may consist of as many as 30 families, more than 100 men, women and children in all. On the move from one encampment to another they fill the surrounding forest with the sound of shouted chatter, laughter and song. Along with the venting of high spirits, this ensures that lurking leopards and buffaloes will be flushed into the forest well ahead of the band and not be accidentally cornered on the trail. The women, carrying or herding the infants, dart from the trail to gather food, and the men scout the forests for game on the flanks and in the van of the ragged procession. Arriving at the campsite in no particular order, all join in the task of building huts. The men usually cut the saplings to make the frames and sometimes also the giant Phrynium leaves to cover them; the women take charge of the actual building. The saplings are driven securely into the ground around a 10-foot circle, then deftly bent and intertwined to form a lattice dome; on this structure the leaves are hung like shingles, in overlapping tiers. Before nightfall, with the first arrivals helping the stragglers to complete their tasks, the camp is built and the smoke of cooking fires rises into the canopy of the forest. The entire enterprise serves to demonstrate a salient feature of BaMbuti life: everything gets done with no direction and with no apparent organization.

A morning is usually all that is needed to secure the supply of food. The women know just where to look for the wild fruits that grow in abundance in the forest, although they are hidden to outsiders. The women recognize the undistinguished *itaba* vine, which leads to a cache of nutritious, sweet-tasting roots; the kind of weather that brings mushrooms springing to the surface; the exact moment when termites swarm and must be harvested to provide an important delicacy. The men hunt with bows and poison-tipped arrows, with spears for larger game and with nets. The last involves the Pygmy genius for co-operation. Each family makes and maintains its own net, four feet high and many yards long. Together they string the nets across a strategically chosen stretch of ground. The hunters, often joined by the women and older children, beat the forest, driving the game into the nets.

By afternoon they have brought enough food into camp and sometimes a surplus that will enable them to stay in camp the next day. Time is then spent repairing the nets, making new bows and arrows, baskets and other gear and performing various other chores. This still leaves a fair amount of free time, which is spent, apart from eating and sleeping, either in playing with the children and teaching them adult activities or in gathering in impromptu groups for song and dance.

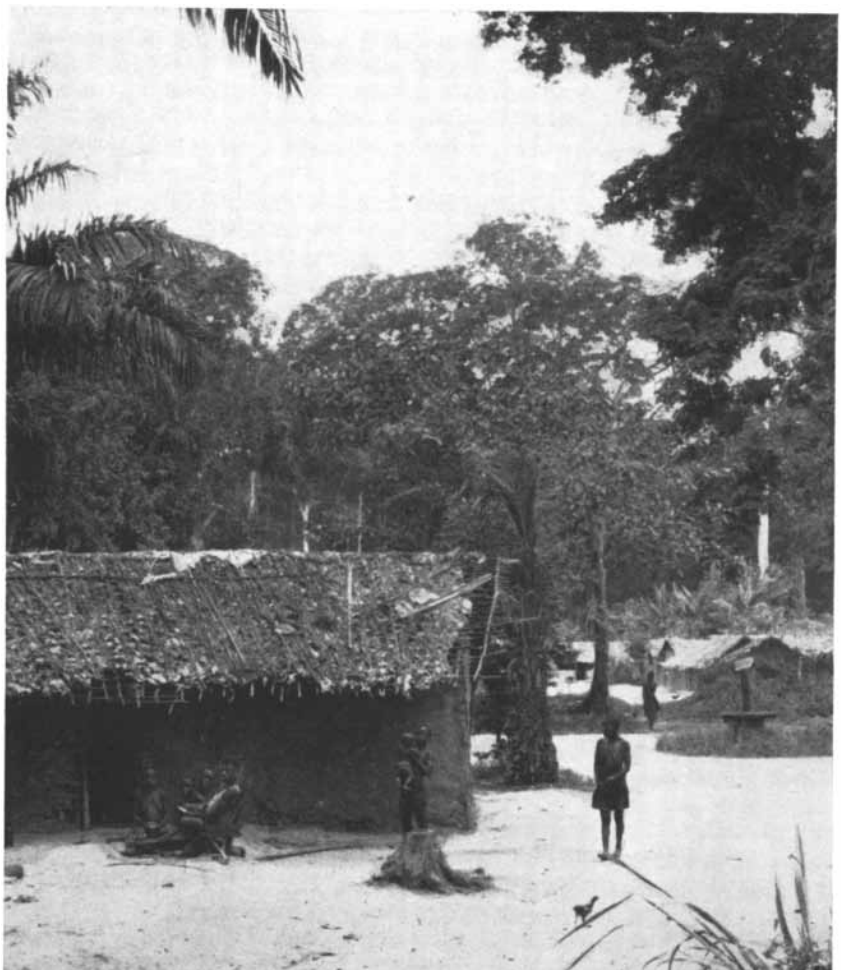
The BaMbuti have developed little talent in the graphic arts beyond the occasional daubing of a bark cloth with red or blue dye, smeared on with a finger or a twig. They do, however, have an intricate musical culture. Their music is essentially vocal and noninstrumental. It displays a relatively complex harmonic sense and a high degree of rhythmic virtuosity. With the harmony anchored in the dominant and therefore all in one chord, the singing is often in canon form, with as many parts as there are singers and with improvisations and elaborations contributed freely by each. A song may have some general meaning, but it may also be totally devoid of words and consist simply of a succession of vowel sounds. The real meaning of the song, its importance and power, is in the sound. In the crisis festival of the *molimo,* the closest approximation to a ritual in the unformalized life of the BaMbuti, the men of the band will sing, night after night, through the night until dawn. The function of the sound now is to "awaken the forest" so that it will learn the plight of its children or hear of their joy in its bounty.

The spirit of co-operation, seen in every activity from hunting to singing, takes the place of formal social organization in the BaMbuti hunting band. There is no headman, and individual authority and individual responsibility are shunned by all. Each member of the band can expect and demand the co-operation of others and must also give it. In essence the bonds that make two brothers hunt together and share their food are not much greater than those that obtain between a member of a band



HUT IN FOREST CAMP is larger than such huts usually are because a section has been added to accommodate a visiting relative. The average hut is the size of the section with an entrance. Camps are built in clearings like this one, found throughout the forest.

PYGMIES AND VILLAGERS dance together during the initial two-week period of the initiation rite described in the text. Of the 10 men in the immediate foreground, from left to right including the one with a white shirt at center, all are Pygmies except the fourth from left and the third from right. The villagers' legs are longer in proportion to their bodies.



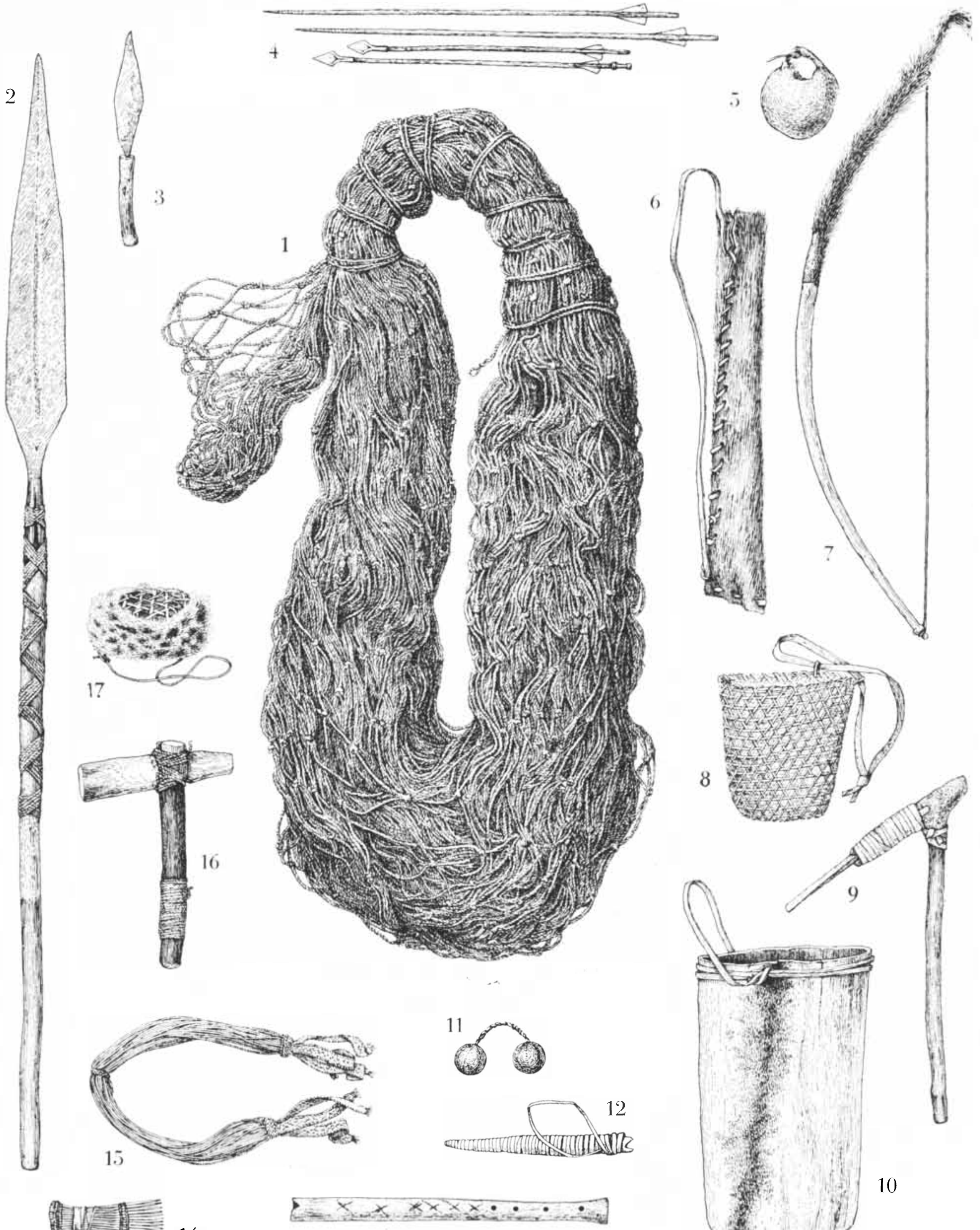
VILLAGE CAMP on the outskirts of Epulu, formerly known as Camp Putnam, includes a village-style house built by a Pygmy, to the author's knowledge the only successful such attempt by a Pygmy in this section of the forest. Usually the villagers provide a house or the Pygmies construct leaf huts. Some of the village houses appear in the background.

and a visiting Pygmy, even if he is totally unrelated. Any adult male is a father to any child; any woman, a mother. They expect the same help and respect from all children and they owe the same responsibilities toward them.

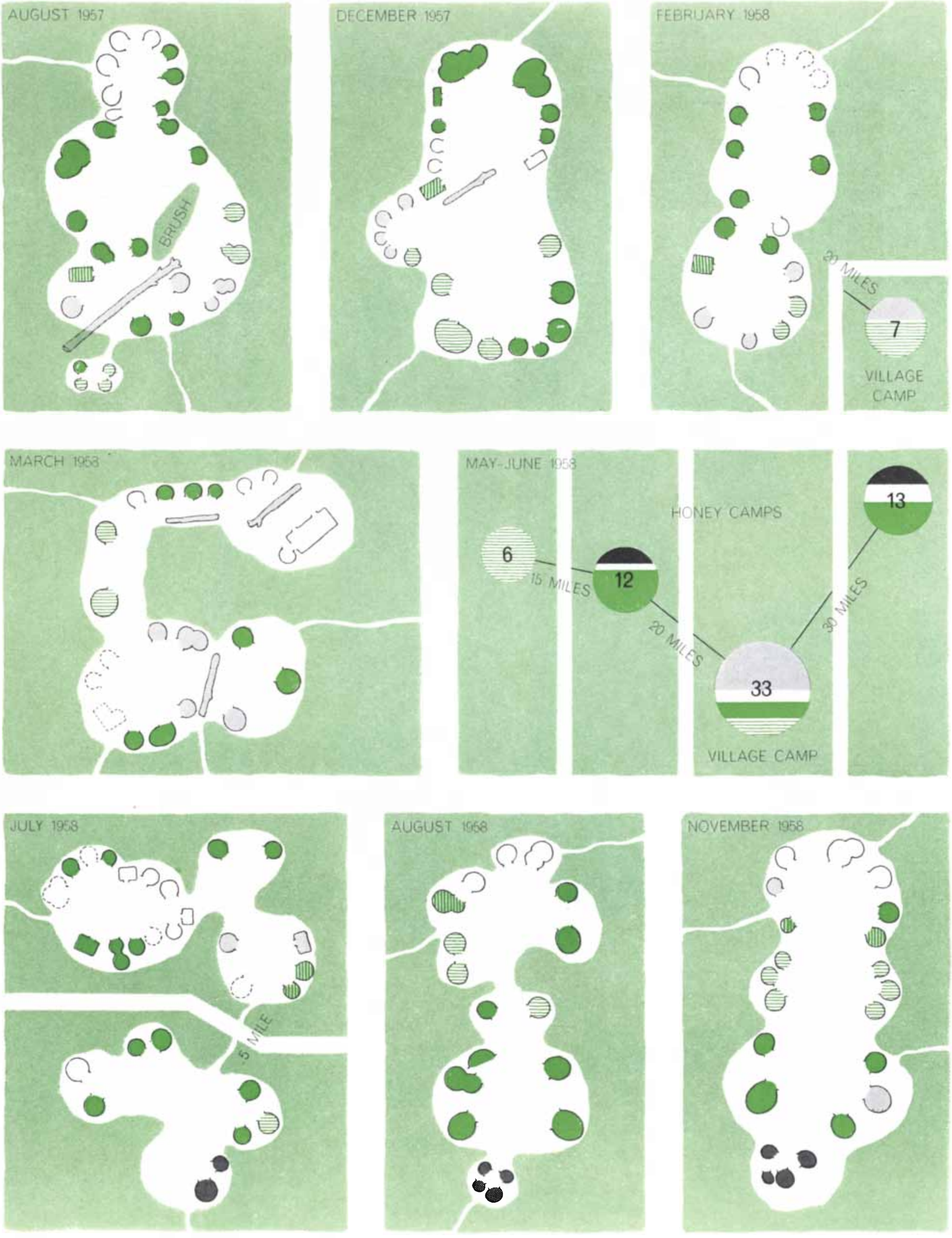
When the Pygmies encamp for a while near a village, the character of the band and its activities undergo profound and complete transformation. This happens even when a lone villager pays a visit to a Pygmy camp. Not only do such activities as singing and dancing and even hunting change, but so also does the complex of interpersonal relations. The Pygmies then behave toward each other as they would if they were in a village. They are no longer a single, united hunting band, co-operating closely, but an aggregate of individual families, within which there may even be disunity. On periodic visits to the village with which their hunting band is associated, the Pygmies occupy their own semipermanent campsite between the village and the forest. Each family usually has a particular village family with which it maintains a loose and generally friendly exchange relation. At such times the Pygmies not only supply meat, they may also supply some labor. Their main function, as the villagers see it, is to provide such forest products as meat, honey and the leaves and saplings needed for the construction of village houses. The villagers do not like the forest and go into it as seldom as possible.

It is on these occasions that travelers have seen the Pygmies and decided that they are vassals to the villagers, with no cultural identity of their own. It is true that this is how the BaMbuti appear while they are in the villages, because in this foreign world their own code of behavior does not apply. In the village they behave with a shrewd sense of expediency. It in no way hurts them to foster the villagers' illusion of domination; it even helps to promote favorable economic relations. As far as the BaMbuti are concerned, people who are not of the forest are not people. The mixture of respect, friendship and cunning with which they treat their village neighbors corresponds to the way they treat the animals of the forest: they use them as a source of food and other goods, respecting them as such and treating them with tolerant affection when they are not needed. The Pygmies have a saying that echoes the proverb of the goose and the golden egg, to the effect that they never completely and absolutely eat the villagers, they just eat them.

In the mistaken interpretations of



PYGMY ARTIFACTS are depicted at about a seventh of actual size: hunting net (*1*), metal-tipped spear (*2*), paring knife (*3*), pair of poison arrows and pair of metal-tipped nonpoisonous arrows (*4*), wrist guard made of monkey skin (*5*) for use with the bow (*7*), quiver made of antelope skin (*6*), child's basket (*8*), honey adz (*9*), bark pail for gathering honey (*10*), castanets (*11*), honey whistle (*12*), flute (*13*), comb (*14*), belt (*15*), hammer with a head of elephant tusk used in making bark cloth (*16*) and a hat (*17*).



FOREST CAMPS change structure and constitution in cyclical fashion as Pygmies move from one campsite to another; they become increasingly fragmented at the approach of the honey season (May through June), break up during the season (*figures show number of families*) and re-form afterward. The disposition of huts, directions in which they face and their shapes are as shown; some were later abandoned (*broken lines*). Of the clans constituting the group with which the author stayed during this period, the main one was the Bapuemi (*solid-colored areas*). A quarrel resulted in a split camp (*lower left*), which gradually re-formed.

this peculiar relation the fact that the Pygmies seem to have lost their original language is often cited as evidence of their acculturation to the village. Linguists, on the other hand, see nothing surprising in this fact. Small, isolated hunting bands, caught up in the intertribal competition that must have attended the Bantu invasion that began half a millennium ago, could well have lost their own language in a couple of generations. It is by no means certain, however, that the Pygmy language is extinct. Certain words and usages appear to be unique to the Pygmies and do not occur in the languages and dialects of any of the numerous neighboring tribes. What is more, the Pygmies' intonation is so distinctive, no matter which of the languages they are speaking, as to render their speech almost unintelligible to the villager whose language it is supposed to be.

Some authorities maintain that the Pygmies rely on the villagers for food and metal. As for food, my own experience has shown that the BaMbuti hunting bands are perfectly capable of supporting themselves in the forest without any help from outside. The farther away from the villages they are, in fact, the better they find the hunting and gathering. If anything, it is the villagers who depend on the Pygmies, particularly for meat to supplement their protein-deficient diet.

It is more difficult to determine to what extent the BaMbuti are dependent on village metal. A few old men speak of hardening the points of their wooden spears in fire, and children's spears are still made in this way. Except for elephant hunting the spear is mostly a defensive weapon, and the loss of metal spear blades would not be serious. Knife and ax blades are more important; the word *machetti*—for the long, heavy-bladed brush-slashing knife—is well established in the Pygmy vocabulary. There are thorny vines, however, that can serve adequately as scrapers and others that when split give a sharp if temporary cutting edge, like that of split bamboo. When I have pressed the question, it has been stated to me that, in the absence of metal blades, "we would use stones." On the other hand, I have never succeeded in persuading a Pygmy to show me how. The answer to such a request was invariably: "Why should I go to all that trouble when it is so easy to get metal tools from the villagers?"

This is in fact the core of the Pygmies' economic relation with the villagers, and it renders the term "symbiosis" inapplicable. There is nothing they need badly enough to make them dependent on the villagers, although they use many artifacts acquired from them. Metal cooking utensils are a good example: the Pygmies can get along without these comfortably. They use them only for the cooking of village foods that require boiling, such as rice; forest foods call for no such utensils. The BaMbuti will exchange goods with the villagers and even work for them, but only as long as it suits their convenience and no longer. No amount of persuasion will hold them. If a villager attempts coercion, the Pygmy simply packs up and goes back to the forest, secure in the knowledge that he will not be followed. On the next occasion he will offer his goods in another village. Tribal records are full of disputes in which one villager has accused another of stealing "his" Pygmies.

In the absence of effective economic control the villagers attempt to assert political and religious authority. The villagers themselves are the source of the myth that they "own" the Pygmies in a form of hereditary serfdom. They appoint Pygmy headmen, each responsible for his band to the appropriate village headman. Because the bands not only shift territorially but also change as to their inner composition, however, a village headman can no more be sure which Pygmy families comprise "his" band than he can tell at any time where the band has wandered. In his appointed Pygmy headman he has a scapegoat he can blame for failure of the band to fulfill its side of some exchange transaction. But the Pygmy has no wealth with which to pay fines and can rarely be caught for the purpose of enforcing any other restitution.

The villagers nonetheless believe themselves to be the masters. They admit it is a hard battle and point out that the Pygmies are in league with the powerful and tricky spirits of the forest. The fear the villagers have of the forest goes beyond a fear of the animals; it is also a respect based on the knowledge that they are newcomers, if of several hundred years' standing. This respect is even extended to the Pygmies. Some villages make offering to the Pygmies of the first fruit, acknowledging that the Pygmies were there before them and so have certain rights over the land. This offering is also expected to placate the forest spirits. Ultimately, however, the villagers hope to subject the Pygmies to the village spirits and thereby to assume total domination.

In carrying the contest into the realm of the supernatural, the villagers invoke the full armory of witchcraft and sorcery. To the villagers these methods of social control are just as scientific and real as, say, political control through armed force. Moreover, although witchcraft and sorcery generally get their results by psychological pressure, they can sometimes be implemented by physiological poisons. There are strange tales of illness and of death due to sorcery, and no Pygmy wants to be cursed by a villager. On receiving threats of this kind the hunting band takes to the forest, secure in the belief that village magic is no more capable of following them into the forest than are the villagers themselves.

More subtly, the villagers engage the Pygmies in the various important rituals of the village culture. A Pygmy birth, marriage or death, occurring when the hunting band is bivouacked near a village, sets in motion the full village ceremonial appropriate to the occasion. The "owner" of the Pygmy in each case assumes the obligation of providing the child-protecting amulet, of negotiating the exchange of bride wealth or of paying the cost of the obsequies. Such intervention in a Pygmy marriage not only ensures that the union is regularized according to village ritual; it also gives the owners in question indissoluble rights, natural and supernatural, over the new family. The Pygmies willingly submit to the ritual because it means a three-day festival during which they will be fed by the villagers and at the end of which, with luck, they will be able to make off with a portion of the bride wealth. On returning to the forest the couple may decide that it was just a flirtation and separate, leaving the villagers to litigate the expense of the transaction and the wedding feast. Although they are economically the losers, the villagers nonetheless believe that by forcing or cajoling the Pygmies through the ritual they have subjected them, at least to some extent, to the control of the village supernatural.

The same considerations on both sides apply to a funeral. The ritual places certain obligations on the family of the deceased and lays supernatural sanctions on them; death also involves, almost invariably, allegations of witchcraft or sorcery. Once again, therefore, the villagers are eager to do what is necessary to bring the Pygmies within the thrall of the local spirit world. And once again the Pygmies are willing to co-operate, knowing that the village funerary ritual prescribes a funerary feast. Even though their custom calls

COLLECTING HONEY takes place during a season that lasts approximately two months. The Pygmy reaching into the tree with his left hand holds a honey adz in his right. This instrument is used whenever it becomes necessary to open the tree in order to get at the hive. The honey is usually found much higher up in a tree. All the photographs that appear in this article were made by the author.

for quick and unceremonious disposal of the dead, they are glad to let the villagers do the disposing and even to submit to head-shaving and ritual baths in return for a banquet.

By far the most elaborate ritual by which the villagers hope to bring the Pygmies under control is the initiation of the Pygmy boys into manhood through the ordeal of circumcision, called *nkumbi*. All village boys between the ages of nine and 12 are subject to this practice, which takes place every three years. Pygmy boys of the appropriate age who happen to be in the vicinity are put through the same ceremony with the village boys. A Pygmy boy is sent first "to clean the knife," as the villagers put it, and then he is followed by a village boy. These two boys are thereafter joined by the blood they shed together in the unbreakable bond of *kare*, or blood brotherhood. Any default, particularly on the part of the Pygmy, will invoke the wrath of the ancestors and bring all manner of curses on the offender. So once more the Pygmies are placed under the control of the village spirits and the putative bonds between the serfs and their owners are reinforced. Some villagers also see this practice as a means of securing for themselves an assured complement of Pygmy serfs to serve them in the afterworld.

As in all the other ritual relations, the BaMbuti have their own independent motivation and rationalization for submitting their sons to the pain and humiliation of *nkumbi*. For one thing, the Pygmy boys acquire the same secular adult status in the village world as their village blood brothers. The Pygmies, moreover, have the advantage of knowing that the bonds they do not consider unbreakable nonetheless tie their newly acquired village brothers; they made use of this knowledge by imposing on their *kare*. Finally, for the adult male relatives of the Pygmy initiates the ceremony means three months or so of continuous feasting at the expense of the villagers.

Once the *nkumbi* is over and the Pygmies have returned to the forest, it becomes clear that the ritual has no relevance to the inner life of the family and the hunting band. The boys who have gone to such trouble to become adults in the village sit on the laps of their mothers, signifying that they know they are really still children. In Pygmy society they will not become adults until they have proved themselves as hunters.

Back in the forest the Pygmies once again become forest people. Their counter to the villagers' efforts to bring them under domination is to keep the two worlds apart. This strategy finds formal expression in the festival of the *molimo*. The *molimo* songs are never sung when a band is making a visitation to a village or is encamped near it. Out in the forest, during the course of each night's singing, the trail leading off from the camp in the direction of the village is ceremonially blocked with branches and leaves, shutting out the profane world beyond.

The relation between the Pygmy and the village cultures thus resolves itself in a standoff. Motivated as it is by economics, the relation is inherently an adversary one. The villagers seek to win the contest by domination; the Pygmies seek to perpetuate it by a kind of indigenous apartheid. Because the relation is one of mutual convenience rather than necessity, it works with reasonable success in the economic realm. The villagers ascribe the success, however, to their spiritual domination; any breakdown they cannot correct they are content to leave to rectification by the supernatural, a formula that works within their own society. The Pygmies hold, on the other hand, that the forest looks after its own, a belief that is borne out by their

PESTLE AND MORTAR are used by a Pygmy woman to make plantains, such as those beside her, into a paste. Pestle, mortar, plantains and metal dish at left are village products.

DRYING MEAT OVER A FIRE preserves it against the time when it will be taken to the villages to be traded. Otherwise the meat would rot quickly. The Pygmies never store or preserve food for their own use.

daily experience. In the nature of the situation, each group is able to think it has succeeded, as indeed in its own eyes it has. The very separateness of the two worlds makes this dual solution possible. But it is a solution that can work only in the present context.

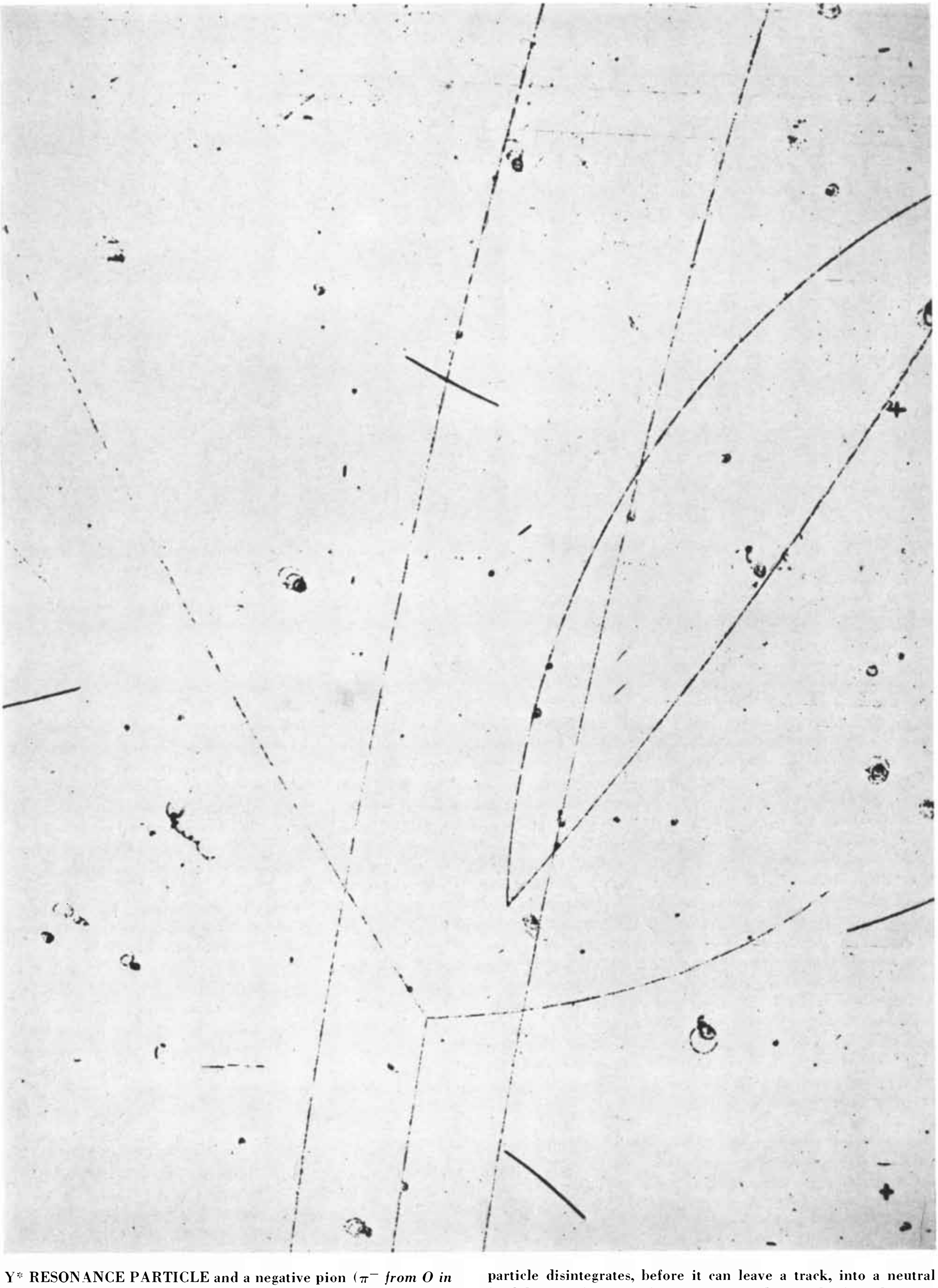
A breakdown began when the Belgians insisted that the villagers plant cotton and produce a food surplus. The villagers then needed the Pygmies even more as a source of manpower. At the same time, with roads being cut through the forest, the movement of game became restricted. If the process had continued, the Pygmies would have found it increasingly difficult to follow their hunting and food-gathering way of life and would indeed have become the economic dependents of the villagers. The present political turmoil in the Congo has given the Pygmies a temporary reprieve.

In some areas, however, the Belgians had decided to pre-empt the untapped Pygmy labor force for themselves and had already set about "liberating" the Pygmies from the mythical yoke of the villagers, persuading them to set up plantations of their own. The result was disastrous. Used to the constant shade of the forest, to the purity of forest water and to the absence of germ-carrying flies and mosquitoes, the Pygmies quickly succumbed to sunstroke and to various illnesses against which the villagers have some immunity. Worse yet, with the abandoning of hunting and food gathering the entire Pygmy social structure collapsed. Forest values were necessarily left behind in the forest, and there was nothing to take their place but a pathetic and unsuccessful imitation of the new world around them, the world of villagers and of Europeans.

This whole problem was much discussed among the Pygmies just prior to the independence of the Congo. In almost every case they reached the determination that as long as the forest existed they would try to go on living as they had always lived. More than once I was told, with no little insight, that "when the forest dies, we die." So for the Pygmies, in a sense, there is no problem. They have seen enough of the outside world to feel able to make their choice, and their choice is to preserve the sanctity of their own world up to the very end. Being what they are, they will doubtless continue to play a masterful game of hide-and-seek, but they will not easily sacrifice their integrity.

It is for future administrations of the Congo that the problem will be a real one, both moral and practical. Can the vast forest area justifiably be set aside as a reservation for some 40,000 Pygmies? And if the forest is to be exploited, what can one do with its inhabitants, who are physically, temperamentally and socially so unfitted for any other form of life? If the former assessment of the Pygmy-villager relation had been correct and the Pygmies had really been as acculturated as it seemed, the problem would have resolved itself into physiological terms only, serious enough but not insuperable. As it is, seeing that the Pygmies have for several hundred years successfully rejected almost every basic element of the foreign cultures surrounding them, the prospects of adaptation are fraught with hazards.

Traditional values die hard, it would seem, and continue to thrive even when they are considered long since dead and buried. In dealing with any African peoples, I suspect, we are in grave danger if we assume too readily that they are the creatures we like to think we have made them. If the Pygmies are any indication, and if we realize it in time, it may be as well for us and for Africa that they are not.



Y* RESONANCE PARTICLE and a negative pion (π^- *from O in drawing at right*) are produced in this bubble-chamber collision between a negative K meson ($\bar{K}^-$) and a proton at *O*. The resonance particle disintegrates, before it can leave a track, into a neutral lambda particle, which leaves no track (*broken line*), and a positive pion (π^+). The lambda decays into a proton (p^+) and a nega-

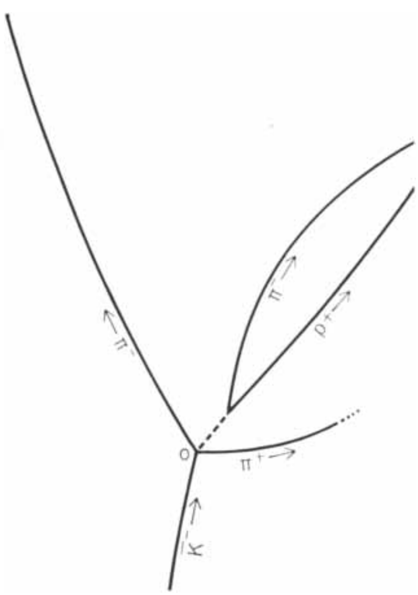
RESONANCE PARTICLES

Most of the 32 fundamental particles of matter decay rather quickly. There are still other particles that decay even more quickly. It now seems that the latter are "resonant" associations of other particles

by R. D. Hill

When is a particle "fundamental"? The fact that most subatomic particles decay quite quickly into other particles has made this a perennial question of physics. Now the difficulty is compounded by a new group of "particles" that are even more evanescent than the particles known earlier.

The list of "old" particles, which are generally considered fundamental and which I shall call Type I, has been static for some time [*see illustration on page 41*]. It still consists only of those particles mentioned as discovered or predicted in an article that appeared in SCIENTIFIC AMERICAN more than five years ago [see "Elementary Particles," by Murray Gell-Mann and E. P. Rosenbaum; SCIENTIFIC AMERICAN, July, 1957].



tive pion (π^-). The photograph was made by the experimental team under Luis W. Alvarez at the Lawrence Radiation Laboratory.

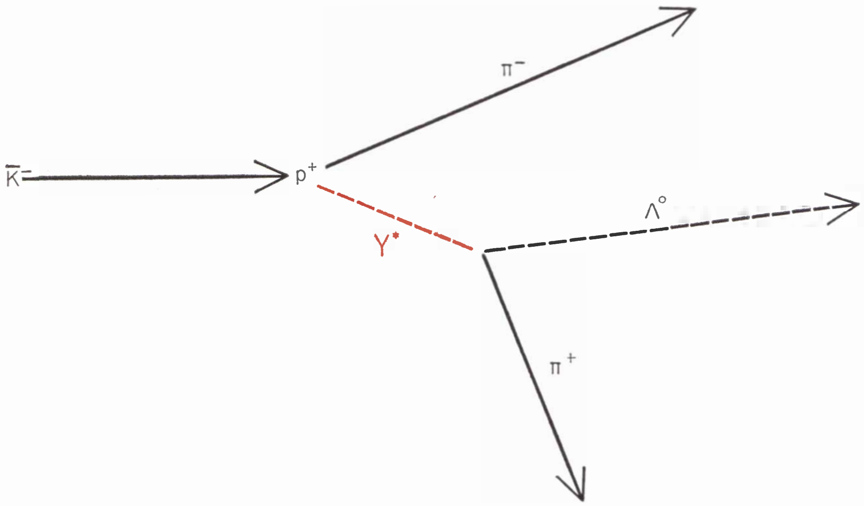
Apart from the inherently stable particles, most of the Type I particles decay in about a ten-billionth of a second. This lifetime gives them a chance to move measurable distances in a detector such as a bubble chamber. The new particles, which I call Type II, decay in about the time it takes for light to move a distance equal to a few diameters of an atomic nucleus. Their lifetimes are measured in hundred-thousandths of a billion-billionth of a second (10^{-23} second)—far too short a time to leave visible tracks or to be observed directly in any way. Their existence can only be inferred by studying the Type I particle products of their disintegrations. The question is: Were they ever autonomous particles or were they merely a group of separate pieces that moved together for a short time before flying apart? Physicists have avoided the question by calling the particles "resonances," implying that they may indeed have been temporary associations of other particles.

How is their existence detected at all? To help the reader understand the way in which they were found I shall begin by describing a fanciful experiment in classical physics, that is, the kind of physics that obtained before the introduction of quanta and relativity. Like all classical explanations of quantum and relativistic events, the analogy is far from perfect. It should nonetheless serve to provide a rough idea of what is involved.

Suppose an odd kind of artillery shell is made by gluing together three pieces of strong glass around an explosive charge. One of the pieces is red; the other two are perfectly transparent and therefore invisible. The shell is fired, moving, let us suppose, on a straight trajectory at a constant speed. As observers we move parallel to the shell in an airplane traveling at the same speed. When the shell explodes, it breaks into its three component pieces. The center of mass of these pieces continues to move in its original direction at its original speed, according to the law of the conservation of momentum. We too continue to move in this direction and at this speed. Therefore it is as if the shell and we were both stationary when the shell exploded. We are observing in the "center-of-mass system" of the exploding fragments.

Since two of the three pieces are invisible, after the explosion we can see only the red piece. We measure its speed with respect to our own position. If we perform the experiment a large number of times, we will obtain a continuous spectrum of speeds of the red fragment varying from zero up to some maximum. Zero speed corresponds to the case in which all the energy in the explosive charge is carried off by the other two pieces. This will not happen often, but it can happen. More likely is a fairly equal division of energy among the three pieces. Very unlikely is a sharing of all the energy between the red piece and the other two pieces when the latter do not separate. Thus the expected speed, or energy distribution, of the observed piece is a smooth curve [*see bottom illustration on next page*].

Suppose now that the two invisible pieces are cemented together with a glue that does not give way in the explosion. Then the shell breaks only into two pieces. When we observe the speed of the red piece, we find that it is always the same, because the energy of the explosion can be shared in only one way with the invisible piece. A plot of the energy



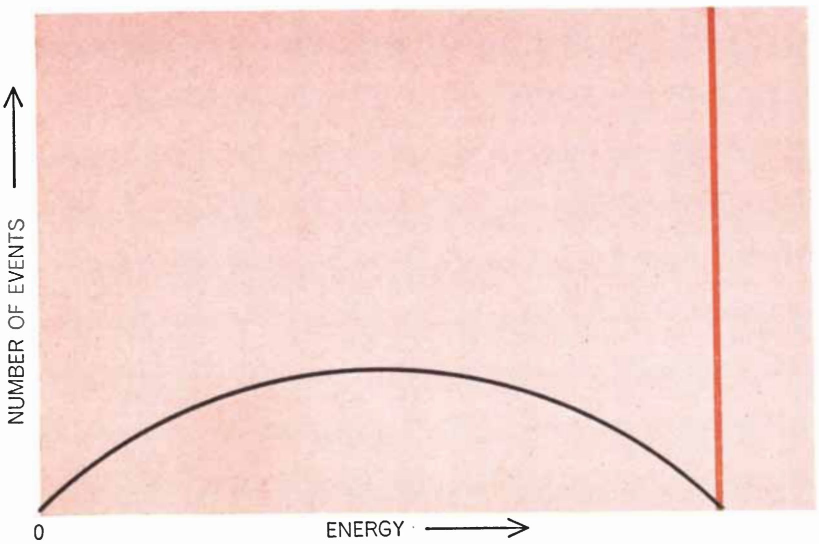
Y* PARTICLE PRODUCTION shown in the photograph on page 38 is depicted in greater detail. The resonance particle in this instance was positive; the pion produced along with it was therefore negative. Conversely, if the particle had been negative, the accompanying pion would have been positive and the second pion (from the decay of the Y*) would have been negative. The distance traveled by the Y* (*broken colored line*) is of the order of 10^{-13} centimeter; thus in a bubble chamber the π^+ appears to come from the point of collision.

is a sharp line. In this way the energy distribution of the visible piece enables us to tell whether or not the invisible section broke apart in the explosion.

The first particle experiment comparable to the one I have described was performed by the bubble-chamber group at the Lawrence Radiation Laboratory of the University of California in the summer of 1960. The Lawrence Laboratory workers were shooting a beam of high-energy negative K mesons at the liquid hydrogen in the bubble chamber. They observed that when a $\bar{K}^-$ meson struck a proton (p), a small fraction of the collisions produced a neutral lambda particle ($\Lambda°$) and a negative and a positive pi meson, or pion (π^- and π^+). The reaction is written: $\bar{K}^- + p^+ \rightarrow \Lambda° + \pi^+ + \pi^-$.

The experimental team (Margaret Alston, Luis W. Alvarez, P. Eberhard, Myron L. Good, W. Graziano, Harold K. Ticho and Stanley G. Wojcicki) observed a few hundred of these events and with the help of a computer analyzed the energies represented by the visible pion tracks. They found a distribution with energy peaks indicating that, in a certain fraction of the selected events, one of the charged pions (plus or minus) was recoiling from one rather than two other particles [*see bottom illustration on page 43*]. The implication was that the other pion and the lambda particle did not "break apart" immediately but remained together as a single unit at least long enough for the observed pion to recoil from it. This single unit the physicists named Y*. The reaction was envisaged as: $\bar{K}^- + p^+ \rightarrow Y^{*+-} + \pi^{-+}$. (The double plus and minus signs refer to the fact that the charge of the Y* was either + or − and was opposite to that of the pion.) In a very short time, so short that the Y* can leave no visible track, this reaction is followed by: $Y^{*+-} \rightarrow \Lambda° + \pi^{+-}$.

Calculations of the energies and momenta involved in the processes showed that the Y* acts like a particle with a mass of 1,384 million electron volts (Mev). This figure is made up of the rest masses of the two particles into which the Y* decays: 140 Mev for the pion and 1,115 Mev for the lambda, plus an additional kinetic energy of 129 Mev with which the pion and lambda fly apart. (According to the celebrated relation $E = mc^2$, energy and mass are equivalent quantities. In particle physics it is now customary to measure rest mass in energy units. The mass of an electron is .51 Mev; the mass of a proton, 938.2 Mev.) The reader will notice that the energy "spikes" representing the recoil from the Y* are not infinitely sharp like the spike in the projectile example. Instead they have a finite, measurable width of about 60 Mev. This width, which is made up of a spread in the energies of the various particles observed, constitutes an uncertainty in the mass-energy of the Y*. According to the uncertainty principle of quantum mechanics, uncertainty in energy is inversely proportional to uncertainty in time. An infinitely sharp spike would have an energy uncertainty of zero and therefore an infinite time uncertainty. This is the same as saying that the particle or state whose energy is represented "lives" forever; that is, it is completely stable. An energy uncertainty of 60 Mev, on the other hand, corresponds to a time uncertainty of something on the order of 10^{-23} second. This is the period



DISTRIBUTION OF ENERGY to one of three pieces of an exploding shell (in the imaginary experiment described in the text) over a number of events can be represented by a smooth curve. But if two of the three pieces always stick together, the third piece will, in theory, always receive the same amount of energy; its energy curve becomes a straight line.

within which the Y* can exist as a separate entity; in other words, it is a measure of its average lifetime.

What exactly is the Y*? Is it a pion and a lambda particle traveling briefly together before they take separate paths? Or is it an elementary particle that turns into a pion and a lambda particle in about 10^{-23} second? No one really knows. It may even be that with such short lifetimes the distinction is not meaningful. Whatever might be the final decision on this point, the current usage is to describe the Y* as a resonance particle. The basis of the term "resonance" is as follows.

After the Y* had been found its discoverers at once pointed out its similarity to a previously known resonance: the resonance between the pion and the proton (or neutron). According to the present convention the resonance could be called an N*, N representing a nucleon (proton or neutron). This had been discovered in quite a different way. In 1952 Enrico Fermi and his colleagues at the University of Chicago were carrying out experiments in which a beam of pions was scattered by protons. They, and somewhat later other workers at the Carnegie Institute of Technology, found that the cross section, which is a measure of the probability, of scattering increased sharply beginning at a beam energy of about 100 Mev and continued to increase up to nearly 200 Mev, the highest-energy pion beam available from the accelerators of the time. When the three-billion-electron-volt Cosmotron at the Brookhaven National Laboratory went into operation, Luke C. L. Yuan and Seymour J. Lindenbaum were able to show that the cross section reached a distinct peak at a pion energy of 195 Mev and then fell off quite sharply again.

Keith A. Brueckner, then at Indiana University, suggested that there was an unusually strong and characteristic interaction between a pion and a proton that caused them to have a resonance at this energy. The characteristic feature of such an N* resonance is the phase, or relative timing, of the oscillations of the wave associated with the scattered pion. (Thinking of particles as waves is, of course, always permissible in quantum mechanics. The probabilities of pion-scattering at different energies are related to the changes of phase of the pion waves as they pass by and through the nucleon. The amounts of phase change can be inferred from scattering observations.) As in many other resonant vibrating systems that are encountered in physics, the phase of the scattered pion wave is shifted a quarter wavelength, or 90 degrees, at resonance, and the angle measuring the amount of shift increases and decreases smoothly on both sides of the resonance point [*see bottom illustration on page 45*].

Here too arises the question: What is the physical interpretation of the resonance? Do the target proton and the incident pion temporarily merge into a single fundamental particle—the N*—when they are close together at the right energy or do they retain their individuality and merely interact (for example, whirl about each other) very strongly? Again the answer is uncertain, but again the answer may be meaningless. In any case the N* behaves like a particle with a rest mass of 1,237 Mev and a lifetime even a little shorter than that of the Y*.

In the years from 1952 to 1960 much effort went into analyzing the nature of the pion-nucleon resonance at 195 Mev and also into a search for additional resonances in the pion-scattering cross section at higher energies. Several more resonances have in fact been found, and their characteristics are now known to be different from those of the original resonance. To understand wherein lies the difference it is necessary to become acquainted with two rather technical concepts of particle physics.

One of these is reasonably straightforward in that it has an analogy in classical physics. It is angular momentum. Many fundamental particles have an intrinsic angular momentum, or spin. (Some have no spin.) In all cases a measurement of the amount in a preferred direction is quantized: it may in a particular case be + 1/2 or − 1/2 unit (the plus sign refers to spin in one direction; the minus, to spin in the opposite direction), + 1, 0 or − 1, + 3/2 or − 3/2 units and so on, but never other than integral or half-integral values. Continuing the classical particle analogy still further, in a system of two particles that revolve around each other the orbital motion gives them additional angular momentum, which is also quantized. The total angular momentum of a system of two particles consists of the sum of the spin and the orbital angular momentum. Depending on their relative directions the two may add to or subtract from each other.

The pion has no intrinsic angular momentum, or spin; the nucleon has a spin of 1/2. Analysis of the interactions of

	PARTICLE	PARTICLE CHARGE STATES	ANTIPARTICLE CHARGE STATES	MASS (MEV)	MEAN LIFE (SECONDS)
LEPTONS	NEUTRINO	ν_e, ν_μ	$\bar{\nu}_e, \bar{\nu}_\mu$	0	STABLE
	ELECTRON	e^-	e^+	.51	STABLE
	MUON	μ^-	μ^+	105.66	2.2×10^{-6}
BOSONS	PHOTON	γ	γ	0	STABLE
	PION	π^0	π^0	135	2.3×10^{-16}
		π^+	π^-	139.6	2.6×10^{-8}
	K MESON	K^+	$\bar{K}^-$	494	1.2×10^{-8}
		K^0	$\bar{K}^0$	497.8	6×10^{-8} 1×10^{-10}
BARYONS	PROTON	p^+	$\bar{p}^-$	938.2	STABLE
	NEUTRON	n^0	$\bar{n}^0$	939.5	1×10^3
	LAMBDA	Λ^0	$\bar{\Lambda}^0$	1115.4	2.5×10^{-10}
	SIGMA	Σ^+	$\bar{\Sigma}^-$	1189.4	$.8 \times 10^{-10}$
		Σ^0	$\bar{\Sigma}^0$	1191.5	$< .1 \times 10^{-10}$
		Σ^-	$\bar{\Sigma}^+$	1196	1.6×10^{-10}
	XI	Ξ^0	$\bar{\Xi}^0$	1311	1.5×10^{-10}
		Ξ^-	$\bar{\Xi}^+$	1318.4	1.3×10^{-10}

TYPE I PARTICLES are considered fundamental particles by virtue of their relatively long lifetimes, which average a ten-billionth of a second (10^{-10} second). On the basis of their masses the particles on this list have been classified as leptons, bosons or baryons.

pions and nucleons shows that their orbital angular momentum in the N* state is 1. Depending on the relative directions, the spin of the nucleon could combine with the orbital angular momentum so as to add or subtract from it and give a total spin of 1/2 or 3/2. In the case of the pion-nucleon resonance at 195 Mev the two apparently add to give an angular momentum of 3/2. If the resonance is thought of as a single particle, the two components can be considered to have merged into the spin of this particle. If the resonance is thought of as composite, there is a mixture of spin and orbital momentum.

The second concept used to classify the resonances bears the rather deceptive name of isotopic spin. The name is misleading because the word "spin" is used largely in a figurative sense. Isotopic spin is actually a series of quantum numbers, like those describing real spin, which describe the possible charge states of a particle. For example, a particle such as the lambda, which is always neutral, is said to have an isotopic spin of zero. The nucleon, which is either the positive proton or the neutral neutron, is assigned isotopic spin of 1/2. A spin of +1/2 corresponds to positive charge; a spin of −1/2, to neutral charge. Some particles, including the pion, have three possible charge states: positive, negative and neutral. The isotopic spins corresponding to these are +1, −1 and 0. When two particles form a resonant system, their isotopic spins are "aligned" in such a way as to add or subtract. In the case of the pion-nucleon resonance at 195 Mev the pion isotopic spin of 1 is added to the nucleon isotopic spin of 1/2 to give a total of 3/2. Therefore the resonance is called a 3/2, 3/2 state; that is, the isotopic spin is 3/2 and the angular momentum is 3/2.

As described above isotopic spin might seem to be an arithmetical label for charge. Actually it is more than that. The quantum numbers have a deeper physical significance that can only be hinted at here. It turns out that the probabilities of various reactions that are otherwise equivalent depend sensitively on isotopic spin. Specifically the theory predicts that the proton-scattering cross section at the N* resonance for positive pions and protons should be three times the cross section for negative pions and protons. As can be seen in the illustration on page 44, this ratio is found almost exactly in the experiments.

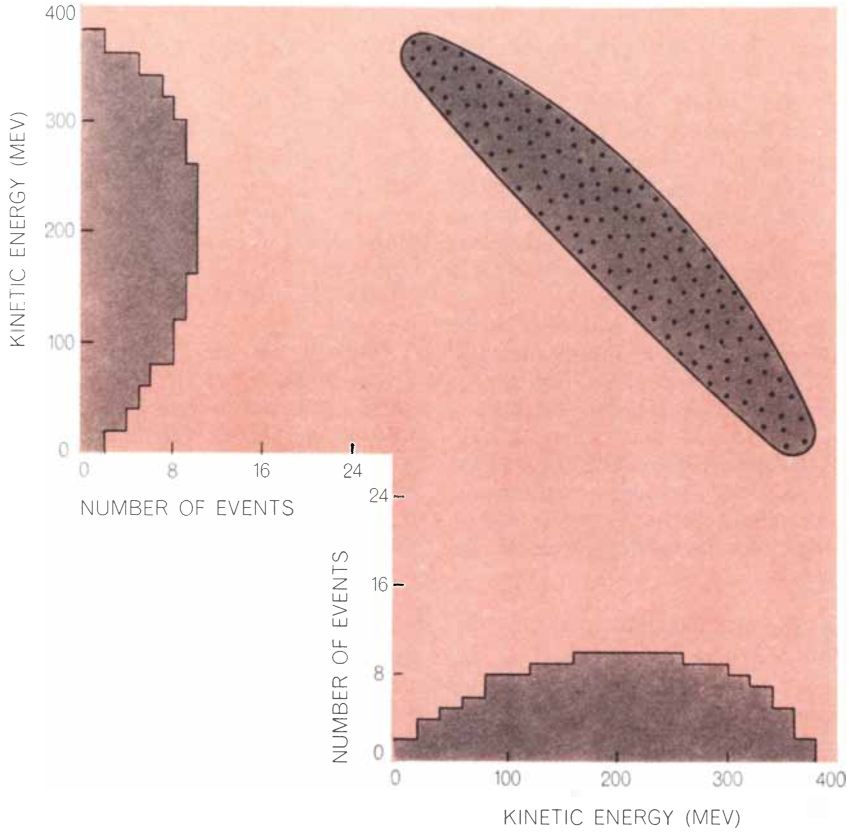
Ordinary spin and isotopic spin, then, are two of the most important properties of any particle or resonance particle. A knowledge of these quantities makes it possible to predict many of the reactions in which the particle may participate. As the illustration at the left shows, a large number of resonances have now been found. For some the ordinary spin and isotopic spin have been definitely determined. For others the values are still doubtful or, in a few cases, unknown.

The present article aims at no more than a "phenomenological" description of the resonance particles and not at a theoretical interpretation. Many theorists are busy trying to find schemes to account for them, but I shall mention these attempts only briefly.

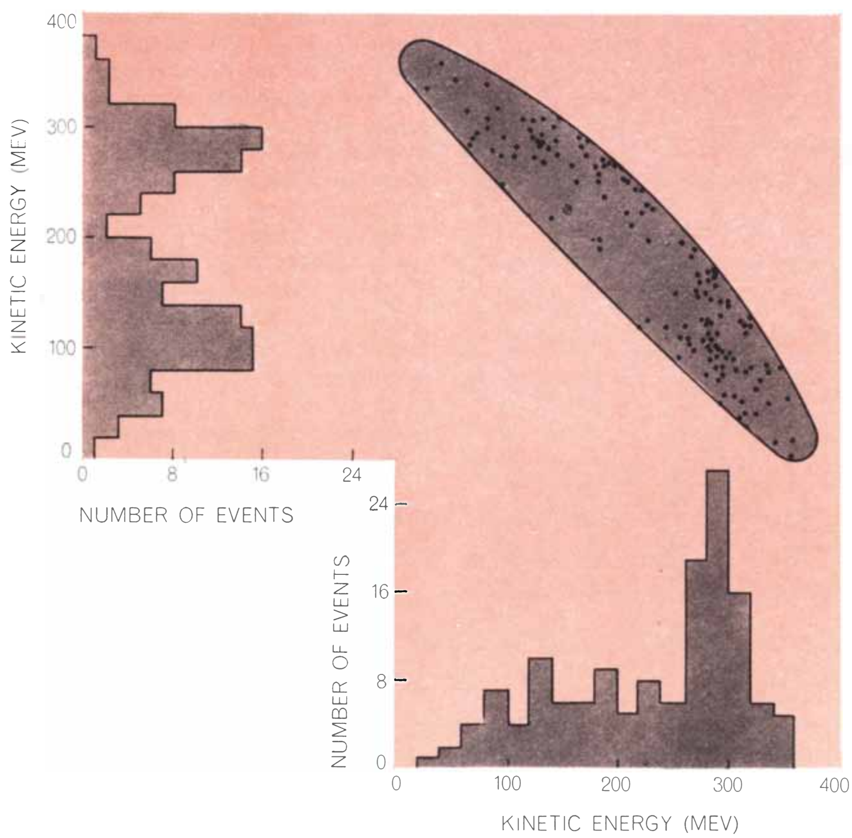
Some of the resonances were in fact predicted before they were found. In the case of the original Y* the experimenters were led to analyze their data in the way they did by an idea put forward by Murray Gell-Mann of the California Institute of Technology. He suggested that there should be a general symmetry among the interactions of pions with all the various "baryons"—

RESONANCE PARTICLE	ISOTOPIC SPIN	TOTAL ANGULAR MOMENTUM	MASS (MEV)	PARTICLE PRODUCTION
$\eta\,(\pi^+\pi^-\pi^\circ)$	0	0	550	$\pi^+ + d^+ \to \eta^\circ + p^+ + p^+$
$\rho\,(\pi\pi)$	1	1	760	$p^+ + \overline{p}^- \to \rho^\circ + \pi^+ + \pi^-$ $\pi^\pm + p^+ \to \rho^\pm + p^+$
$\omega\,(\pi^+\pi^-\pi^\circ, \pi^\circ\gamma)$	0	1	790	$p^+ + \overline{p}^- \to \omega^\circ + \pi^+ + \pi^-$ $\pi^+ + d^+ \to \omega^\circ + p^+ + p^+$
$K^*\,(K\pi)$	1/2	1	880	$\overline{K}^- + p^+ \to K^* + p^+$ $\pi^- + p^+ \to K^* + \Sigma$
$K\overline{K}$	?	?	1,020	$\pi^- + p^+ \to \overline{K}^\circ + K^\circ + n^\circ$ $\overline{K}^- + p^+ \to \overline{K}^- + K^+ + \Lambda^\circ$
$N^*\,(\pi N)$	3/2	3/2	1,237	$\pi^\pm + p^+ \to \pi^\pm + p^+$
$Y^*\,(\pi\Lambda, \pi\Sigma)$	1	3/2	1,384	$\overline{K}^- + p^+ \to Y^* + \pi$ $\pi^- + p^+ \to Y^* + \overline{K}$
$Y^{**}\,(2\pi\Lambda, \pi\Sigma)$	0	1/2	1,405	$\overline{K}^- + p^+ \to Y^{**} + \pi$
$N^{**}\,(\pi N)$	1/2	3/2	1,516	$\pi^- + p^+ \to N^{**} + \pi$
$Y^{***}\,(\pi\Lambda, \pi\Sigma, KN)$	0	3/2	1,520	$\overline{K}^- + p^+ \to Y^{***} + \pi$
$\Xi^*\,(\pi\Xi)$	1/2	> 1/2	1,535	$\overline{K}^- + p^+ \to \Xi^* + K$
$N^{***}\,(\pi N)$	1/2	5/2	1,683	$\pi^- + p^+ \to N^{***} + \pi$

TYPE II PARTICLES are the resonance particles. Those listed here are considered to be reasonably well established, but many of the values given are still tentative. No generally accepted nomenclature yet exists. Four are identified by Greek letters: eta (η), rho (ρ), omega (ω) and xi* (Ξ^*). The decay particles are shown in parentheses. For example, an omega particle decays into either three pions or a pion and a photon, the K* decays into a K meson and a pion, the N* into a pion and a nucleon (i.e., proton or neutron), and so on. The column at far right represents the reactions that produce the various particles; *d* represents a deuteron, or the nucleus of a heavy-hydrogen atom, consisting of one proton and one neutron. In contrast to Type I particles, the resonance particles have much shorter lifetimes, of the order of a hundred-thousandth of a billion-billionth of a second (10^{-23} second).



EXPECTED DALITZ PLOT shows the theoretical distribution of energy between the two pion products of the reaction: $K^- + p^+ \rightarrow \Lambda^\circ + \pi^+ + \pi^-$. The energy of the positive pion produced in 141 instances of this reaction can be read on the horizontal scale at bottom; the energy of the negative pion produced in the same events, on the vertical scale at upper left. The distribution of energy between the two pions in a large number of events should be more or less equal, and the energy plot for any one product should result in the type of histogram shown, which is the equivalent of a smooth curve (*see bottom illustration on page 40*). The lenticular area at upper right defines the range of values within which the energies from a single event must fall. The distribution of energies (*dots*) is uniform.



OBSERVED DALITZ PLOT of the interaction of a negative K meson and a proton is based on the studies of the bubble-chamber group under Alvarez. The energy distribution in the lenticular area is not uniform, and the plots show that the distribution of energy occurs mainly in peaks: two relatively strong peaks in the plot of the negative pion and a single stronger peak in that of the positive pion. The distribution is consistent with a reaction that produces two particles rather than three: $\bar{K}^- + p^+ \rightarrow Y^* + \pi$. The width of the strongest resonance peak is 60 Mev, which corresponds to an average lifetime for the Y^* of 10^{-23} second. This type of graphic analysis received its name from Richard H. Dalitz of the University of Chicago, who developed it to study tau-meson decay.

particles as heavy as nucleons or heavier. Since a resonance between pion and nucleon was already known, this suggested that there should also be a resonance between the pion and the lambda particle, which is one of the baryons.

Another line of theoretical work has led to the discovery of several resonances among pions. This work got its impulse from recent studies of the scattering of electrons by nucleons. Robert Hofstadter and his colleagues at Stanford University were the pioneers in this field [see "The Atomic Nucleus," by Robert Hofstadter; SCIENTIFIC AMERICAN, July, 1956], and they were later joined by Robert R. Wilson's group at Cornell University and G. R. Bishop's group at the Orsay laboratory of the French National Center for Scientific Research. Their experiments have shown that both the electric and the magnetic properties of protons and neutrons are not concentrated at a point but are distributed over a space of finite size. In other words, the experiments are depicting the electromagnetic structure of the nucleon.

That structure turns out to be analyzable into three separate parts. First, there is a core: a small, central region of positive charge that accounts for about a fourth of the total charge. Second, there is a "vector" portion that is positive in the proton and negative in the neutron and that extends over the whole nucleon; it accounts for about half of the total charge. Third, there is a positive "scalar" portion, also extending over the whole particle and contributing a fourth of the total charge.

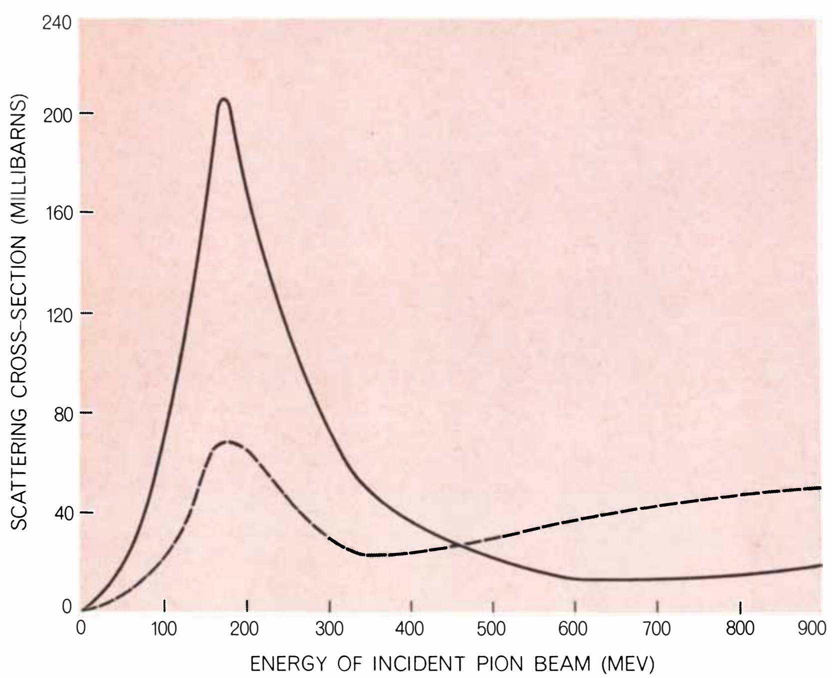
As for magnetism, part of it in the case of the proton is directly identified with the spinning charge. But there is another part, which occurs in both proton and neutron, that cannot be identified with the net over-all charge. This is known as the anomalous magnetic moment. It too turns out to consist of three components resembling those of the charge.

When the detailed pictures of the electromagnetic structure of the nucleon began to emerge, it was at once apparent that they would not fit satisfactorily into the then prevailing theory of the nucleon. All such theories are based on still another concept peculiar to quantum theory: the idea of virtual "field particle" emission. Briefly, it is believed that a proton or neutron continually emits and reabsorbs virtual pions. The time that the nucleon spends in this virtual state and the distance that the pion separates from the nucleon are consistent with the uncertainty principle. Thus for a certain fraction of the time the core of the nucleon is surrounded by a meson cloud, and it is this cloud that accounts for the extended charge and magnetic moment.

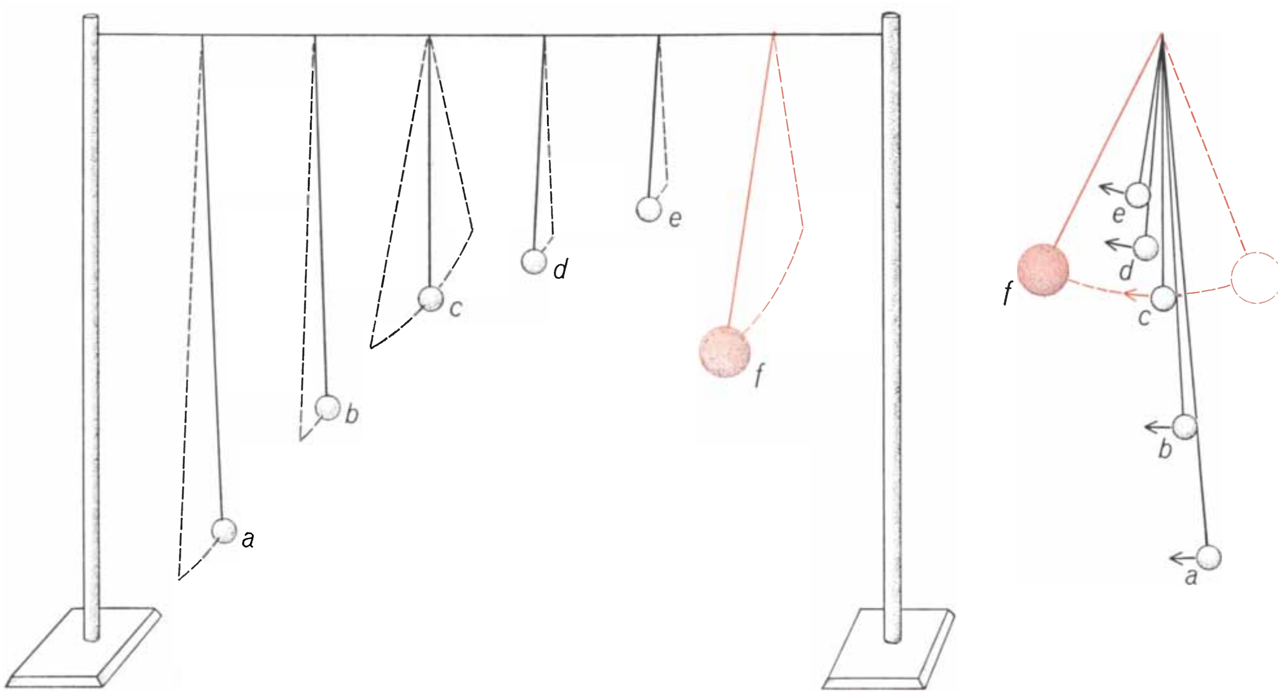
Originally the virtual-emission process was envisaged in terms of noninteracting pions. But Hofstadter's results could not be explained in this way. In 1959 William R. Frazer and Jose R. Fulco of the Lawrence Radiation Laboratory showed that the vector part of the charge and the magnetic properties would be accounted for if the nucleon emitted two pions and these entered into a strong, or resonant, interaction while they were out in the cloud. To put it another way, the calculations predicted a two-pion resonance particle, and they showed that it should have an isotopic spin of 1, an angular momentum of 1 and a mass of approximately 600 Mev.

These calculations prompted experimenters to look for a 600-Mev resonance particle in various pion-pion interactions. Evidence for it was soon found independently by a number of groups. One result, for example, showed that when a high-energy pion produces a second pion by colliding with a proton, there is a strong attraction between the two pions. Eventually experiments analogous to those outlined for the Y^* demonstrated that the resonance known as the rho particle has a mass of approximately 760 Mev, which is in good agreement with the current theory of electromagnetic structure of the nucleon.

Also in 1959 Geoffrey F. Chew of the Lawrence Radiation Laboratory pointed out that the scalar part of the nucleon electromagnetic structure could be understood in terms of another resonant interaction, this time involving three pions. Since this part of the nucleon structure is the same for proton and neutron, the isotopic spin of a three-pion resonance interaction needed to explain this feature has to be zero; that is, it must exist in only one neutral charge form. Chew suggested that it was not unreasonable to anticipate the existence of a strong three-pion resonance particle, which should have a mass approximately the same as the two-pion resonance state. It should be mentioned that Chew's suggestion of a zero isotopic-spin particle was not the first. Two years earlier



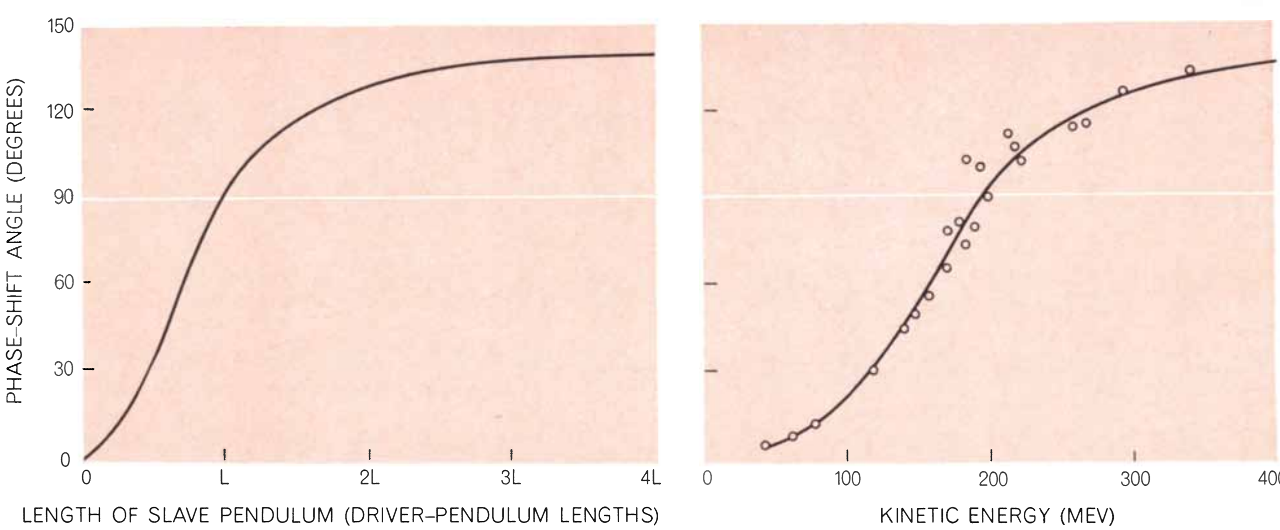
PION-PROTON RESONANCE, discovered in 1952, was the first of its kind. The two curves plot the probability that a beam of positive (*solid line*) and negative pions (*broken line*) will be scattered by protons. The scattering cross section, or probability (measured in millibarns), for positive pions begins to increase sharply at about 100 million electron volts (Mev), reaches a peak of somewhat more than 200 Mev and then falls off almost as sharply. In contrast, the resonant effect for the scattering of negative pions is only a third as strong.



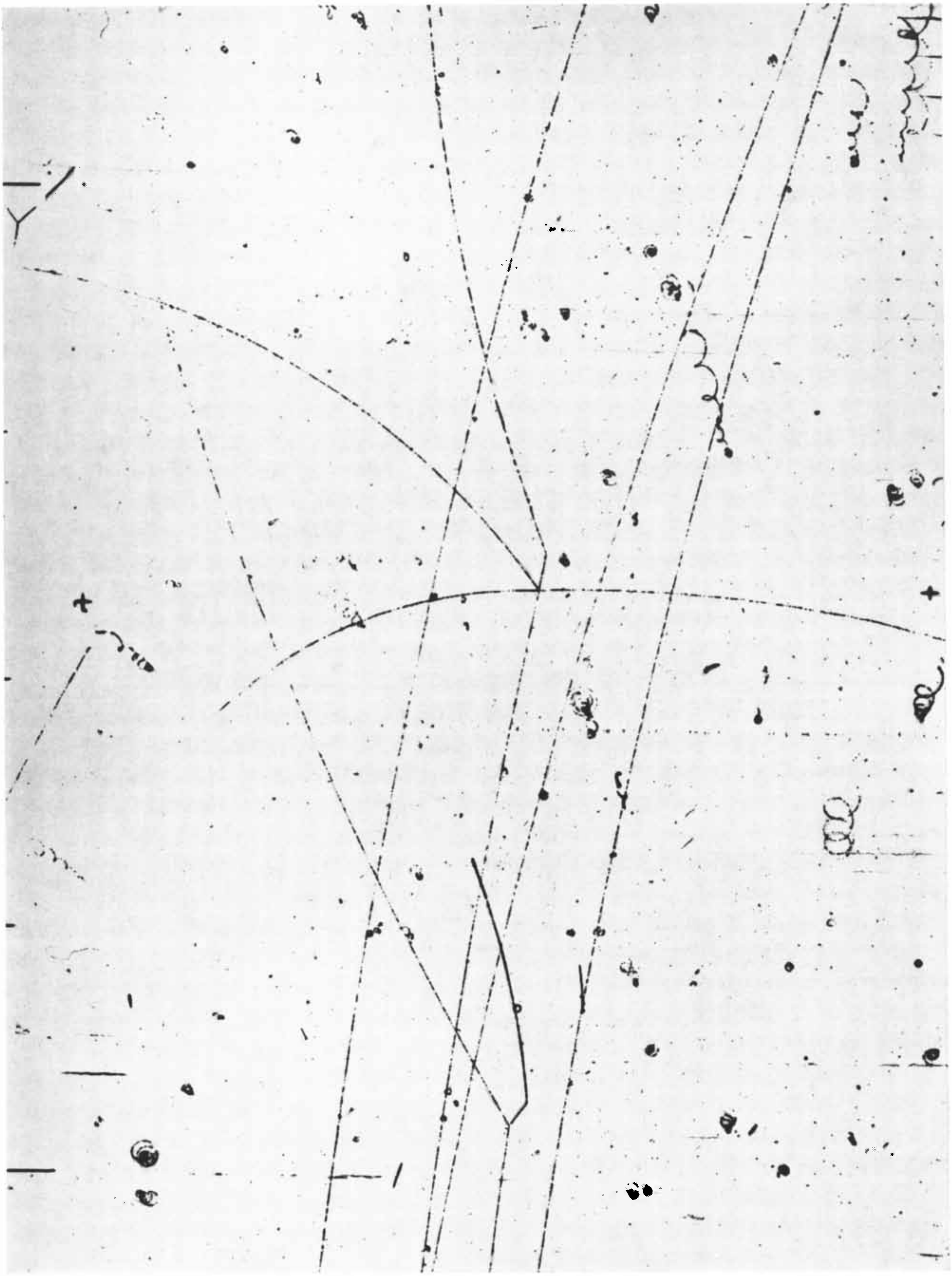
COUPLED PENDULUMS provide a mechanical illustration of a resonant system. The frequency of the driver pendulum (*f*) is greater than that of the first two "slave" pendulums (*a and b*), the same as that of the third (*c*) and smaller than that of the last two (*d and e*). The third oscillates 90 degrees out of phase with the driver (i.e., a quarter of a cycle behind it). The first two oscillate between 90 and 180 degrees behind, the last two between zero and 90 degrees behind. This lag is the phase shift (*see illustration below*).

Yoichiro Nambu of the University of Chicago had suggested the existence of a neutral heavy meson that would contribute to the electromagnetic structure of the nucleon. These ideas were clearly responsible for the research that led to the discovery of the various multiple-pion resonance states now known. Probably the most spectacular experimental discovery was that of the omega: the three-pion resonance that Chew and Nambu had predicted. The experiments were carried out by B. C. Maglic, Luis W. Alvarez, Arthur H. Rosenfeld and M. Lynn Stevenson of the Lawrence Laboratory. They studied the annihilation of antiprotons (p) encountering protons in the 72-inch liquid-hydrogen bubble chamber. Annihilations yield a wide variety of products, but the experimenters concentrated only on those that produced four outgoing pion tracks. Out of 2,500 events of this type only 800 had the following special property: in order to balance energy and momentum in the annihilation process, another neutral pion must have been present with the outgoing particles. These carefully restricted events were therefore examples of the following reaction: $p^+ + p^- \rightarrow \pi^+ + \pi^- + \pi^0 + \pi^+ + \pi^-$.

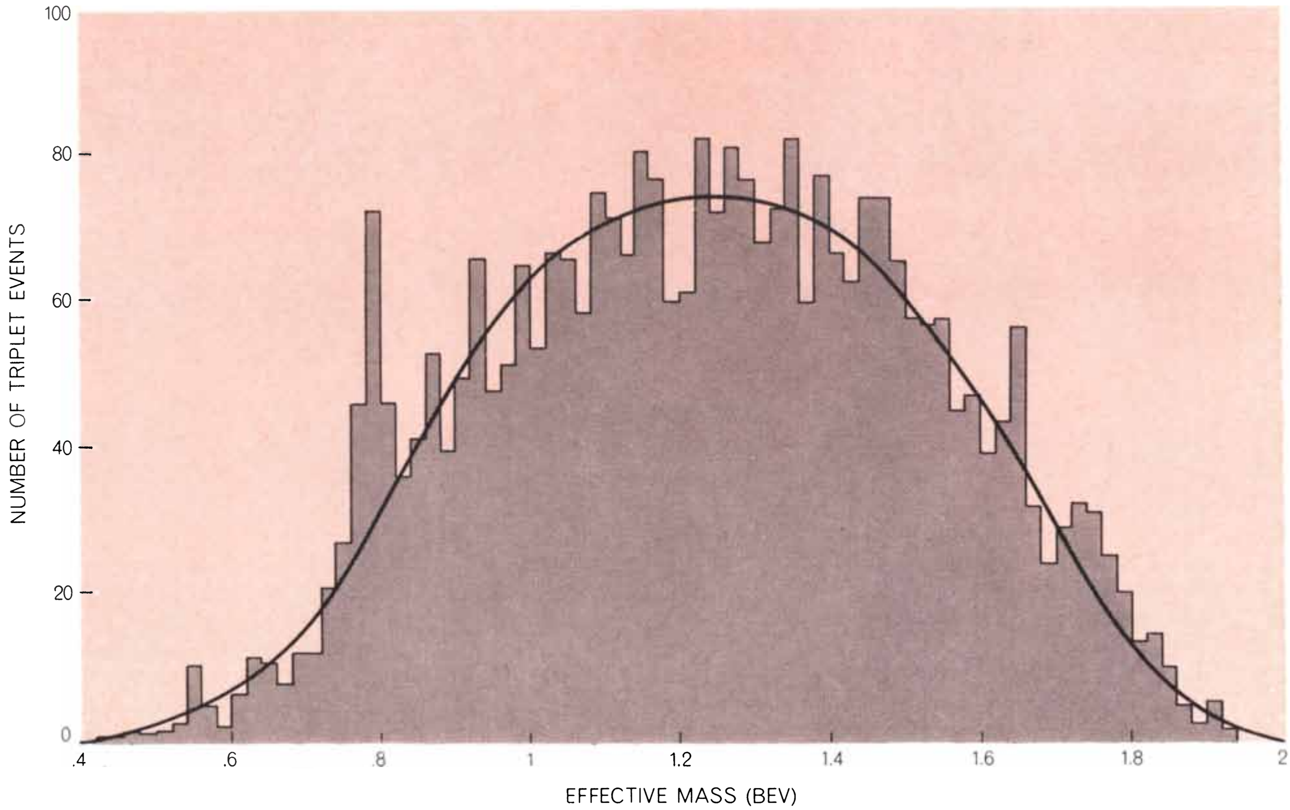
In all 800 examples of the reaction the physicists hoped to find some energy



RESONANCE EFFECT in the scattering of pions by protons becomes apparent when energy is plotted against phase shift (*graph at right*). The curve closely resembles that of the corresponding plot of phase angle against the pendulum length (*graph at left*).

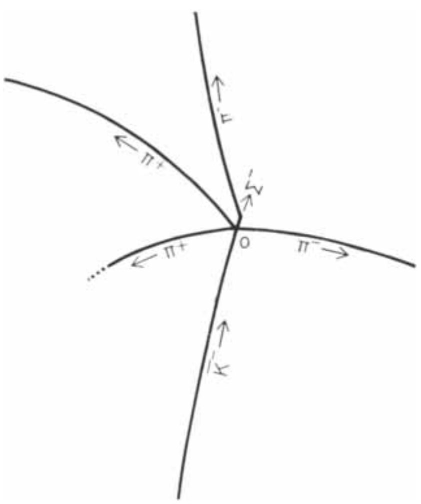


PRODUCTION OF POSSIBLE Y**** from the collision of a negative K meson ($\bar{K}^-$ *in drawing at right*) with a proton at *O* cannot be distinguished from the direct production of a negative sigma particle (Σ^-), one negative pion and two positive pions (and possibly even a neutral pion) in this reaction, unless careful analyses are made of the energies and momenta of the particles involved.



OMEGA RESONANCE PARTICLE, a three-pion particle, was discovered in experiments carried out at the Lawrence Radiation Laboratory. Its observed mass (*peak near .8 Bev*) was 790 Mev. All the other masses tended to average out along the smooth curve.

where three of the pions exhibited a resonant interaction. (Since they were looking for a neutral resonance, they knew that one of the pions would have to be neutral and the other two oppositely charged.) A further detailed analysis of the dynamics of the 800 events was



The sigma particle decays into a negative pion and a neutron, which leaves no track. Photograph was made by the Alvarez group.

then performed (using high-speed digital computers throughout) and an "effective" mass was computed for every possible combination of three of the five pions present in each event. The method was similar to that already discussed in connection with the discovery of the Y*.

It was found that only the expected combination—namely, the π^+, π^-, π° combination—led to a group of mass values having a peak value characteristic of a single particle [*see illustration above*]. Very few of the pion triplets, in fact only 93, showed the property of being in the resonant state. Presumably almost all the other cases represented production of independent pions. Nevertheless, there were enough to point clearly at the omega particle (ω°), and to show that it is a neutral combination (π^+, π^-, π°) arising from the reaction: $p^+ + \bar{p}^- \rightarrow \omega^\circ + \pi^+ + \pi^-$. The observed mass of the omega resonance particle is 790 Mev, and its lifetime, as determined from the width of the particle resonance, is equal to or greater than 4×10^{-23} second.

At present the nature of the resonance particles is very much in question. As has been mentioned, certain theoretical ideas account fairly well for certain of the particles. But there are some particles that seem to have no such pedigree.

Of course, theoretical physicists are trying hard to find some general framework that will accommodate all the resonances. There have been several independent lines of attack, which I can do no more than to identify in a few words. One has been to regard some of the resonance particles as the quanta of certain fields, just as the photon is the quantum of the electromagnetic field and the pion the quantum of the nuclear-force field. Another approach has been to consider that all possible particles are associated with a representation of the mathematical form known as a group. A third line makes use of a new idea in the mathematics of quantum theory known as Regge poles. Here all particles are regarded as equally fundamental and equally composite, each being representable as a dynamical interaction of the others.

On this necessarily mysterious note the article closes. If the reader is mystified, so are physicists. The place of the resonance particles in the scheme of things is one of the most puzzling physical questions to which the future, one hopes, will provide the answer.

The Structure of Viruses

The electron microscope reveals that these infectious particles possess three principal types of symmetry. Each species of virus is ingeniously assembled from just a few kinds of building block

by R. W. Horne

When the smaller members of the virus family are enlarged several hundred thousand times in the electron microscope, they are found to possess an extremely high degree of structural symmetry. In such viruses it is probable that the subunits visible in electron micrographs are individual protein molecules, often identical in kind, packed together to form a simple geometric structure. In the larger viruses the geometry is usually more complex, and a certain degree of structural flexibility begins to appear. Viewing the micrographs one has the impression of being shown how the inanimate world of atoms and molecules shades imperceptibly into the world of forms possessing some of the attributes of life.

Viruses are the smallest biological structures that embody all the information needed for their own reproduction. Essentially they consist of a shell of protein enclosing a core of nucleic acid—either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA). The shell serves as a protective jacket and in some instances as a means for breaching the walls of those living cells that the virus is capable of attacking. The nucleic acid core enters the cell and redirects the cell machinery toward the production of scores of complete virus particles. When the job is done, the cell ruptures and the viruses spill out.

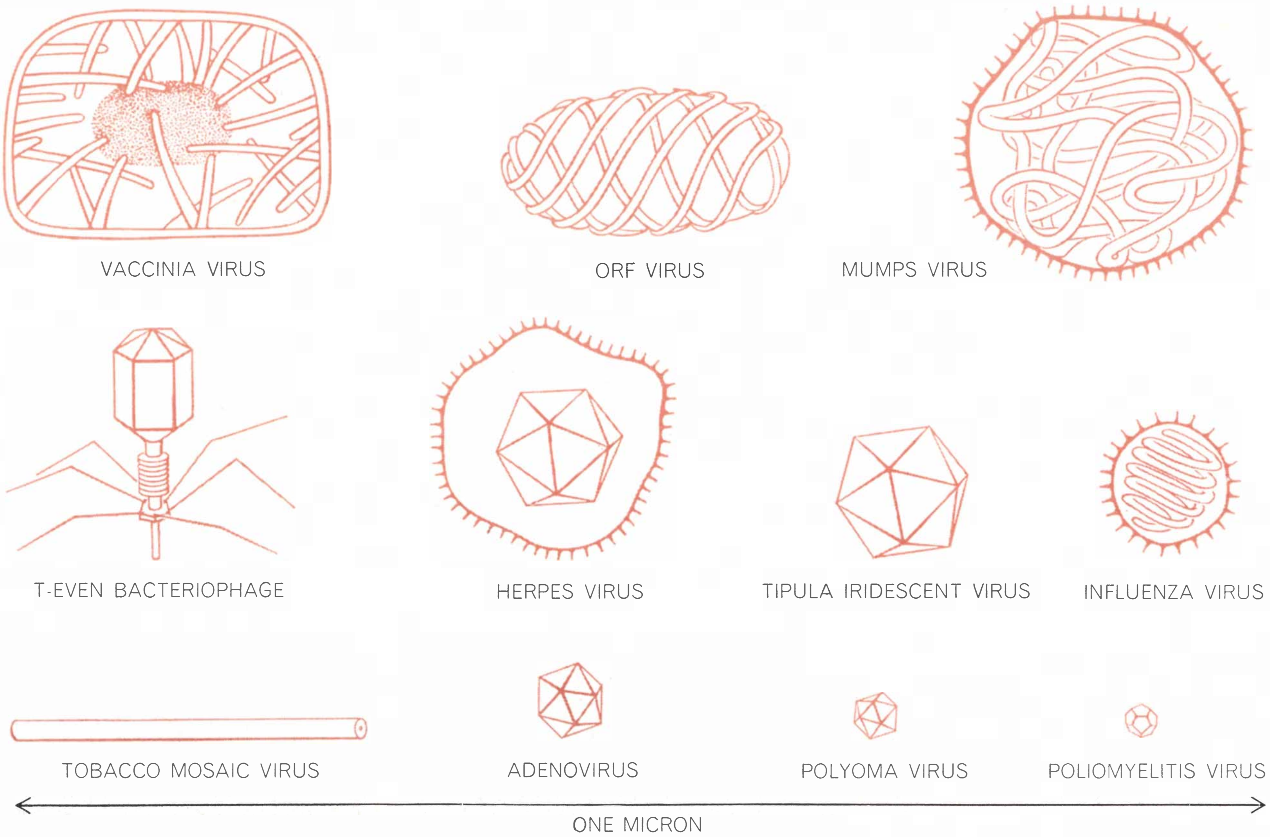
Most viruses fall in a size range between 10 and 200 millimicrons; in other terms, between a fortieth of a wavelength and half a wavelength of violet light. Since objects smaller than the wavelength of light cannot be seen in an ordinary microscope, viruses can be observed directly only with the aid of the electron microscope. These instruments employ a beam of electrons whose wavelength is much smaller than the dimensions of a virus. Viruses can also be studied indirectly by placing crystals of a pure virus preparation in an X-ray beam and recording the diffraction patterns produced when the X rays are reflected from the planes of atoms in the crystal. Analysis of such X-ray diffraction patterns suggested that the protein subunits forming the virus shell were arranged symmetrically. The tobacco mosaic virus, for example, showed up in early electron micrographs as a slender rod without visible subunits. When the virus was examined by X-ray diffraction, however, one could see patterns suggesting that the subunits were arranged in a helix. On the other hand, most small viruses, which looked spherical in electron micrographs, gave rise to X-ray patterns indicating that they had a cubic symmetry. This suggested that they were regular polyhedrons and also members of the group of Platonic solids: solids with four, six, eight, 12 and 20 sides.

In the light of the X-ray results, and arguing from general principles, F. H. C. Crick and James D. Watson proposed in 1956 and 1957 that the amount of nucleic acid present in the small viruses was limited, and that the information it carried would be sufficient to code for only a few kinds of protein. They suggested, therefore, that the shells of small "spherical" viruses were probably built from a number of identical protein subunits packed symmetrically. The most likely way for identical units to be packed on the surface of a sphere, Crick and Watson pointed out, would be in some pattern having cubic symmetry.

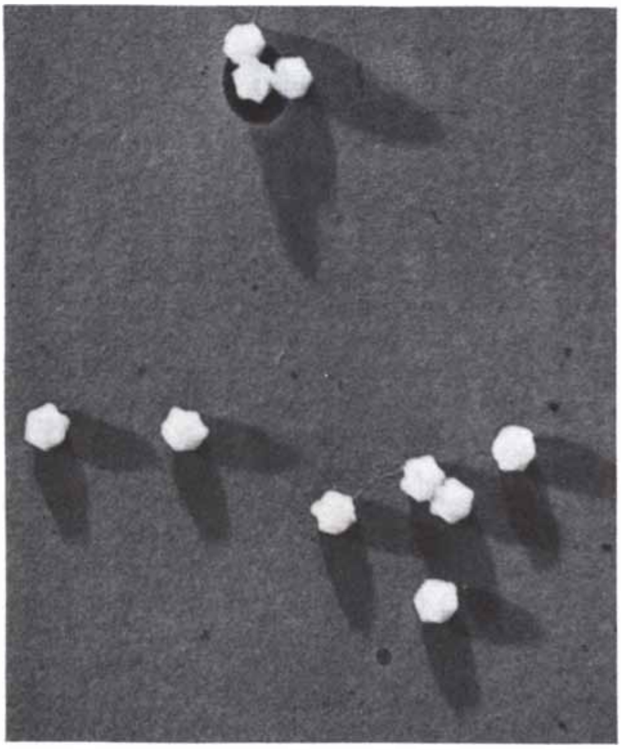
Some of the predictions of Crick and Watson were subsequently confirmed by electron micrography. There was a period, however, when the design and development of the electron microscope outpaced methods of preparing virus specimens for observation. Dehydrated virus particles are essentially transparent to an electron beam. Various techniques have had to be devised to make the particles visible. One of the earliest and simplest methods was to create "shadows" by allowing a stream of heavy-metal atoms to fall on the virus particles at an angle. This was done by placing the specimen of virus particles in a vacuum chamber and evaporating the metal atoms from a source toward the side of the chamber. The metal atoms that accumulated on the virus particle itself would block the passage of electrons, whereas electrons could pass freely through the shadows where metal atoms had not been deposited. In this way it was possible to discern the overall shape of the virus particle but not all the fine details of its surface structure.

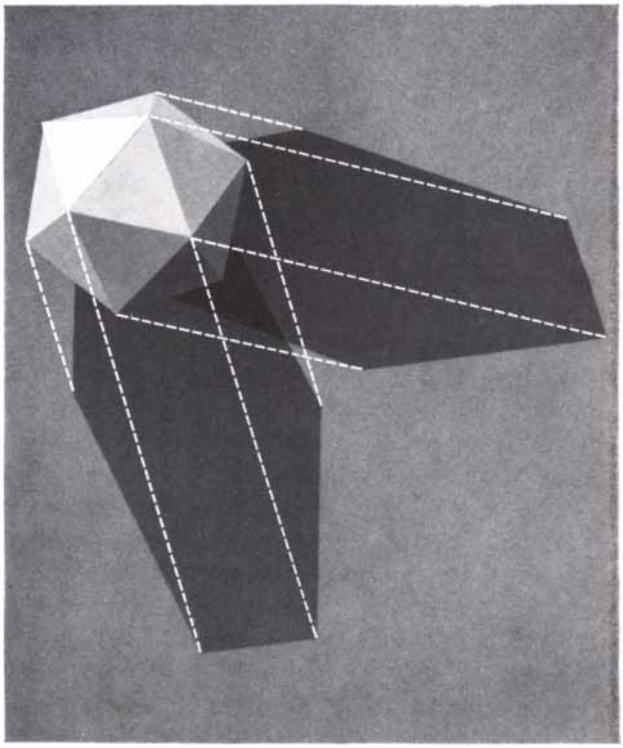
Within the past few years a new and simple method of "staining" isolated particles such as viruses and large protein molecules has been even more successful than shadowing for revealing fine detail at the high magnifications now available in electron microscopes. It consists of surrounding the particles to be examined by an electron-dense material: potassium phosphotungstate. This is achieved by mixing the virus suspension with a solution of the phosphotungstate and spraying the mixture or depositing droplets on the specimen mounts. Since the phosphotungstate method produces images that are reversed compared with those obtained with the normal preparation procedures, it is called "negative staining" or "negative contrast." Application of this method to a large number of viruses has shown that they fall into three main symmetry groups: those with cubic symmetry, those with helical symmetry and those with complex symmetry or combined symmetries.

The class of polyhedrons that have

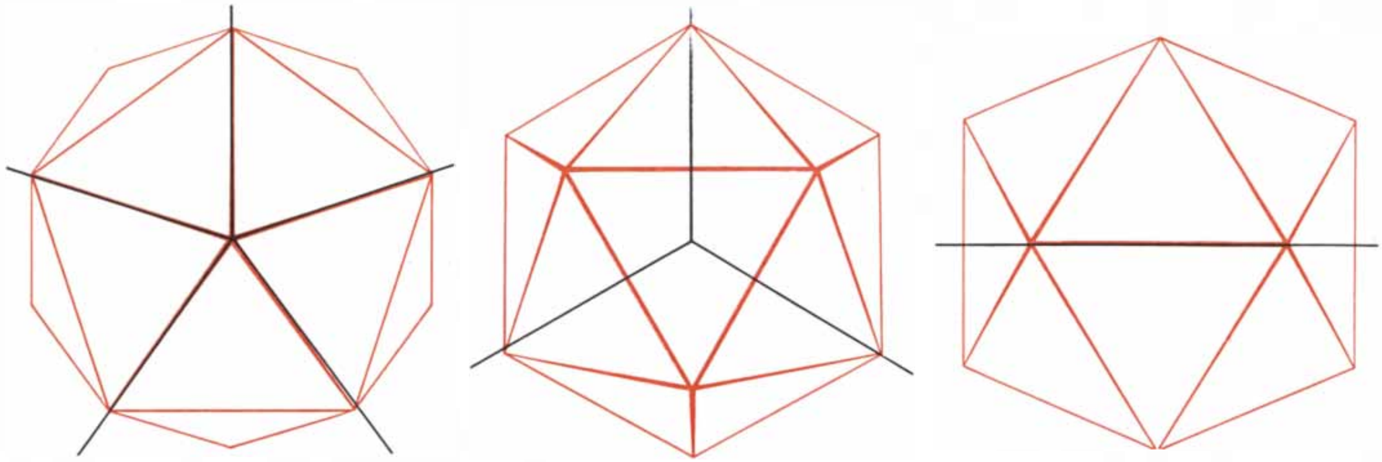


RELATIVE SIZES OF VIRUSES are shown in this chart. A micron, used as a measuring stick, is a thousandth of a millimeter; it is enlarged 175,000 times. The five viruses with polyhedral structures possess cubic symmetry. The tobacco mosaic virus and the internal components of influenza and mumps virus have helical symmetry. The remaining viruses exhibit complex symmetry.

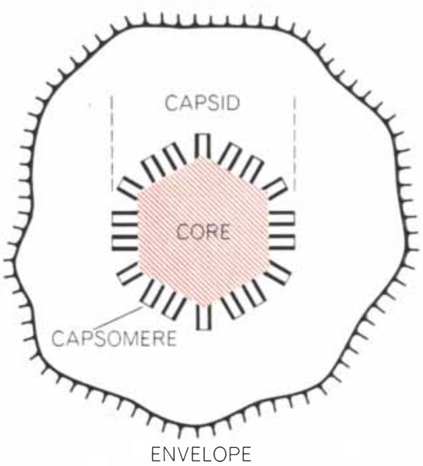




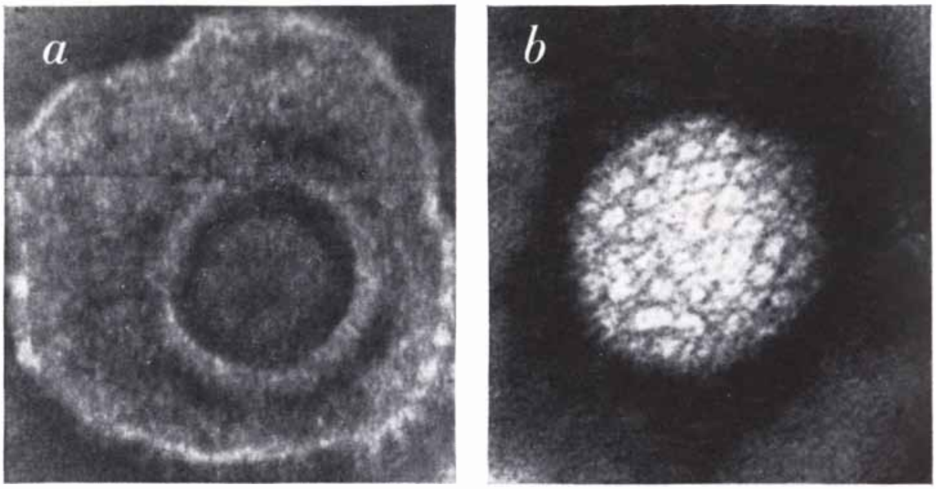
TIPULA IRIDESCENT VIRUS, an insect virus, is so large that its geometrically regular structure shows up clearly when specimens are shadowed with atoms of a heavy metal and enlarged in the electron microscope. In the doubly shadowed micrograph (*left*) the virus particles are enlarged about 58,000 diameters. The shadows indicate that each particle is a regular icosahedron (*right*). The micrograph was made by Kenneth Smith of the University of Cambridge and Robley C. Williams of the University of California.



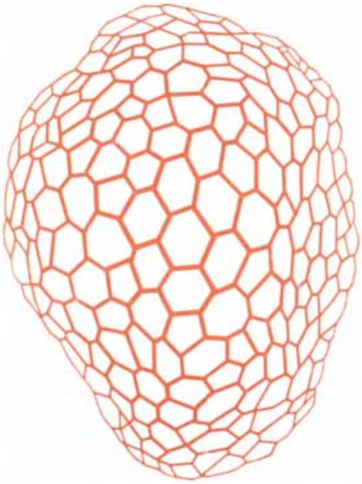
AXES OF SYMMETRY are shown for a regular icosahedron, a figure with 12 corners, 20 faces and 30 edges. Viewed along an axis at any corner, the figure can be rotated in five positions without changing its appearance (*left*). Rotated around any face axis, a regular icosahedron exhibits threefold symmetry (*middle*). Rotated around any edge axis, the figure shows twofold symmetry (*right*).



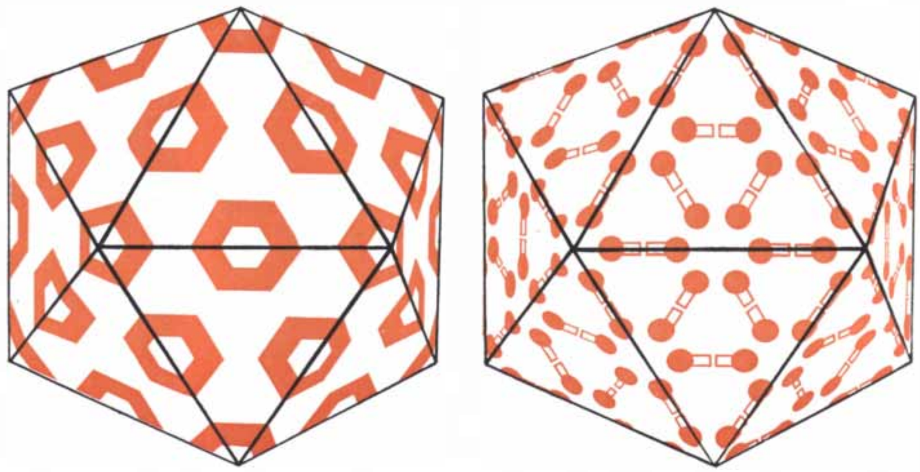
VIRUS NOMENCLATURE covers principal features observed in electron micrographs.



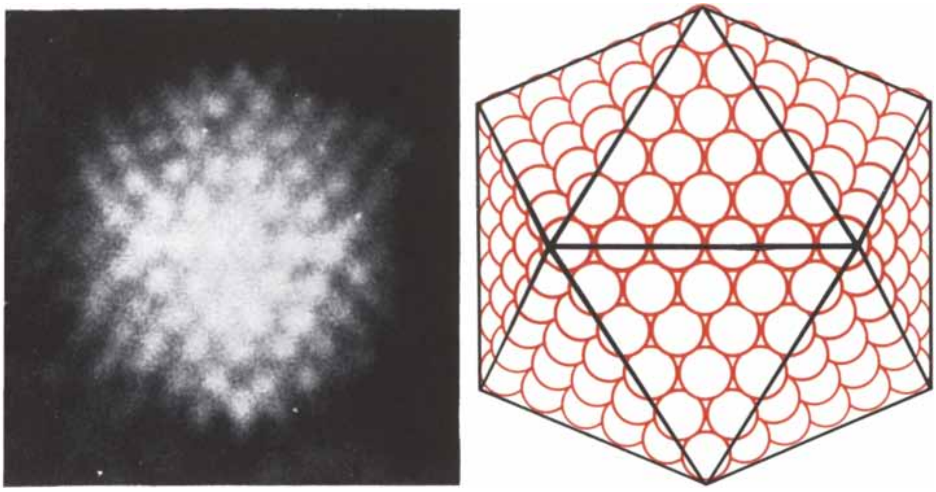
HERPES VIRUS sometimes has an envelope (*a*). The magnification is 310,000 diameters. The capsid (*b*) is composed of 162 capsomeres. Negative staining (*c*) indicates



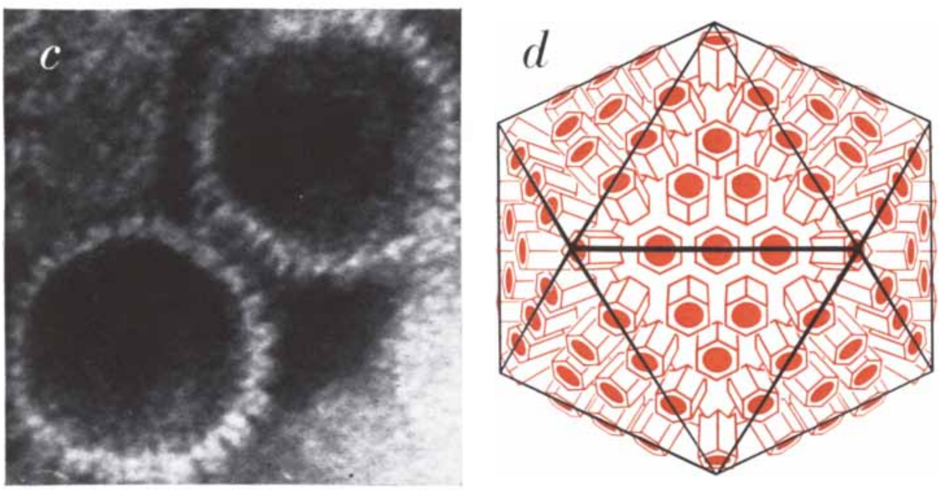
RADIOLARIANS, small marine organisms, have skeletons built of pentagons and hexagons.



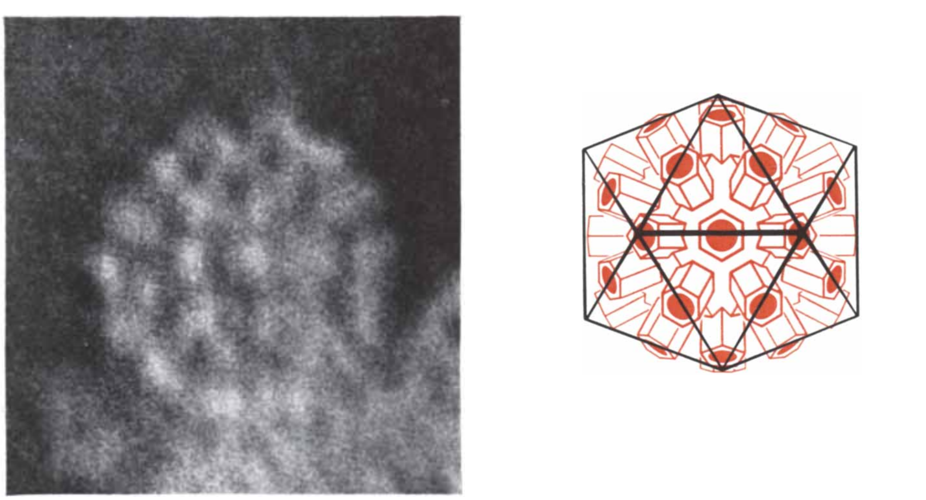
ALTERNATIVE SCHEMES show how a regular icosahedron containing 42 pentagonal and hexagonal capsomeres (*left*) could be built up from 120 (or 240) small subunits.



ADENOVIRUS is shown embedded in phosphotungstate, magnified about one million diameters (*left*). The drawing shows how the particle's 252 surface subunits, or capsomeres, are arranged with icosahedral symmetry. There are 12 on corners, 240 on faces or edges.



that they are hollow. The drawing (*d*) shows icosahedral arrangement. Micrographs are by P. Wildy and W. C. Russell of the Institute of Virology in Glasgow and the author.

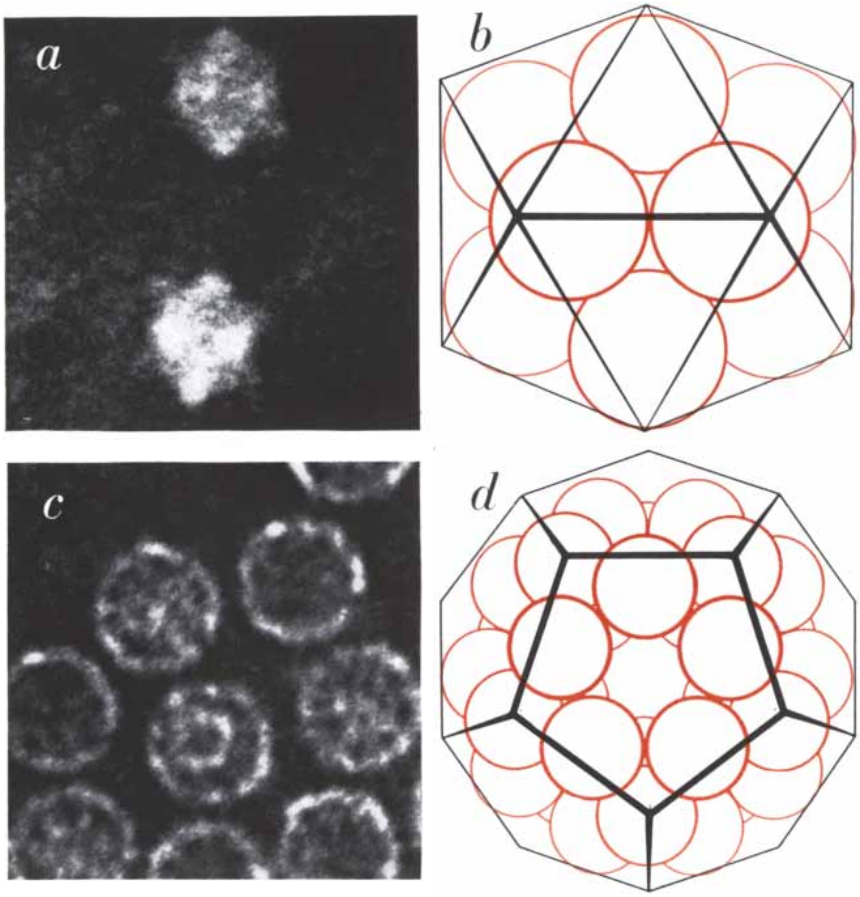


POLYOMA VIRUS is magnified one million diameters in micrograph by Wildy, M. G. P. Stoker and I. A. Macpherson of the Institute of Virology. It has 42 capsomeres (*right*).

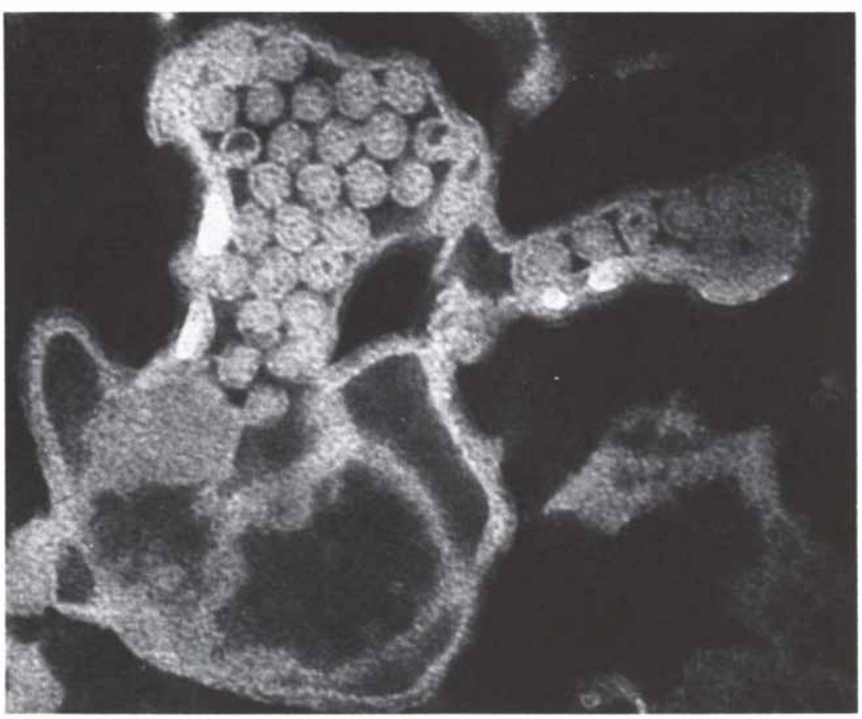
cubic symmetry includes the regular tetrahedron (four faces), dodecahedron (12 faces) and icosahedron (20 faces). Shadowed preparations of the tipula iridescent virus, which causes a disease in the larvae of several insects, showed it to have the shape of a regular icosahedron, and the symmetry was self-evident [*see bottom illustration on page 49*]. Smaller viruses, on the other hand, do not reveal symmetry unless they are examined at very high magnification, and this requires the use of negative phosphotungstate staining.

Consider the symmetry properties of a regular icosahedron, in which each face is an equilateral triangle. If spokes are projected from the center of the icosahedron through the corners of the triangles, the spokes will represent one axis of rotational symmetry. Spokes projected from the center of the solid through the center of each face will represent a second axis. And spokes projected from the center through the midpoint of each edge will represent a third axis. (There will be 12 corner spokes, 20 face spokes and 30 edge spokes.) If the icosahedron is viewed along the spoke at any corner, one finds that the body can be rotated in five positions without changing its appearance [*see top illustration on opposite page*]. If the icosahedron is viewed along the spoke at any face, the body can be rotated in three positions without changing its appearance. And if the icosahedron is viewed along an edge spoke, it can be rotated in two positions without change of appearance. The regular icosahedron is thus said to have 5.3.2. symmetry.

Let us see now what implication this symmetry pattern has for a particle of adenovirus, which is associated with respiratory disease in man. The electron microscope shows that the surface of the particle is composed of regularly arranged structural units resembling tiny balls. Moreover, these balls are seen on the vertexes, faces and edges of an icosahedron [*see top illustration on this page*]. One can identify certain balls surrounded by five neighbors, which indicates that they are located on vertexes and therefore on axes of fivefold symmetry. Balls surrounded by six neighbors must lie on faces or edges and thus must occupy axes of either threefold or twofold symmetry. Along each edge there are six balls, including two balls occupying vertexes. To calculate the total number of balls covering the entire icosahedron one applies the simple formula $10(n-1)^2+2$, where n is the number of balls along one edge. Substituting 6



BACTERIOPHAGE ΦX174, magnified 750,000 diameters in *a*, appears to consist of 12 capsomeres arranged in icosahedral symmetry as shown in *b*. In other micrographs (*c*) smaller subunits seem to be arranged in ringlike structures. Each capsomere might actually be formed from five subunits as shown in *d*. Thirty such subunits would form a dodecahedron.



POLIOMYELITIS VIRUS PARTICLES are shown inside a fragment of an infected cell. The particles, magnified 250,000 diameters, appear to be composed of subunits smaller than the typical capsomere. The structural arrangement is not established. Electron micrograph is by Jack Nagington of the Public Health Laboratory in Cambridge and the author.

for *n* yields 252 as the number of morphological units composing the shell of the adenovirus particle.

For purposes of description (and to avoid the term "subunit," which can be applied to morphological, structural or chemical features) I shall adopt the recent terminology suggested for the various viral components [*see illustration at middle left on page 50*]. The morphological units composing the shell have been given the name "capsomeres." The shell itself is the "capsid." The region inside the capsid is the "core." The outer membrane, seen surrounding the capsid of some viruses, is the "envelope."

One merit of the negative-staining technique is that the electron-dense material is capable of penetrating into extremely small regions between, and even within, the capsomeres. A striking instance of such penetration can be seen in the electron micrograph of the herpes virus shown at the middle left on the preceding page. (In man the herpes virus causes, among other things, "cold sores.") Electron micrographs of the shadowed particle had indicated that it had the same external shape and symmetry as the adenovirus. When the two viruses were negatively stained and still further magnified, however, it could be seen on close examination that the capsomeres of the herpes virus, unlike those of the adenovirus, were elongated hollow prisms, some hexagonal in cross section and others pentagonal. In a number of particles the phosphotungstate penetrated into the central region, or core, normally containing the nucleic acid. In these "empty" particles the elongated capsomeres stand out clearly in profile at the periphery of the virus, and one can see their hollow form and the precision of their radial arrangement.

From the micrographs the number of capsomeres located on each edge was estimated to be five, giving a total of 162 capsomeres for the herpes virus. Of the 162 capsomeres, 12 are pentagonal prisms and 150 are hexagonal prisms. To satisfy the packing arrangement in accordance with icosahedral symmetry, the 12 pentagonal prisms would have to be placed at the corners and the 150 hexagonal prisms located on the edges or faces of the particle [*see drawing at middle right on preceding page*].

The need for pentagonal units goes deeper than the simple need to satisfy icosahedral symmetry. As early geometers observed, there is no way to arrange a system of hexagons so that they will enclose space. But if pentagonal units are included with hexagons, it is possible to enclose space in an almost endless variety of ways, with forms both regular and irregular. The radiolarians, a group of marine protozoa, provide a fascinating example of varied structures assembled from pentagonal and hexagonal units [*see illustration at bottom left on page 50*].

Viruses smaller than the herpes virus usually have fewer capsomeres, but the relation between size and capsomere number is somewhat variable. The polyoma virus, which produces tumors in rodents and has stimulated a search for viruses in human cancer, appears to be almost spherical when examined by the shadowing technique. Nevertheless, negative staining shows that the outer shell is probably composed of 42 elongated angular capsomeres arranged in icosahedral symmetry [*see bottom illustration on page 51*]. Such a shell can be constructed by placing 12 pentagonal prisms at the corners of an icosahedron and 30 hexagonal prisms on the 30 edges. In this case the 20 faces have no capsomeres of their own, which helps to explain the nearly spherical appearance of the virus.

In the electron microscope the turnip yellow mosaic virus, which causes a disease of the leaves in the turnip and related plants, appears to have 32 capsomeres arranged in accordance with cubic symmetry. Crystals of the same virus studied by X-ray diffraction also show cubic symmetry, but this method indicates that there are 60 subunits instead of 32. Strictly speaking, neither number can be used to construct an icosahedron. But both numbers of subunits can be disposed symmetrically on the surface of an icosahedron. The smaller number can be distributed by placing 12 subunits on corners, 20 on faces and none on edges. (The 32 capsomeres could also be placed on the 32 vertexes of a pentakis dodecahedron or a rhombic triacontahedron.) The larger number can be distributed according to strict icosahedral symmetry by placing two subunits on each of the 30 edges and none on corners or faces. It is evident that if the two figures were transparent, one could be fitted over the other and the subunits of one would fall precisely in between the subunits of the other without overlapping. This suggests that the 60 subunits inferred from X-ray diffraction patterns may combine in some fashion to give the appearance of 32 subunits when the virus particle is observed in the electron microscope.

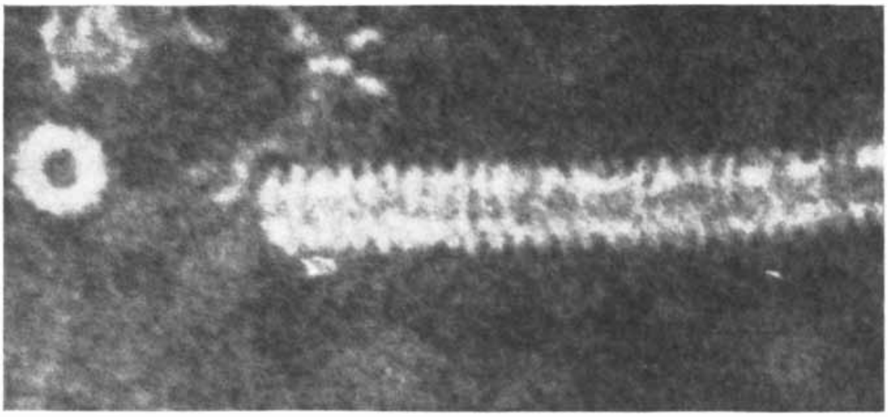
It has therefore been suggested that in the small spherical viruses the morphological features resolved as pentagons and hexagons may actually be built up from smaller structural subunits. These subunits may not all be identical, but they may be of two or three different molecular species. The diagram at the bottom right on page 50 indicates how such subunits might be assembled to produce pentagonal and hexagonal units, in strict accordance with icosahedral symmetry. The arrangement illustrated, one of several possible combinations, was proposed by A. Klug, D. L. D. Caspar and J. Finch of the University of London. It shows how 42 capsomeres could be formed from 120 (or 240) smaller subunits. Recent evidence suggests that the capsomeres in some of the larger viruses are linked together by small structures that may well correspond to the subunits.

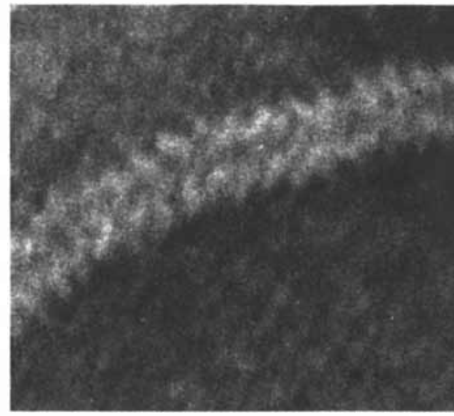
High-resolution electron micrographs have revealed that structures originally identified as capsomeres in one very small virus are indeed composed of still smaller subunits. The virus, known as φX174, has been intensively studied because it contains an unusual single-stranded form of DNA [see "Single-stranded DNA," by Robert L. Sinsheimer; SCIENTIFIC AMERICAN, July, 1962]. When first examined in the electron microscope, the virus appeared to have a shell composed of 12 spherical capsomeres, the minimum number needed for icosahedral symmetry. More recent electron micrographs indicate that each capsomere is formed from five subunits, but since each capsomere may be shared with a neighbor, the number of subunits is 30 [*see top illustration on opposite page*]. If they are not shared and each capsomere is composed of five subunits, the total would be 60 and the shape would be that of a dodecahedron. Similar subunits smaller than capsomeres have been observed in electron micrographs of the virus of poliomyelitis, but it has not yet been possible to count them accurately [*see bottom illustration on opposite page*].

The second broad group of viruses I shall discuss are those that have helical symmetry. Far and away the best known of this group is the virus that causes the mosaic disease of tobacco. Its helical structure was originally inferred from X-ray diffraction data. These data, combined with evidence from other physical and chemical observations, have led to a detailed knowledge of the tobacco mosaic virus' architecture. The

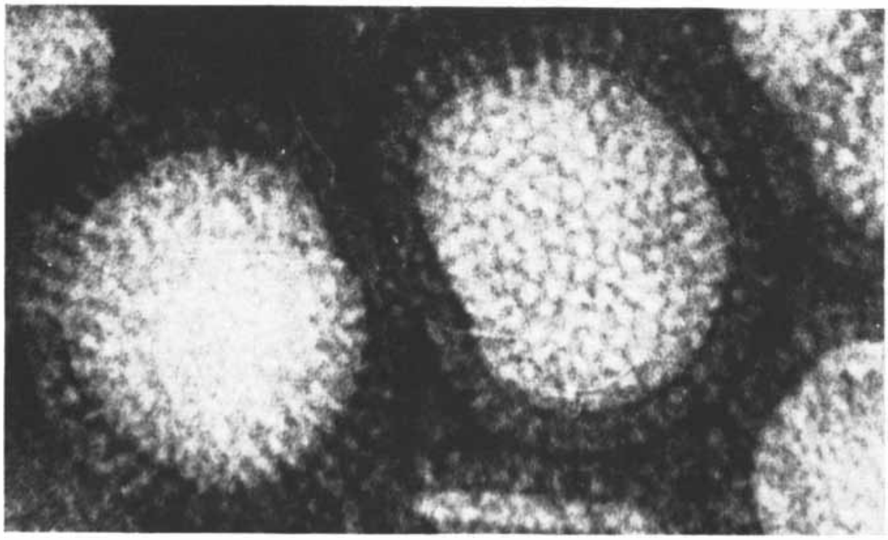
VIRUS	SYMMETRY	NUMBER OF CAPSOMERES	SIZE OF CAPSID (ANGSTROM UNITS)	NUCLEIC ACID
TIPULA IRIDESCENT	CUBIC	812	1,300	DNA
ADENOVIRUS	CUBIC	252	700–750	?
GAL (GALLUS ADENO-LIKE)	CUBIC	252	950–1,000	?
INFECTIOUS CANINE HEPATITIS	CUBIC	252	820	?
HERPES SIMPLEX	CUBIC	162	1,000	DNA
WOUND TUMOR	CUBIC	92	?	RNA
POLYOMA	CUBIC	42	450	DNA
WARTS	CUBIC	42	500	?
TURNIP YELLOW MOSAIC	CUBIC	32	280–300	RNA
ΦX174	CUBIC	12	230–250	DNA
TOBACCO MOSAIC	HELICAL	2,130	3,000 × 170	RNA
MUMPS	HELICAL	—	170 (DIAMETER)	RNA
NEWCASTLE DISEASE	HELICAL	—	170 (DIAMETER)	RNA
SENDAI	HELICAL	—	170 (DIAMETER)	?
INFLUENZA	HELICAL	—	90–100 (DIAMETER)	RNA
T-EVEN BACTERIOPHAGE	COMPLEX	—	1,000 × 800 (HEAD)	DNA
CONTAGIOUS PUSTULAR DERMATITIS (ORF)	COMPLEX	—	2,600 × 1,600	?
VACCINIA	COMPLEX	—	3,030 × 2,400	DNA

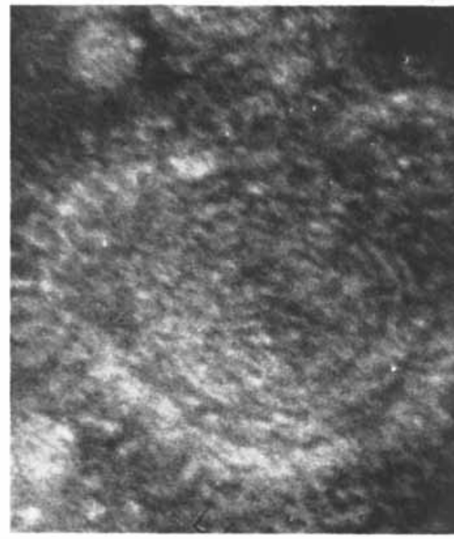
TABLE OF VIRUSES shows the symmetry classification, number of capsomeres and capsid size of some of the principal families. (An angstrom unit is a ten-millionth of a millimeter; the wavelength of violet light is 4,000 angstrom units.) Nucleic acid (*column at far right*) is the genetic material of the virus. DNA is deoxyribonucleic acid; RNA, ribonucleic acid.



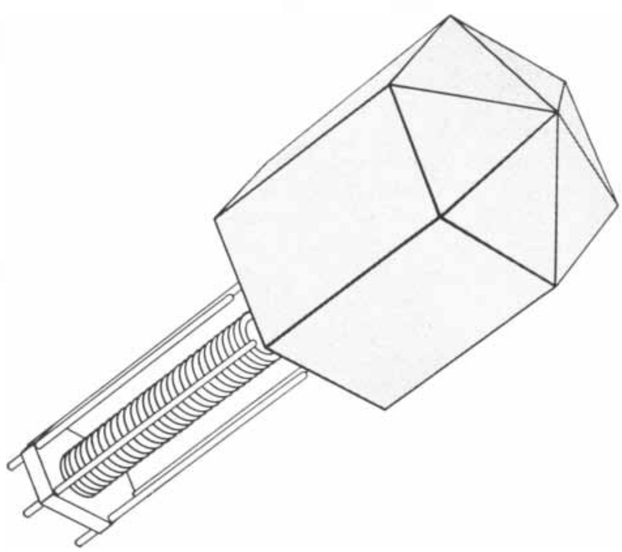


HELICAL SYMMETRY is shown in the electron micrographs of the rodlike tobacco mosaic virus, magnified 800,000 diameters, at left. The second electron micrograph, of the same magnification, shows an internal thread from a disrupted member of the myxovirus group. It too seems to possess helical symmetry. (Intact myxovirus particles are shown directly below.) The tobacco mosaic virus has

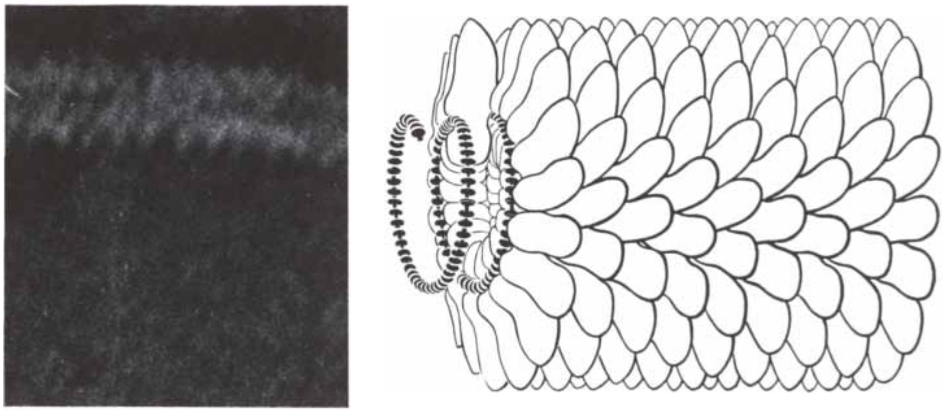




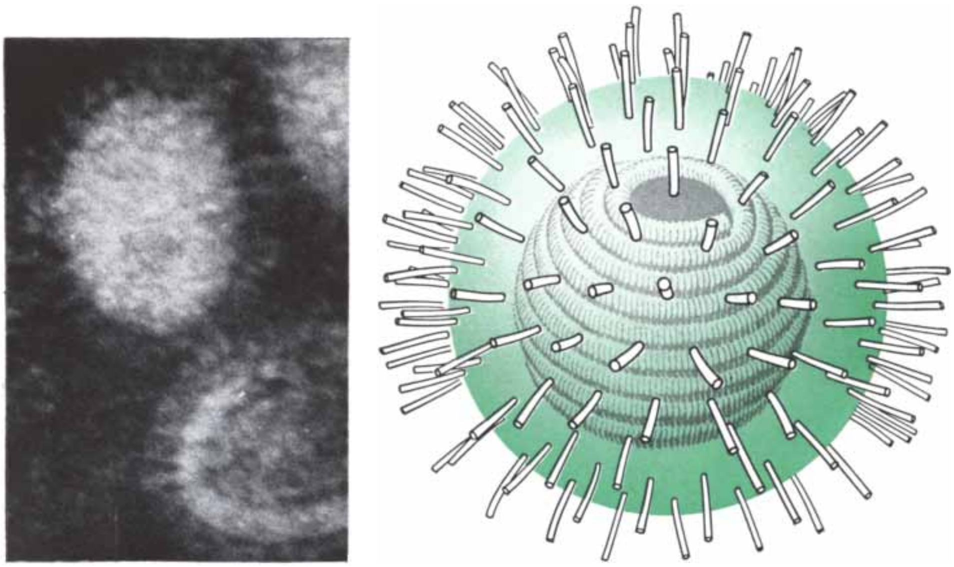
INFLUENZA VIRUS PARTICLES, members of the myxovirus family, are magnified 700,000 diameters in the electron micrograph at left. Although the particles are irregular in both size and shape, they appear to bristle with regularly spaced surface projections. In the second micrograph, which has a magnification of 600,000 diameters, phosphotungstate has penetrated the core of a particle, reveal-



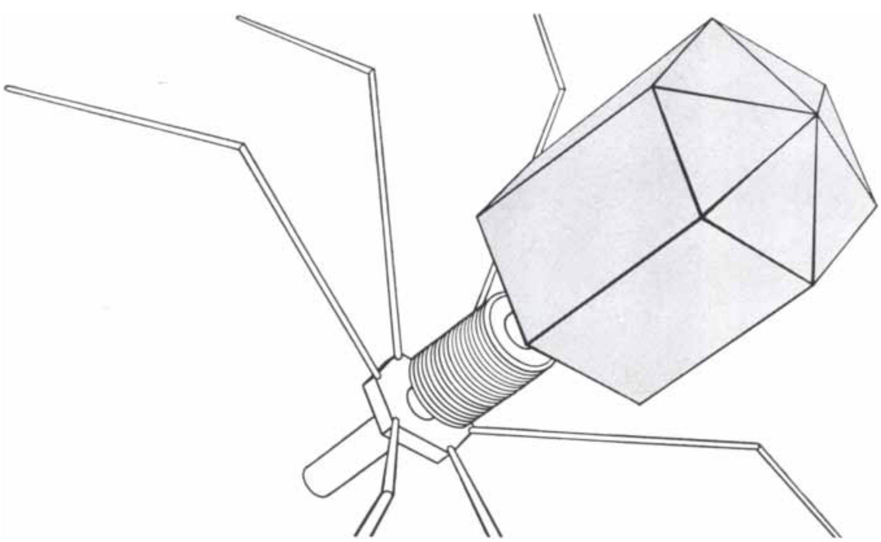
COMPLEX SYMMETRY is displayed by the T2 bacteriophage and other members of the "T even" family. Electron micrographs, in which the particle is magnified 300,000 diameters, clearly show that T2 exists in "untriggered" and "triggered" forms. The untriggered form is shown in the first pair of illustrations. The head of the phage is a bipyramidal hexagonal prism. The tail is a tube-like structure surrounded by a helical sheath. An end plate carries six tail fibers. When triggered, as shown in the second pair of illus-



2,130 elongated capsomeres, consisting of protein molecules, arranged around a hollow core, as shown in the diagram at far right. The helical coil embedded in the capsomeres represents viral nucleic acid. The micrographs are by Nagington, A. P. Waterson and the author.



ing a coiled structure inside. The diagram at right shows a possible arrangement of the components in a typical myxovirus. The diagram follows a model built by L. Hoyle, Waterson and the author. The micrographs are by Waterson, Wildy, A. E. Farnham and the author.



trations, the sheath contracts away from the end of the tail and the tail fibers are released. Presumably this coincides with the ejection of the DNA core (*not shown*), which previously had been coiled up in the head of the particle. The micrographs are by Sydney Brenner, George Streisinger, S. Champe, Leslie Barnett, Seymour Benzer, M. Rees and the author.

subunits appear to be elongated structures so arranged that about 16 subunits form one turn of a helix. The subunits project from a central axial hole that runs the entire length of the virus. The nucleic acid of the virus does not occupy the hole, as might be expected, but is deeply embedded in the protein subunits and describes a helix of its own. The virus is composed of 2,130 identical protein subunits. Each subunit is a large molecule formed by the joining together of 168 amino acid molecules. The diagram of the virus' structure at the top of this page is based on a model by R. E. Franklin, Klug, Caspar and K. Holmes of the University of London.

Until recently helical symmetry was observed only in plant viruses. Now it has also been found in the complex animal viruses that are members of the influenza, or myxovirus, group. The group includes the viruses of mumps, Newcastle disease (a respiratory ailment of fowl), fowl plague and Sendai disease (a form of influenza). Electron micrographs produced by the shadow-casting technique showed these viruses to be of various shapes and sizes. Some were roughly spherical, some were filaments and others were complex and irregular. Thin sections of purified virus and particles seen at the surface of infected cells suggested the existence of an internal component in the form of ringlike structures surrounded by an outer membrane.

Recent studies using the negative staining method have shown that the internal component, or capsid, has the same dimensions and appearance as the rods of tobacco mosaic virus but is more flexible. This is particularly evident in electron micrographs of mumps virus, which show that the helical capsid forms coils or loops after being released. The particles of influenza and fowl plague are more structurally compact than the mumps virus and, unless subjected to special chemical treatment, are rarely observed releasing their internal components.

The envelopes of influenza virus and fowl plague virus carry surface projections that evidently contain the protein known as hemagglutinin, so named because it causes red blood cells to agglutinate. If these two viruses are treated with ether, the internal helix is released and can be separated from the hemagglutinin in a centrifuge. When this inner component is studied by electron microscopy, it is found to be of smaller diameter than that in the viruses of mumps, Newcastle disease virus and Sendai disease virus. The precise length of the helical components in the various myxoviruses is not yet known, nor the way they are packed within their envelopes. A possible arrangement for a typical myxovirus is shown in the diagram at the middle on the preceding page.

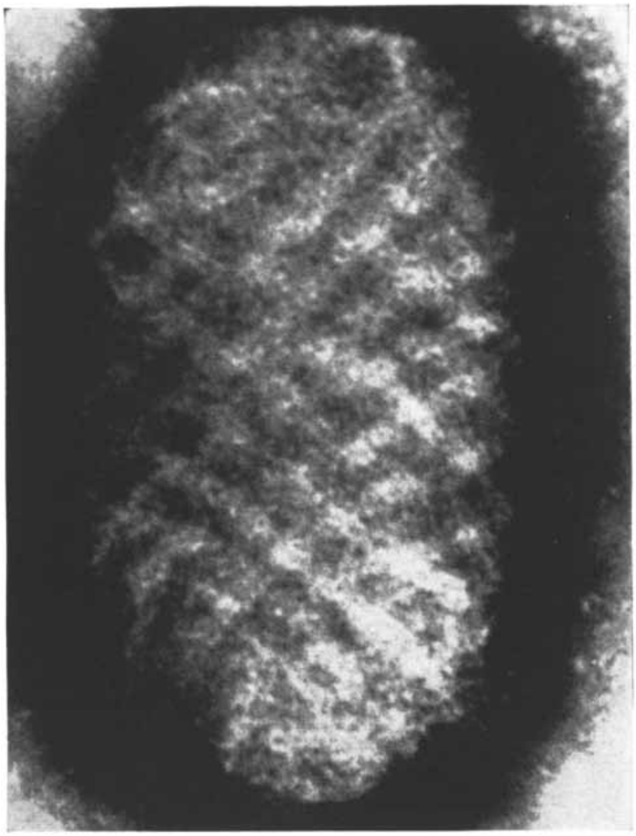
The last of the three broad groups of viruses are those whose symmetry is complex. This category includes the large bacterial viruses, such as the T2 virus that infects the bacterium *Escherichia coli,* and the large pox viruses. The T2 virus and several of its "T even" relatives are particularly remarkable because they contain some sort of contractile mechanism, a feature that has not been discerned in any other family of viruses. The electron micrographs at the bottom of page 54 show that the T2 virus has a head shaped in the form of a bipyramidal hexagonal prism. Attached to one end of the prism is a tail structure consisting of a helical contractile sheath surrounding a central hollow core. At the extreme end of the core there is a curious hexagonal plate carrying six slender tail fibers. The plate structure and tail fibers probably make initial contact with the wall of the bacterium that is being attacked. After contact has been made the helical sheath contracts, allowing the nucleic acid core of the virus to enter the bacterium.

The contraction of the T2 sheath raises many fascinating questions. The entire T2 virus appears to contain only a few different kinds of protein molecule. If these are allocated to the construction of the different structures—head, sheath, tail plate and tail fibers—one must conclude that the contractile sheath is composed of only two or at most three different kinds of protein. How can so few kinds of building block produce a sheath with contractile ability? What substances trigger the contraction? And how is the contraction related to the ejection of the long DNA molecule that is tightly packed in the T2 core?

Still larger viruses having complex symmetry are several important members of the pox virus family: the viruses of variola, vaccinia, cowpox and ectromelia. They are among the few viruses large enough to be seen in the light microscope. In early shadowed electron micrographs the vaccinia virus appeared to have a three-dimensional bricklike shape with a spherical dense central region. More detailed studies of the virus seen in infected cells after staining and thin sectioning revealed morphological features not observed in other viruses. The central dense region appeared to be surrounded by a number of layers, or membranes, of varying opacity to the electron beam. In some micrographs tubelike structures could be seen between the outer membranes and the central region. The electron micrographs below illustrate the structural variations that exist between two members of the pox group. In the particles of the virus that causes orf, or contagious pustular dermatitis, the tubular components form a definite crisscross pattern. It is difficult to say whether the tubular structures should be described as capsids or as capsomeres, nor can one say just where the nucleic acid is located in relation to them.

The electron microscope, together with other methods, has greatly contributed to the study of viruses, and it has shown that they come in a surprising variety of mathematically ordered families. It has been understood for many years, of course, that proteins are versatile building blocks and that they account for the tremendous diversity of living forms. But it required the electron microscope to reveal directly what intricate and exquisite structures can be created by putting together only a few kinds of protein molecule.

VACCINIA VIRUS, one of the giant pox viruses, is about twice the diameter of the smallest living cells, which are known as pleuropneumonia-like organisms. The magnification is 400,000 diameters.



ORF VIRUS, another pox virus, has components wound in a crisscross pattern. The magnification is 450,000 diameters. Micrographs of the orf and vaccinia viruses are by Nagington and the author.

Kodak reports on:

what a good fighter's buttons are like . . . a book that's new and blue . . . new definition for Win, Place, and Show

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They shall beat their swords into plowshares and their spears into pruning hooks. Nation shall not lift up sword against nation. Neither shall they learn war any more.

— ISAIAH

Lockheed is very proud of its F-104 Starfighter. At a recent U. S. Air Force Fighter Weapons Meet at Nellis AFB, Nev., an F-104 (C model) outflew, outgunned, and outbombed all 13 of its competitors.

Lockheed has given us permission to disclose that the F-104 carries a 19.25mm hemisphere of KODAK IRTRAN 2 Optical Material on the flat face of which we deposit by a unique method a 4mm x 4mm film of lead sulfide to which leads are attached. This kind of infrared sensor we call a KODAK EKTRON Detector, Type Q-5, Modified. The hemisphere has been made also out of another high-index infrared-transmitting material, strontium titanate. Replacement of this by IRTRAN 2 material seems to make the time constant of the detector—which is about 250 μsec at 25°C—more stable over long periods with less effect from storage conditions. Also, the dark resistance stays put better. Therefore the s/n drifts less. Incidentally, signal and noise levels are both high, which lessens the demands on the associated circuitry. (NEP, however, is less than 6.7 x 10^{-11} watts for 600°C radiation chopped at 2500 cycles/sec over a 1 cycle/sec bandwidth.)

We mention high index. We are rather pleased at having it in the record that some years ago we suggested to the brethren that the same principle that makes an oil-immersion microscope objective resolve more detail than the best dry objective could also be worked for another purpose in the infrared game. Putting the detector film on the high-index hemisphere flat boosts the signal by 3.4×.

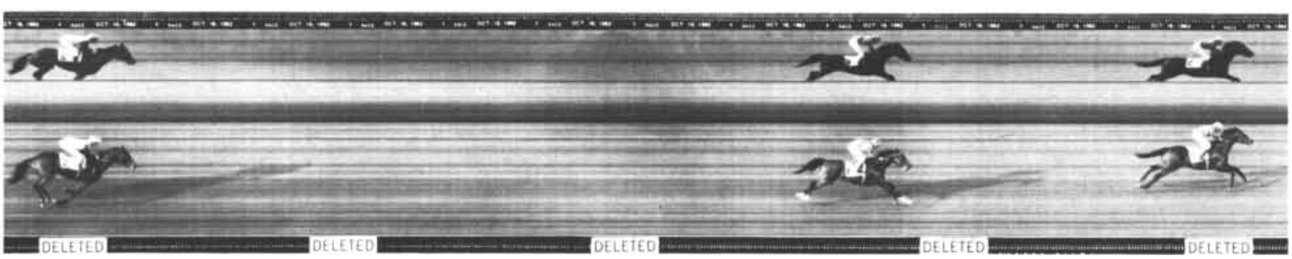
Safe as the F-104 makes us feel as we sit before our hearths, we'd feel even safer if we had more sales outlets for these buttons than just one make of airplane. We sure would like it if it turned out, in line with the prophet's beautiful allusion to old iron, that an entirely different use were found in addition for Type Q-5 detectors. Eastman Kodak Company, Special Products Division, Rochester 4, N. Y. can help you think about that.

Chemical advice

Virtually every laboratory that ever has occasion to work with organic compounds has a green book entitled *Eastman Organic Chemicals List No. 42.* It gives the accepted nomenclature, structural formulas, melting range or boiling range, and prices for convenient quantities of thousands of compounds, many of them in several grades of purity. Perhaps you have a copy.

Get rid of it.

It is out of date. The new one bears the designation *List No. 43*, which seems logical enough. It is BLUE. There are many, many changes and some 350 compounds that weren't in the old one. Check around and see whether it has come in. If it has not turned up by now, please notify Distillation Products Industries, Rochester 3, N. Y. (Division of Eastman Kodak Company).



Jones' film

The horseplayers of America have made a contribution to engineering. True horseplayers spend their lives contributing. They contribute by a process based on ordinal digits. Determination of the digits often requires instrumentation. A sound technology has developed to support this instrumentation. The horseplayers gladly support the technology by their contributions. The technology is now old enough to have added the expression "photo finish"* to common speech.

A photo finish negative is projected for the judges less than 25 seconds after the last horse crosses the finish line. They nearly always wait for the last horse. If the last horse is quite late, it looks longer than the first horse because there is hardly need for it to hurry any more as it passes the finish line. The finish line is the optical conjugate of a narrow slit at the focal plane of the camera. The film is exposed only at that point as it moves past the slit at constant speed.

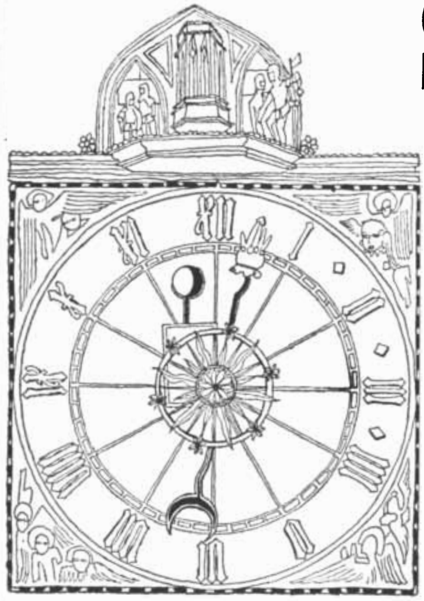
We have just introduced a new KODAK Timing Negative Film for this work. We don't see why the new film should be denied to off-track use. It is a 35mm film with the perforations omitted and the edge legend KODAK SAFETY FILM reduced in height to .014″, all in order to make room for the timing signal and other indicia (some of which have been deleted from the above illustration to protect the privacy of the jockeys). When developed for 10 seconds in the proper hot developer, it yields extraordinary definition at an Exposure Index of about 100. Fixation is extremely rapid. Contrast is readily controlled by the processing parameters. Spectral sensitivity is notably uniform from the ultraviolet to 630mμ.

An inquiry to Eastman Kodak Company, Special Sensitized Products Division, Rochester 4, N. Y. will get you some data about this film. There is another possible approach. Our No. 1 customer for the product is Jones Precision Photo Finish, Inc., 2 Crest Avenue, Elmont, N. Y., who make their own cameras and provide race timing service for about 65 out of 100 race tracks in the country. They have more practical experience with the film than we do. Perhaps you can induce Jones to diversify.

*Two words. The one word "photofinish" is a verb that refers to something entirely different, namely what you should have had done by now to any family snapshots taken during the recent festive season.

Eastman Kodak Company ads like this have been appearing for 10 years. They suggest that we make a wide variety of products. Possibly you have at one time or another thought of buying one but, not knowing how to go about it, have said, "The devil with it." Are you interested enough to send for a pocket reference book that may help you and us achieve mutually beneficial contact? If so, address Eastman Kodak Company, Dept. 8, Rochester 4, N. Y. It is a tiny bit out of date, but that can't be helped. (Everybody dies a little each day.)

SCIENCE AND



The Black Box

The "black box" robot seismographic station for detecting underground nuclear explosions was placed on the table at the Geneva disarmament conference last month. This idea had been put forward by three U.S. and three Soviet scientists during the nongovernmental "Pugwash" conference in London last September. It contemplated the installation at various points in the U.S.S.R. and the U.S. of unmanned, sealed, automatic seismographic stations—enough "so that seismic events will be seen on many instruments." The records from the instruments would be turned over periodically to an international commission for inspection. The Pugwash scientists suggested that the black boxes might "provide a new basis for negotiation in the Geneva discussions and ease the problem of resolving the on-site inspection issue."

That problem has been the major point of contention in devising a policing system for underground tests, which remains the principal barrier to a treaty to end all testing. The U.S. has held out for detection stations manned by international teams and mandatory on-site inspection of any unidentifiable seismic events they detect. The U.S.S.R. has insisted that detection stations should be manned by nationals of the country involved and that there must be no obligatory on-site inspection. The neutral nations at the Geneva conference have suggested compromises involving national detecting stations controlled by an international commission, with inspections on a quota basis or by invitation of the country accused of an infraction. The Pugwash suggestion was advanced to provide "minimal interference with the host country" and "a maximum amount of completely objective seismic information," which would "substantially reduce the number of necessary on-site inspections."

Semiofficial comment from Moscow favorable to the idea drew semiofficial expressions of reserve from Washington. Then, on December 10, Soviet delegate Semyon K. Tsarapkin said his government would permit installation of "two or three" robot stations in earthquake-prone regions of the country and would permit "international personnel" to visit the stations to bring in and take out the sealed recording apparatus. This offer, he said, contained "some elements" of the international control demanded by the U.S. But the U.S.S.R. still rejected any "compulsory on-site inspection." The Soviet proposal—implying that black boxes could serve in the place of manned international stations and inspection—was completely unacceptable, according to Charles C. Stelle of the U.S. delegation, although he welcomed the possibility that the U.S.S.R. was ready to discuss "precise details" of a system involving the robot stations. Other U.S. spokesmen pointed out that any Western proposal for such a system would call for hundreds of black boxes rather than two or three.

Although the two great nuclear powers had yet to find a solution to the problem of policing an underground-test ban, they found themselves under increasing pressure from the neutrals and from the United Nations to write a treaty. The mood on both sides seemed favorable: Stelle spoke of "the tenuous barriers between us" and *Izvestia* suggested that a "relatively small push" could achieve an agreement. Meanwhile the U.S. and the U.S.S.R. had each completed a major series of atmospheric tests and presumably felt no pressing need to resume in the near future.

Emphasized Breeder

Nuclear reactors should be producing about half of the electricity in the U.S. by the end of this century and nearly all of it by the middle of the next century, according to calculations presented

THE CITIZEN

in the Atomic Energy Commission's recent report "Civilian Nuclear Power." The study was made in response to President Kennedy's request of last March that the Commission "take a new hard look at the role of nuclear power in our economy."

According to the A.E.C., projections of the increased demand for power indicate that readily available low-cost fossil fuels such as coal, oil and gas will be exhausted in a century or less and "presently visualized total supplies in about another century. In actual fact, long before they become exhausted we will be obliged to taper off their rate of use by supplementing them increasingly from other sources." Fossil fuels, the report says, must be preserved in reasonable amounts for future generations, since such fuels are invaluable for many special purposes.

The Commission proposes to expand its $200-million-per-year program of research and development in nuclear reactors by $30 million, placing increasing emphasis on the development of "converter" reactors, which produce some nuclear fuel while generating power, and on "breeder" reactors, which generate power while producing more fissionable fuel than they consume. The report expresses the opinion that nuclear reactors will be economically competitive with conventional generators during the 1970's; reactors can already compete in some areas distant from sources of fossil fuel.

The complex breeder reactors will be necessary because the present reactor fuel, uranium 235, makes up only .7 per cent of the uranium found in nature, and all easily accessible supplies of U-235 will be exhausted by the 1990's. Breeder reactors can convert the abundant uranium 238 into the fissionable plutonium 239, or thorium 232 into fissionable uranium 233. Both the uranium and the thorium occur in usable amounts in the granite that makes up much of the crust of the earth. Breeder reactors that can "burn the rocks" thus promise an almost unlimited source of fuel (see "Breeder Reactors," by Alvin M. Weinberg; Scientific American, January, 1960). One small experimental breeder has been in operation for several years at the National Reactor Testing Station in Arco, Idaho; another, the first to employ plutonium as a fuel, was put into operation there a few days after the A.E.C. issued its report near the end of November; a third, the Enrico Fermi breeder reactor in Detroit, is scheduled to begin producing 65,900 kilowatts of electric power by the end of this year. Great Britain and the U.S.S.R. have also built breeders. With present technology it will take such a reactor 15 to 20 years or even longer to produce enough fissionable material to fuel another reactor of the same size. Therefore, the A.E.C. explains, it will be several decades before breeders begin to play a dominant role in the production of power and because of this it is necessary to move ahead rapidly in the program to develop them.

Agreement in Space

A minor speed record for a Soviet-U.S. agreement was set last month when the two countries reported to the United Nations on a scheme for co-operative research in space. Premier Khrushchev, in a note of congratulation on John H. Glenn's orbital flight, had suggested last February 21 that the U.S. and the U.S.S.R. pool some of their space-research efforts. President Kennedy answered by proposing co-operation in space medicine, weather satellites, communications satellites, mapping the earth's magnetic field and tracking space vehicles. Last June, Soviet rocket expert Anatoli A. Blagonravov and Hugh L. Dryden, Deputy Administrator of the National Aeronautics and Space Administration, met and drew up recommendations for specific joint programs in three of those areas. After approval by both governments—and a short delay caused by the Cuban crisis—the agreement was announced during the UN debate on the peaceful uses of outer space.

Working groups of scientists from the U.S. and the U.S.S.R. are expected to meet soon to implement the agreement, which provides for joint efforts in meteorology, geomagnetic mapping and satellite communications. In meteorology the two countries agreed to start by exchanging data gathered by their current experimental weather satellites, and they contemplated an operational joint weather-satellite system beginning in 1964 or 1965. Looking toward the compilation of a map of the earth's magnetic field, the agreement recommends that both countries launch magnetometer-equipped satellites in time for the International Year of the Quiet Sun (1964–1965), when solar disturbances should be at a minimum. Specialists from the two nations are to co-ordinate the instrumentation and orbital characteristics of the satellites and methods of data collection and processing. As for communications, the first step will be joint experiments with *Echo II,* a large passive reflector satellite scheduled to be launched by the U.S. early this year. Experiments with active repeater satellites will be considered later. The eventual objective is an experimental global satellite communication system.

Curb on Degeneracy

In recent discussions of the genetic code the term "degeneracy" frequently appears. Since it implies ambiguity in the meaning of code words, it suggests a certain looseness, or nonspecificity, in the process used by the cell to construct proteins. Recent work by Seymour Benzer, Bernard Weisblum and Robert W. Holley at Purdue University has uncovered features of this process that may limit some of the ambiguity.

The genetic code resides in the DNA (deoxyribonucleic acid) that constitutes the genes of a cell. The code is transmitted to the sites of protein synthesis by "messenger" RNA (ribonucleic acid), which uses as code letters four bases: A, U, G and C (adenine, uracil, guanine and cytosine). It appears that some combination of three of these letters supplies the code word for each of the 20 amino acids, the subunits that link together to form polypeptide chains, or proteins. A doublet code would provide only 16 code words; a triplet code yields $4 \times 4 \times 4$, or 64, words. Since 64 are more than the 20 needed, it was predicted that more than one word might specify a given amino acid. This is one possible type of degeneracy, and it was subsequently found experimentally. For example, the amino acid leucine is coded by either of two triplets: GUU or CUU (the actual sequence is not yet known).

Benzer and his associates looked for the physical mechanism behind this degeneracy. Inside the cell the amino acids are conveyed to the site of protein synthesis by a special soluble form of RNA designated sRNA. For each of the 20 amino acids there is at least one specific sRNA. It had been known that leucine can be recognized and transported by two kinds of sRNA, which have slight molecular differences. Benzer and his colleagues conjectured that one of the leucine sRNA's may respond to the GUU code and the other to the CUU code. They found that in the colon bacillus, at least, this is the case. In other words, coding specificity in the sRNA may compensate for lack of specificity in the messenger RNA.

There is, however, a second form of degeneracy wherein a given triplet codes for two or more amino acids. For example, the triplet UUU codes primarily for phenylalanine, but it seems also to code to a lesser degree for leucine. The Purdue workers found that the form of leucine sRNA that responds to GUU also responds somewhat to UUU. The implications of this ambiguity are still being studied.

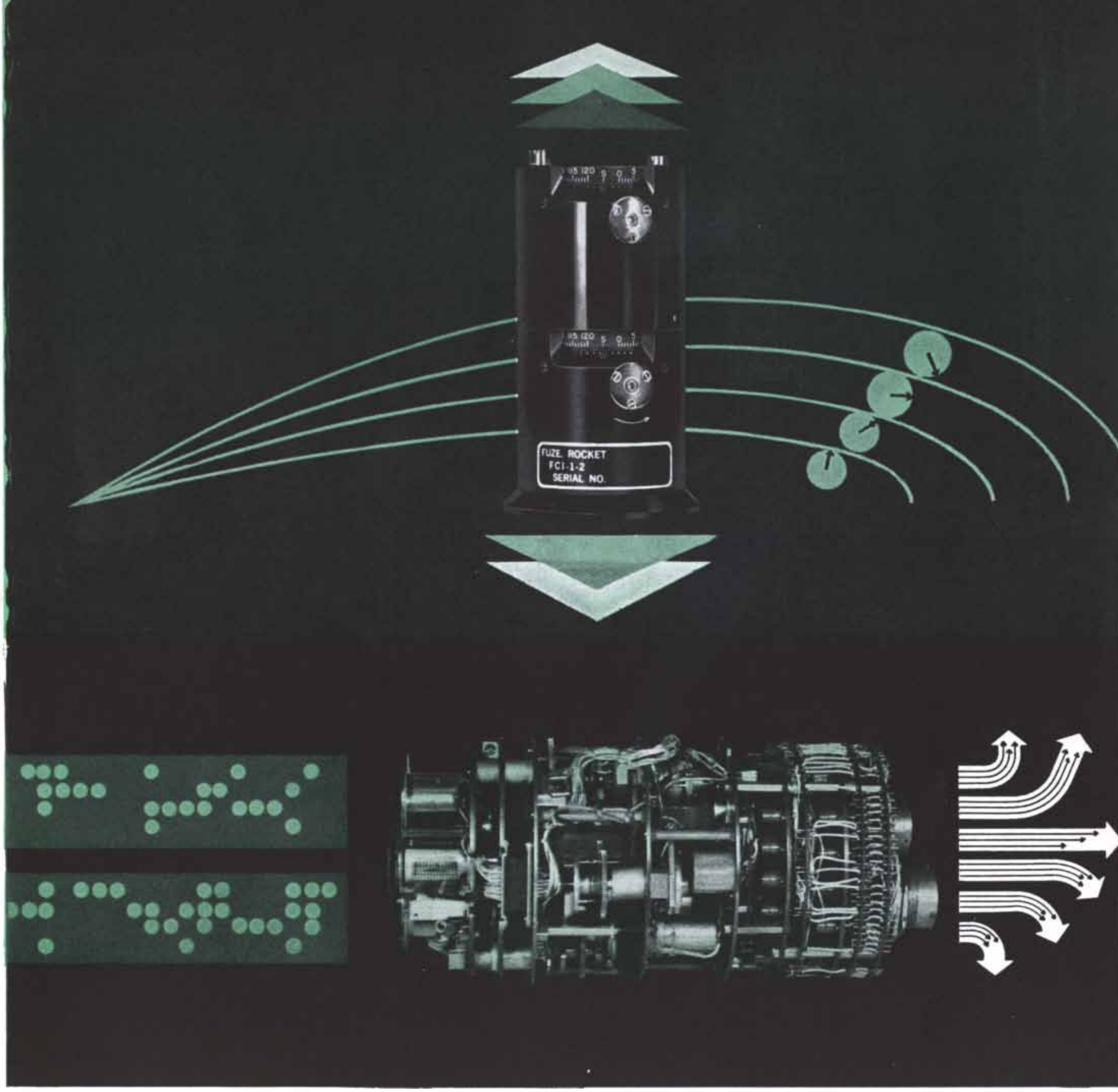
Writing in the *Proceedings of the National Academy of Sciences*, Benzer and his colleagues speculate that "some degree of degeneracy may confer increased survival value upon a cell, by reducing the number of nonsense coding units, i.e., those that correspond to no amino acid. A mutation that changes one amino acid in a polypeptide chain to another amino acid is less likely to be deleterious than one which completely impedes the completion of the growing chain."

Blue Means Go

What does the frog's eye tell the frog's brain? This question has been closely studied for some years in the Research Laboratory of Electronics at the Massachusetts Institute of Technology. The latest finding is that the frog's eye is acutely sensitive to blue light and that this sensitivity is reflected in the frog's behavior. The work is reported by W. R. A. Muntz in the November issue of the *Journal of Neurophysiology*.

Muntz recorded the electric output of individual nerve fibers that pass to the region of the frog's brain called the diencephalon. During the recordings he stimulated the frog's eye with light of various wavelengths. Frequency of nerve firing provided a measure of the response. The most surprising finding was that the frog's eye can distinguish blue as a dominant wavelength even under conditions that might be expected to produce confusion. For example, the frog was presented with two color samples: a dimly lighted piece of blue paper and a brightly lighted piece of greenish-yellow paper. Although more light of blue wavelength was reflected from the greenish-yellow paper than from the blue paper, the frog's optic fibers fired about twice as fast in response to the blue paper. This finding implies that the responsiveness to blue is not produced by a narrow-band photosensitive pigment in the frog's retina.

Muntz next subjected the frogs to behavioral tests. A frog was placed in a black box facing two open windows through which he could jump. The two



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windows were illuminated with lights of different colors. The frog was given a gentle poke to make it jump and the number of jumps through each window was recorded. The frogs jumped preferentially in the direction of blue light. Moreover, they preferred a blue window to one that contained just as much blue light to which green had been added. This again revealed the frog's ability to react to wavelength in preference to light intensity.

Muntz suggests that it is important for a frog sitting on the bank of a stream to be able to jump unerringly into the water when he is startled. In general, there will be more open sky in the direction of the water than in the direction of the land. The sky and the water below will usually be blue, whereas the foliage on land will usually be green. It is to be expected, therefore, that evolution should have endowed the frog with a strong preference for blue.

Surgical Glue

A plastic adhesive may provide surgeons with a simple alternative to stitching for purposes ranging from the attachment of skin grafts to the repair of blood vessels. Already in industrial use under the name Eastman 910, the adhesive cements soft tissues quickly and firmly without catalysts, heat or high pressure. The surgeon simply wipes excess moisture from the surfaces to be joined, applies a film of 910 and holds the surfaces together with siliconized forceps for as long as it takes the adhesive to set—about a minute. No signs of toxicity have appeared in tests so far.

The unusual adhesive is methyl-2-cyanoacrylate, a compound originally investigated by the Tennessee Eastman Company as a source of synthetic fiber. In the course of the study a laboratory technician spread the compound between the prisms of a refractometer to measure its index of refraction. When he had completed the measurement, he found that he could not separate the prisms. Further investigation disclosed that traces of moisture caused the compound to polymerize into an adhesive that strongly bonds metals, ceramics, leather, most plastics and numerous other materials. A single drop has sustained loads of up to 15,000 pounds.

Application of the glue to surgery has been under study for nearly four years. Animal experiments in several centers have shown that it is absorbed after healing takes place and leaves a thinner, softer scar than suturing does. At a recent meeting of the American College of

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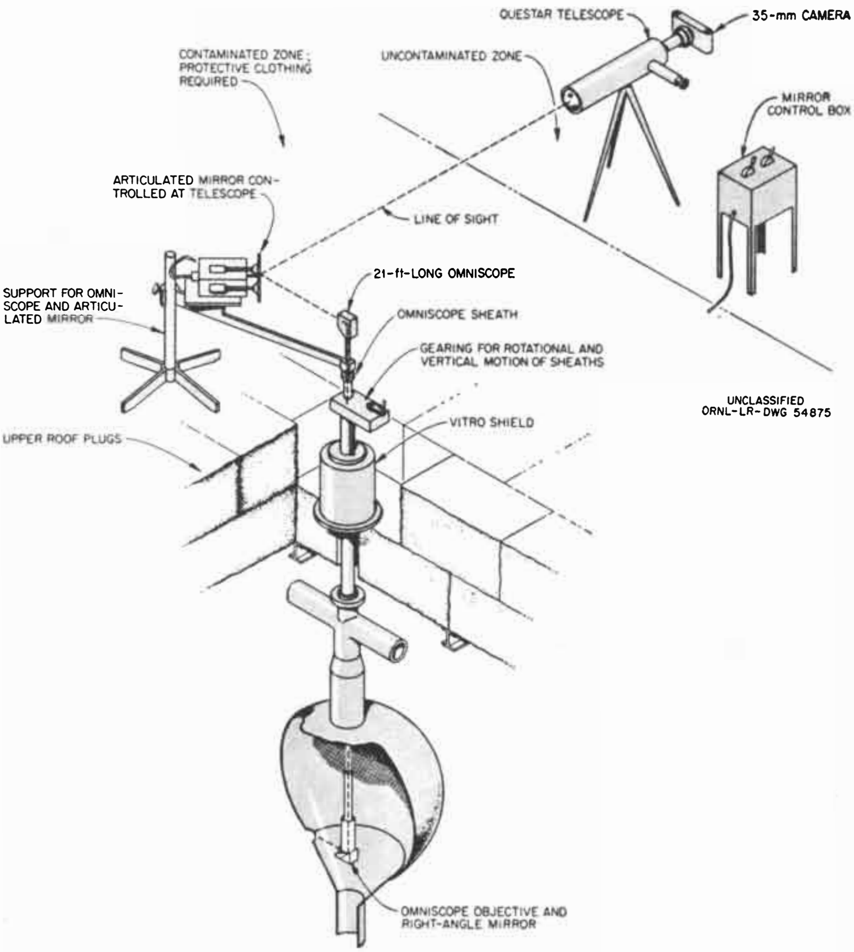
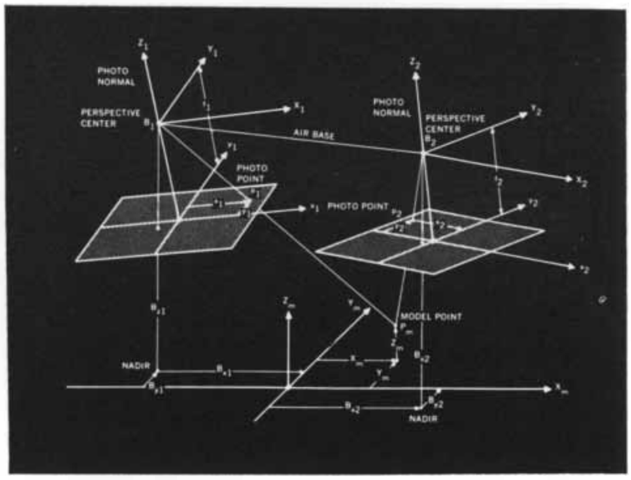


Surgeons, John E. Healey, Jr., and a surgical team from the M. D. Anderson Hospital and Tumor Institute of the University of Texas reported using the adhesive successfully to repair small blood vessels and close bronchial stumps in both experimental animals and human patients and to join pieces of intestine in dogs. Healey and his colleagues have also employed it to cement skin grafts in place when sutures would not hold. A University of Tokyo surgeon, Tsunamasa Inou, has closed skin incisions in 62 patients with the glue.

Troublesome Tool

A new hazard for the innocent bystander has emerged from an innovation in buildingtechnology. The threat is the stud gun, a pistol for firing bolt- and naillike fasteners called studs into a steel or concrete wall. The studs, which are then used for attaching various objects to the wall, leave the gun at velocities of several hundred feet per second.

At least six deaths and two cases of serious injury have been traced to studs that went astray. Writing in *The New England Journal of Medicine,* two surgeons, Samuel Mage and Kenneth Chiache Sze, describe the two injury cases, both brought into the Beekman-Downtown Hospital in New York within an 11-month period. In one, a bank clerk was at his desk near a window on the 11th floor of a financial district skyscraper when he suddenly felt a piercing pain and collapsed, with blood from wounds in his left arm and chest staining his shirt. At the hospital it was found that a "rifle bullet" had passed through his upper arm, entered his chest and pierced the pericardium, the sac surrounding the heart. At first the source of the "bullet," which was removed after the damage to the heart had been repaired, was a mystery. A police ballistics expert, however, identified it as a stud and traced it to a construction job across the street. In the other case, a construction worker suffered multiple wounds from a stud that passed through a two-and-a-half-inch-thick plaster and gypsum-block wall and then went through his abdomen. He was standing nearly 20 feet from the wall at the time. A descendant of a wartime device for attaching underwater demolition charges, the stud gun has become increasingly popular as a laborsaver since its introduction into the construction industry after the war. Safety regulations governing its use have so far been adopted by eight states and the District of Columbia.



Geometry and principal coordinate systems involved in the photogrammetric computations.

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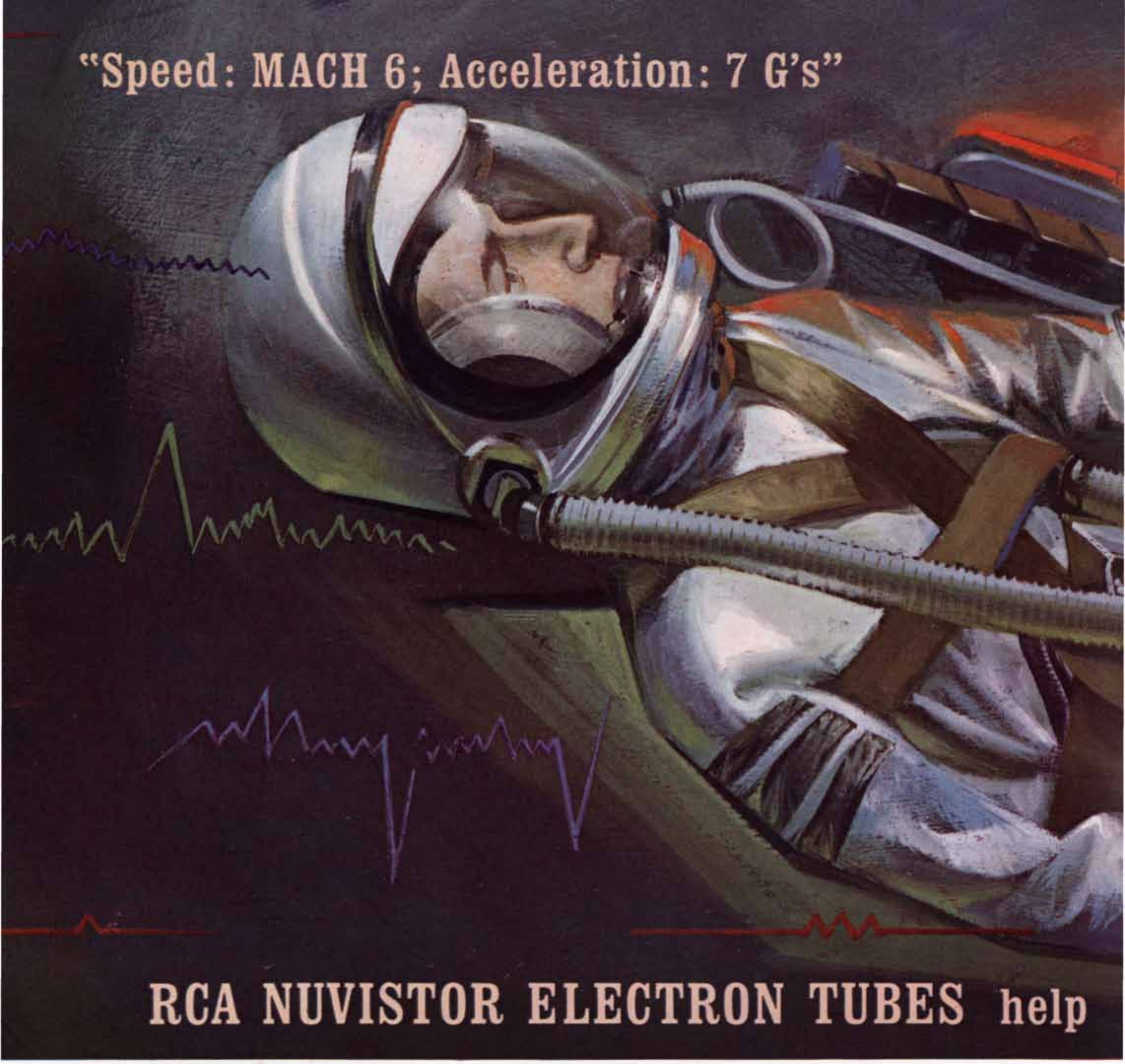

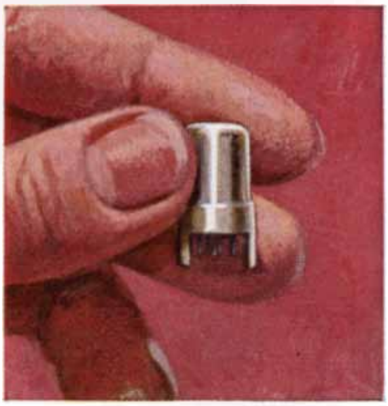

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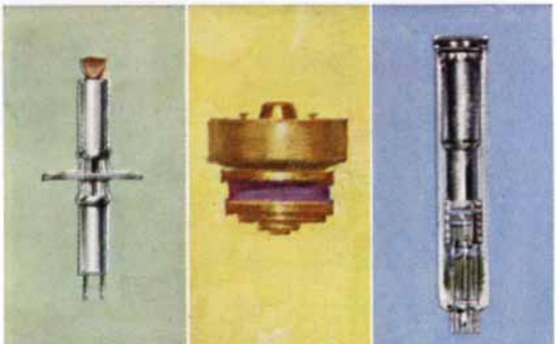

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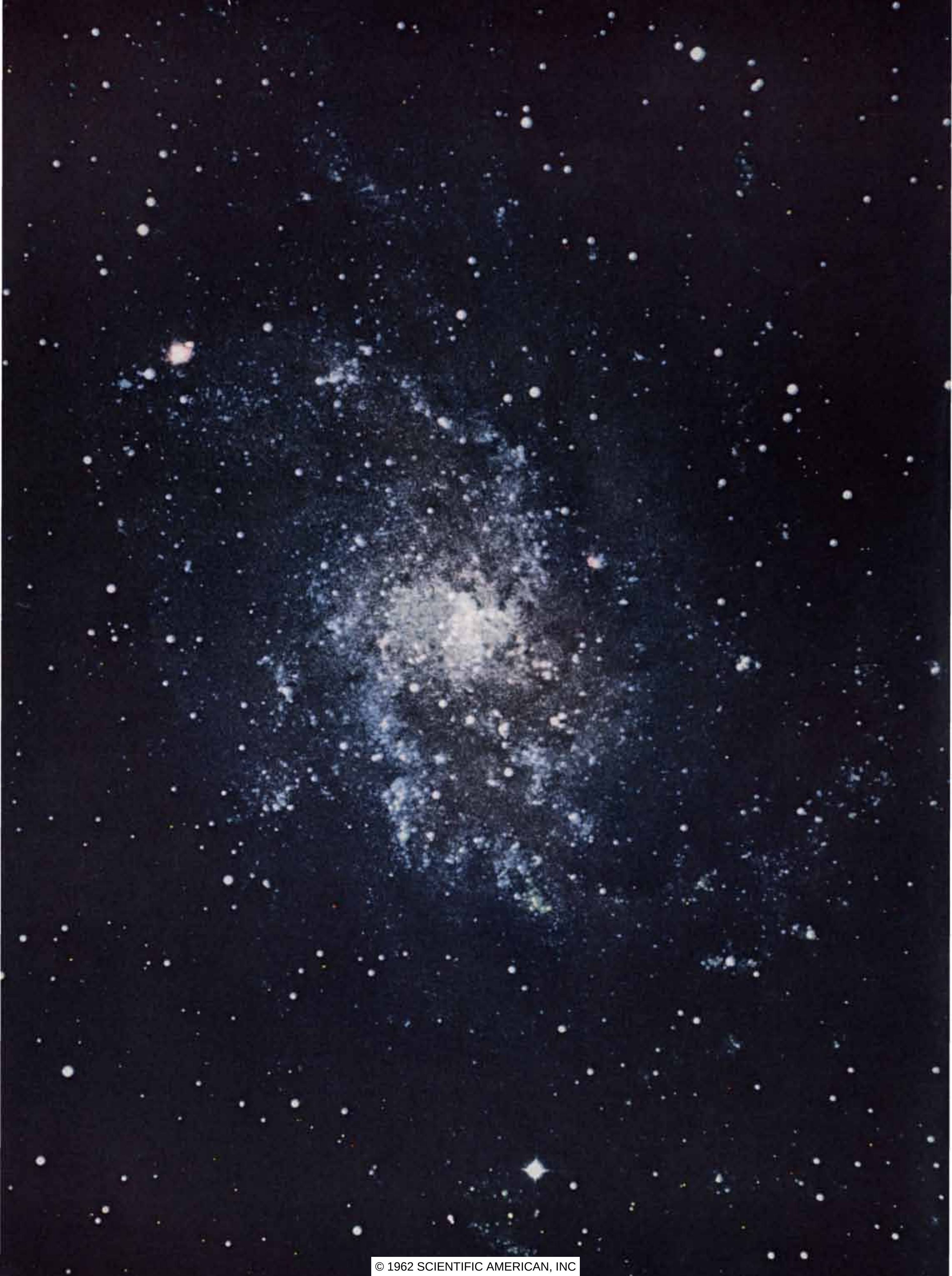


THE EVOLUTION OF GALAXIES

It was once argued that galaxies begin as huge spheroids and become flattened by rotation into spirals. A new inquiry suggests that galaxies look different because they were born different

by Halton C. Arp

It is not quite 40 years since Edwin P. Hubble, using the 100-inch reflecting telescope on Mount Wilson, conclusively demonstrated that the Great Nebula in Andromeda was not a mass of glowing gas but a galaxy—a huge system of stars outside our own. Subsequently Hubble examined thousands of galaxies recorded on Mount Wilson plates and classified them according to their appearance. He was careful never to suggest that his classification scheme represented an "evolutionary" series. His terminology of "early" and "late" spiral galaxies, however, suggested to some astronomers that a galaxy originated as a spherical mass of stars, that it gradually flattened by rotation into an ellipsoid and finally into a disk with more and more open and conspicuous spiral arms. Other astronomers felt, particularly in the last decade, that evolution proceeded in the opposite direction, at least in the spirals. Because a galaxy would presumably take billions of years to evolve from a ball to a disk (or vice versa), there seemed no way to establish the direction of galactic evolution.

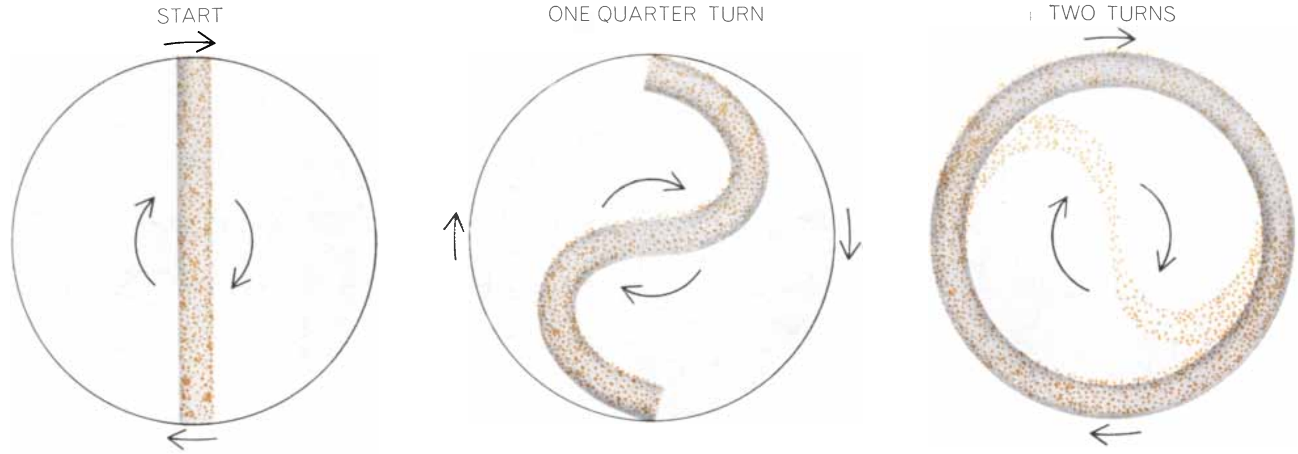
Astronomers, however, have learned to extract a surprising amount of information from the feeble samples of stellar radiation that reach the earth, and they have not been content to ignore the problem of galactic evolution. Before discussing some recent investigations that bear on this problem let me briefly describe our own galaxy. According to Hubble's classification it is an intermediate form of spiral galaxy, technically designated Sb. Viewed edgewise, it would resemble two thin dishes set face to face. Viewed at right angles to its central plane, it would display a dense, luminous nucleus from which star-speckled arms extend in long sweeping arcs. The galaxy contains nearly 100 billion stars; for light to travel across it takes more than 100,000 years. Our sun is located far out in one of the spiral arms, some 33,000 light-years from the center of the galaxy. Distributed in and around the galactic nucleus are more than 100 globular clusters of stars, which contain from a few thousand to a million stars. These are the largest subunits in the galaxy. Smaller subunits range downward in size from gaseous nebulae and stars to atoms of gas and subatomic particles. Electromagnetic energy is radiated by the stars and is radiated or absorbed by the gases, depending on their temperature and density. The energy is observed mostly as light or as radio waves. Magnetic fields organize the pattern of the observed radiation. Dust and solid particles redden and block the light. All the gas and dust and stars are in swirling motion, with the sun's portion of the galactic disk rotating around the center of the galaxy with a speed of about 260 kilometers per second, or almost 600,000 miles per hour. Even at this velocity it takes more than 200 million years for the sun to make one complete circuit of the galaxy. One can estimate, therefore, that there must have been nearly 50 revolutions, or solar-galactic years, since the supposed birth of the universe 10 billion years ago.

The galaxy in Andromeda, technically known as M 31, looks about the way our own galaxy would look if it were seen from outside, tilted about 15 degrees from edge on [*see illustration on page 77*]. Two million light-years away and the nearest of the larger galaxies, M 31 is barely visible to the naked eye as a small hazy patch of light. If it appeared as bright to the eye as it appears in photographs, its long dimension—as seen in the sky—would be about seven times the diameter of the moon. Another spiral galaxy, M 81, seen more at right angles than M 31, is shown on page 78. Both M 31 and M 81 are classified Sb, a designation in which S stands for spiral and b for an intermediate stage of development, according to the Hubble classification. An Sc, or late-type spiral, is shown on the opposite page. Only about two million light-years away, it is a member of our local group of galaxies. A more distant Sc spiral, M 74, appears on page 80. Sc galaxies have smaller nuclei than Sb galaxies and their spiral arms are less tightly coiled and more conspicuous.

The Orientation of Spiral Arms

A picture of a spiral galaxy suggests that it is in motion and that it is rotating perhaps like a pinwheel or a whirlpool. To test this hypothesis early workers recorded the spectra of galaxies and found that the spectral lines were indeed shifted in such a way as to indicate that one edge of the flattened disk is approaching and the other receding. Unfortunately this determination can be made only when a spiral galaxy can be seen more or less edge on, and in this orientation the spiral pattern is hard to see. Conversely, when the spiral is tipped enough for us to see the arrangement of the spiral arms, the direction of rotation is hard to determine. As a result the obvious and important question of whether the spirals rotate in an unwinding sense or rotate with their arms trail-

GALAXY M 33, two million light-years away, has spiral arms more widely separated than those in our own galaxy. According to the system devised by Edwin P. Hubble, it is a late-type (Sc) galaxy. This color photograph was made by William Miller with the 200-inch telescope on Palomar Mountain.



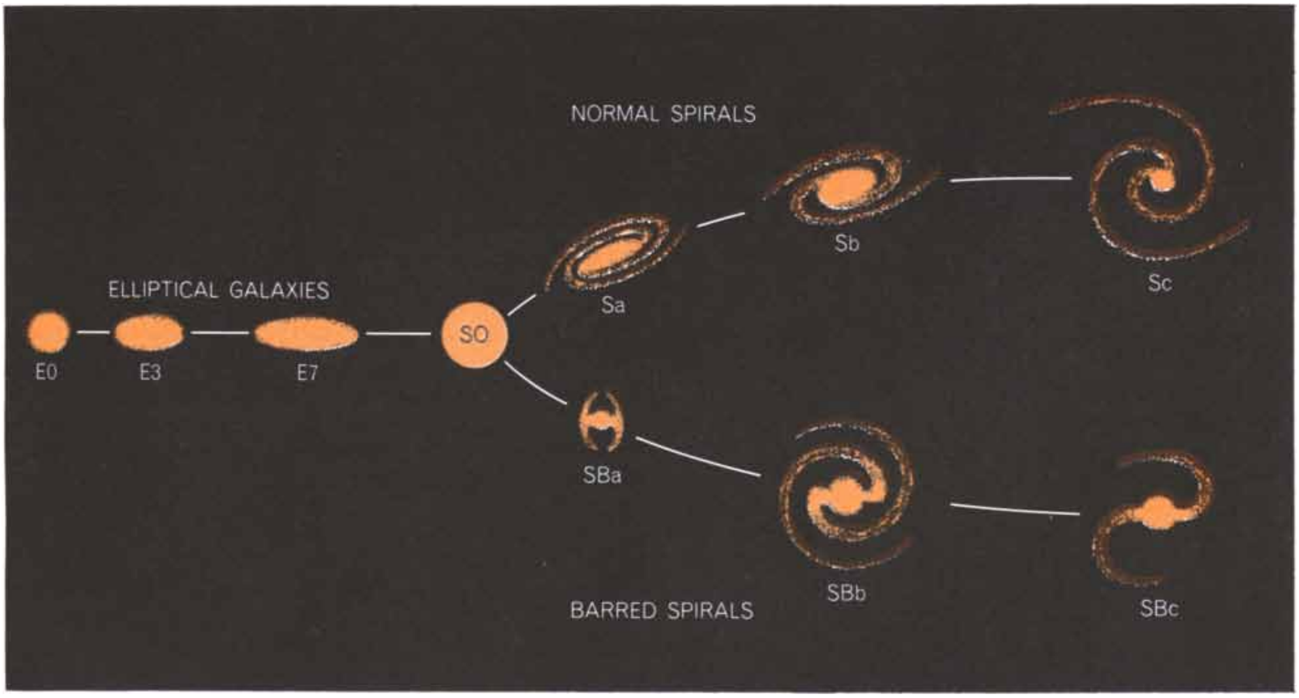
EFFECT OF DIFFERENTIAL ROTATION would be to wind the arms of a spiral galaxy into a ring, unless other forces were at work. The three diagrams show two opposed arms at the start of rotation, after a quarter-turn and after completion of two turns.

ing became a subject of considerable astronomical controversy. Even today a few astronomers maintain that at least some spirals may be rotating in an unwinding sense. Most astronomers feel, however, that the weight of evidence supports the view that spirals rotate with their arms trailing.

A simple physical consideration practically demands that the arms should trail: spirals viewed edgewise are observed to be in differential rotation. That is, the inner parts revolve around the center with a certain speed, but regions farther from the center rotate more slowly. Therefore a radial assemblage of stars forming one of the arms of a galaxy would unavoidably rotate faster toward the center and be drawn out into a spiral form with the outermost stars trailing in the rotation. This concept immediately raises another problem: Any given set of spiral arms will in a few turns be drawn out into what essentially appears as a closed ring around the center [*see illustration above*]. I have already mentioned that our own galaxy has presumably made something like 50 turns since its birth. Inasmuch as there are many spiral galaxies in the universe but few ring galaxies, one must conclude that some unknown agency prevents the spirals from winding themselves up.

A related puzzle is that the spiral arms are marked by very luminous stars that cannot shine for long at their present rate and therefore must be quite young. Evidently some agency replenishes the bright young stars in the arms. In short, the spiral arms are seen to be dynamically fragile and energetically short-lived. A tantalizing puzzle that has occupied astronomers is how spiral arms can be formed and maintained in the face of the forces working to destroy them.

The first step in solving the puzzle has been to try to establish the composition of the spiral arms. As we have seen,



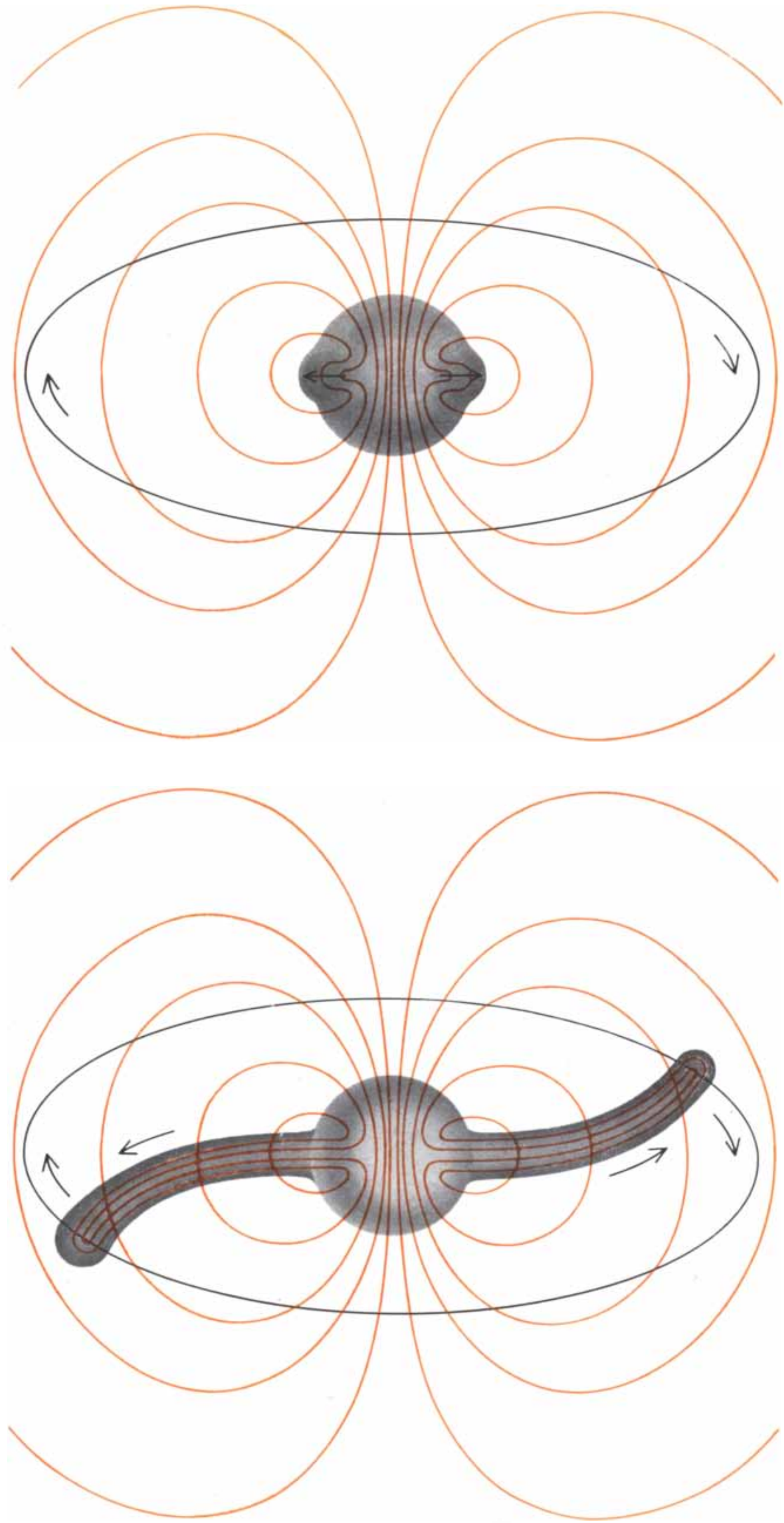
SEQUENCE OF GALACTIC FORMS was proposed by Hubble more than 20 years ago. In his "tuning fork" diagram spherical systems are at the left, followed by elliptical systems, then by disks (SO) and finally by spiral systems of two general types.

the spiral arms sparkle with stars that are hot, blue and from 10,000 to 100,000 times brighter than the sun. Stars can radiate at this rate for only one million to 10 million years, a short time compared with the estimated age of the universe. These supergiant stars are strung out along the spiral arms like beads on a string. Similarly restricted to the arms are great clouds and filaments of dust. Recent radio observations have shown that the spiral arms in our own galaxy are also outlined by hydrogen gas. Clearly this dust and gas furnish material for the formation of the bright new stars that illuminate the spiral arms. In fact, it is possible to observe nearby regions in the spiral arms of our galaxy where stars are in the process of being formed [see "The Pleiades," by D. Nelson Limber; SCIENTIFIC AMERICAN, November, 1962].

But just as the lifetime of very hot stars is limited, so too the supply of dust and gas for creating new stars would seem to be limited. Sidney van den Bergh of the David Dunlap Observatory in Toronto has estimated that at the present rate of star formation the gas in the vicinity of the sun would be exhausted in less than a billion years. He has suggested that the gas was perhaps replenished from the central regions of the galaxy. Subsequently Maarten Schmidt of the California Institute of Technology worked out a galactic model in which sufficient gas was originally present so that a decreasing rate of star formation would still leave about a fifth of the original gas not yet formed into stars. But regardless of whether new material flows in to replenish the old or the spiral arms are simply supplied with a large initial amount of gas, the problem remains of explaining how the material is kept from diffusing out of the spiral arms and away into space.

Evidence for Magnetic Fields

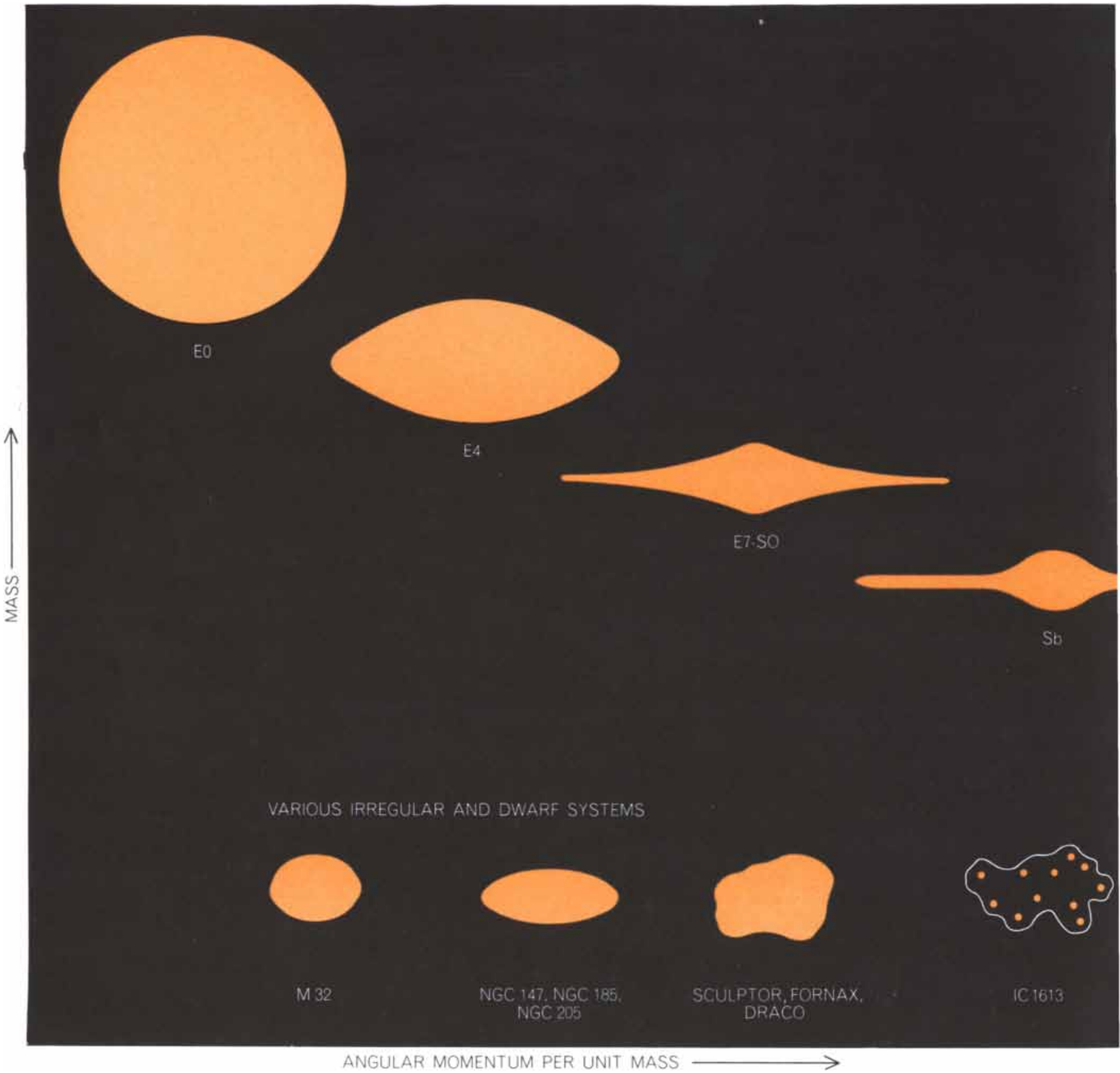
One clue to the solution of the problem may have been provided in 1949, when John Hall and W. A. Hiltner of the Yerkes Observatory observed polarization of the light from nearby arms of the galaxy. Jesse L. Greenstein and Leverett Davis, Jr., of the California Institute of Technology showed that polarization is probably caused by elongated dust particles, all aligned in the same direction, which preferentially absorb the light whose vibration is parallel to the long axis of the particles. The important outcome of this work seems to be that only a magnetic field aligned along the



MAGNETIC FIELD OF GALAXY might originally have the general form shown in the top illustration. In the nucleus ionized, or electrically charged, particles of gas would be tightly bound to lines of magnetic force (*color*). If the gas were thrown outward by rotation of the galaxy, the ejected mass would pull the lines of magnetic force with it, as shown in the bottom illustration. Thereafter ejected material would tend to follow these lines and form arms.

spiral arm can explain the preferential alignment of the dust particles. A magnetic field would also serve to trap any atoms of hydrogen that have lost an electron as a result of collisions with photons or other energetic particles. Atoms that lack one or more electrons are said to be ionized. If it is placed in a magnetic field, an ionized particle can move only by spiraling along one of the lines of magnetic force. Even a weak magnetic field may be enough to bottle the gas within the spiral arms of a galaxy. Although only a fraction of the interstellar hydrogen is ionized and thus susceptible to magnetic trapping, the ionized atoms "frozen" to the lines of magnetic force would form a vast web through which un-ionized particles would find it difficult to escape. The actual picture is somewhat complicated because a gas confined in this way is under pressure and therefore tends to expand. Moreover, the magnetic field itself tends to push outward. It can be shown, however, that the gas in the spiral arms probably has enough mass to produce a gravitational force sufficient to offset the dispersive forces.

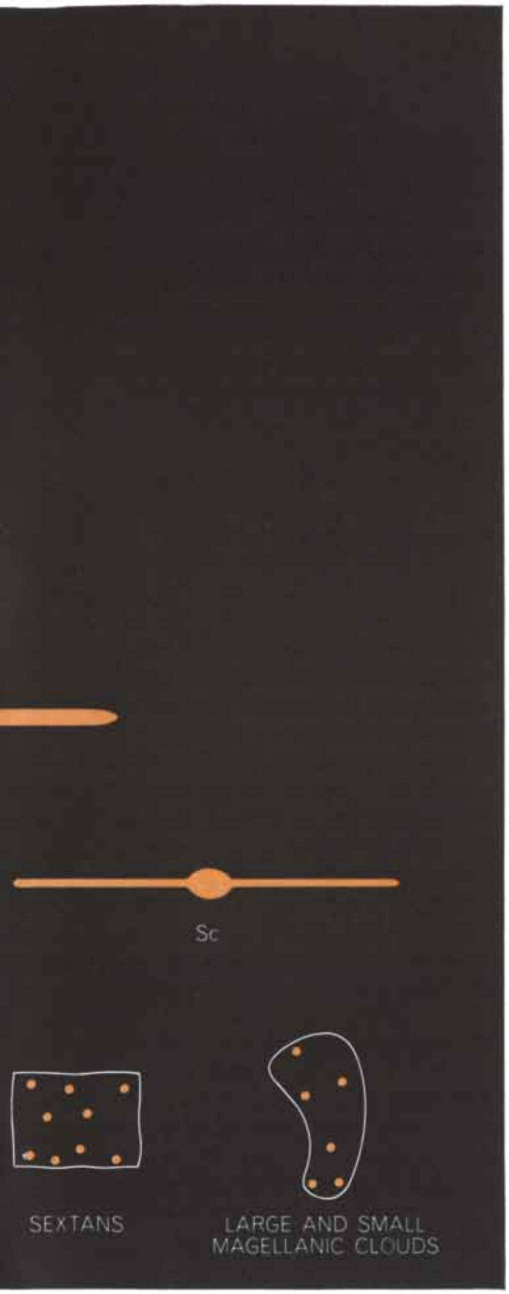
The proposal that the magnetic field in a spiral arm is held in shape by the gravitational attraction of the mass within the arm was made in 1953 by Subrahmanyan Chandrasekhar and Enrico Fermi of the University of Chicago. They computed that the magnetic-field strength needed to balance the gravitational field was between one millionth and 10 millionths of a gauss. A recent announcement from the Nuffield Radio



SUGGESTED CLASSIFICATION OF GALAXIES is based on two characteristics: mass and degree of flattening. Presumably the massive spherical and elliptical galaxies possess the least amount of rotational energy, or angular momentum per gram. Spiral galaxies and certain dwarf systems possess high amounts. (Many galaxies fall between the extremes plotted.) It is hard to conceive

Astronomy Laboratories at Jodrell Bank in England reports a directly observed value of 25 millionths of a gauss in certain regions of our galaxy and an over-all galactic field of approximately five millionths of a gauss. (The magnetic field of the earth is about .5 gauss.)

A second clue to the solution of the spiral-arm problem was provided by radio astronomy in 1957. It was observed that there is a flow of gas traveling toward the sun from the center of the galaxy. The gas leaves the galactic center at about 50 kilometers a second and contains enough material to create about one star of solar mass each year. More recently the Australian radio observer Frank Kerr has concluded that the outflow still has a velocity of about seven kilometers a second in the vicinity of the sun. Using the 200-inch telescope on Palomar Mountain, Guido Munch has observed a similar outflow of gas in the center of the Andromeda galaxy.



of any mode of galactic evolution that could add (or subtract) mass or angular momentum over the range shown in the chart.

I should like to propose that at least some of the gas observed to be leaving the center of the galaxy is traveling inside the tube of magnetic force that comprises the spiral arm containing our sun. One solar mass of gas per year is ample to keep the spiral arm glowing with hot new stars. It might also be enough to allow for some leakage of material from the spiral arm.

If the spiral arm has an outward component of motion in addition to its motion around the center of the galaxy, this would tend to keep the spiral from winding up on itself and forming a ring. The mechanism would be similar to that of a Fourth of July pinwheel. The outward component of velocity would have to be an appreciable fraction of the rotational velocity, however, in order to keep the spiral open. It is doubtful that the observed outflow in our galaxy meets this requirement. If the outflow is indeed inadequate, the spiral arm containing our sun seems fated to be wound up in a ring very quickly. Other considerations may be involved, however. For one thing it is difficult to estimate how much rigidity may be imparted to the arms by the magnetic field running through them. There is also the possibility that the arms near the sun are not representative of the arms that give the galaxy its over-all shape. The spiral arms near the sun are only about 5,000 light-years apart, which would make our galaxy a rather tightly wound spiral. In M 31 and other Sb spirals the arms are about twice as far apart. To obtain more information on the fate of spiral arms near the sun, a number of observers have looked for differences in rotation velocity between old stars embedded in the disk of the galaxy and young stars in the arms. Although such differences have been found, they involve about the same uncertainties of interpretation as are encountered in the gas-flow measurements.

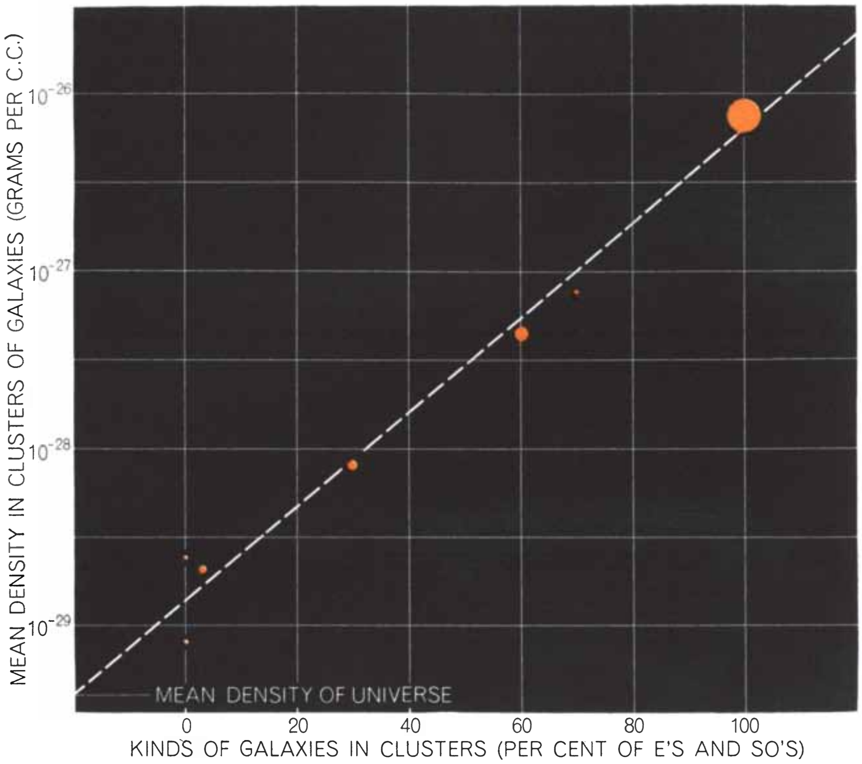
Shaping of the Magnetic Field

Although it has not yet been demonstrated conclusively that there is a net outflow of gas in the disk of spiral galaxies, I offer the hypothesis that such a flow is fundamental to their spiral structure. This hypothesis immediately raises the question of the relation, if any, between the flow of matter and the magnetic field. Offhand it is difficult to imagine why the magnetic field should radiate from the galactic center and form a series of spiral arms. This puzzling distribution might be explained as follows. Suppose the over-all magnetic field of a spiral galaxy has its axis through the center of the galaxy and perpendicular to the plane (like the orientation of the earth's magnetic field with respect to the plane of the earth's rotation). It is reasonable to assume also that many of the gas atoms in the center of the spinning galaxy are ionized and spiraling around lines of magnetic force. It is a characteristic of such magnetically trapped particles that if they are forcibly displaced, they drag the lines of magnetic force with them. As a result, if the ionized atoms are being urged out of the galactic center by centrifugal force or by pressure resulting from the inflow of fresh material from outside the nucleus, the initially ejected material will stretch out the lines of magnetic force behind it like taffy. This magnetic tube would then provide a channel for the flow of more ejected material, consisting of both ions and physically entrained un-ionized particles [*see illustration on page 73*].

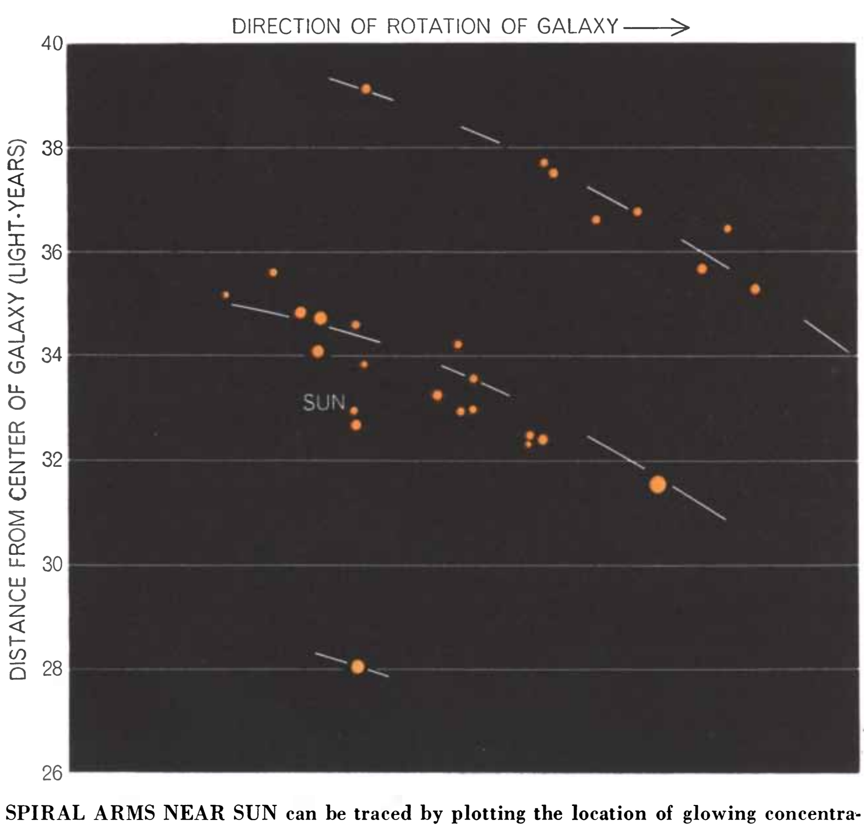
Of course, what causes the magnetic field in a galaxy is not known, and the over-all configuration of the field can only be guessed at. Almost any general field, however, could be distorted locally by sufficient flow of ionized material to produce a field with a spiral-arm pattern. Other questions remain. Where does the material come from that flows out of the center? What would happen if the outflow were larger? Will it someday stop? Answers to these and other questions must await further knowledge of how galaxies evolve.

The Morphology of Galaxies

Let me return now to the problem that fascinated Hubble: Do the various configurations among galaxies offer a clue to their evolutionary development? There are, first of all, a large number of faint galaxies that bear little or no resemblance to the great spiral galaxies. Many of these galaxies are intrinsically small and faint; they must be quite near in order to be readily observable. Good examples of such galaxies are the two clouds of Magellan, the cloudlike



MEAN DENSITY OF CLUSTERS OF GALAXIES is plotted against the kind of galaxy found in the clusters. In the densest clusters the galaxies are all elliptical and disk-shaped (SO). As density decreases, the percentage of spiral galaxies in a cluster increases. At the approximate mean density of the universe there are only isolated galaxies, all spirals.



SPIRAL ARMS NEAR SUN can be traced by plotting the location of glowing concentrations of gas known as gaseous-emission nebulae. They indicate the existence of three arms about 5,000 light-years apart, making our galaxy a rather tightly wound spiral. The data are from W. W. Morgan, D. E. Osterbrock and Stewart Sharpless of Yerkes Observatory.

patches observed by Magellan when he first sailed beneath southern skies. These two galaxies, only about 200,000 light-years away, are so close that some observers have been led to search for filamentary bridges between them and our galaxy. Although no such link has been found, it has recently been shown that the two clouds are themselves linked by a tenuous common envelope of hydrogen gas. The large Magellanic cloud is about 40,000 light-years in diameter and the small Magellanic cloud about 30,000 [*see top illustration on page 82*]. The clouds are therefore between a third and half the size of our galaxy and are somewhat irregular in shape. The relative percentage of gas, particularly in the small cloud, is much larger than that in our own galaxy.

There are a number of systems smaller than the Magellanic clouds, such as the one in the constellation of Leo shown at the bottom of page 82. These faint systems lie at distances of 150,000 to 600,000 light-years and have diameters ranging from about 1,000 to several thousand light-years. As far as can be observed they contain no gas or dust—just stars. Still smaller systems are the "intergalactic globular clusters." Roughly 200,000 light-years away, they are only about 100 light-years across and contain even fewer stars and less mass than an ordinary globular cluster lying within our galaxy. It remains to be seen whether these very small star systems exist predominantly in the neighborhood of large galaxies and can be regarded as subunits or satellites or are spread more widely through the universe and must be considered independent galaxies.

If we turn our attention now to the other end of the spectrum of galactic sizes, we find that the elliptical and particularly the spherical galaxies are so big and bright that they can be seen at immense distances. The spherical galaxy shown at the top of page 84 is about 45 million light-years away in a cluster of galaxies in the constellation of Virgo. Being somewhat featureless and nonphotogenic, elliptical and spherical galaxies are not often used to illustrate popular articles on astronomy; they are nonetheless among the most important constituent "particles" of the universe. In the longest exposures with the 200-inch telescope the most distant objects that can be recorded—those whose light required about two billion years to reach the earth—are assumed to be elliptical and spherical galaxies. Spiral galaxies at the same distance would be too faint to register on photographic plates.

The bottom illustration on page 72

shows Hubble's famous "tuning fork" diagram, in which galaxies of different shapes are arranged in morphological sequence. At the left are the spherical EO's followed by the elliptical galaxies of increasing flatness, designated E1 to E7. The diagram branches at SO (a disklike form that lacks spiral arms) into two categories that Hubble called normal spirals and barred spirals. It was not clear 25 years ago where the irregular galaxies such as the Magellanic clouds belonged, but now the sequence of forms has been filled in. As Sc spirals become more and more open, the nucleus disappears, the arms become more and more irregular, the surface brightness becomes lower and finally one reaches systems in which no organized shape or symmetry remains.

Because of the smooth gradation of forms through the tuning-fork diagram, some astronomers felt that it represented an evolutionary sequence. Scientists have a tendency to simplify concepts—to seek "understanding"—by finding a few simple starting blocks and trying to perceive logical steps of transformation that unify a wide range of observations. But the problem of discerning real evolution in the galaxies is a difficult one. It is as though visitors from another planet were given only a few minutes to observe the human race. They might not immediately grasp the fact that many different races exist and that each experiences a separate but analogous aging process—from babies to children to adults to old people. In their attempt to comprehend and unify us, the visitors might guess initially that all people of a certain size were a certain age—dwarfs and children alike. Or they might order us according to color and conclude that the normal course of aging for the human race was from light skin to olive skin to brown skin to black skin. Given only a snapshot of the human population, they would need keen observation and reasoning in order to separate age characteristics from innate characteristics.

Similarly, in an instant of cosmic time, humans try by acute observation and logic to guess the way galaxies are

GREAT NEBULA IN ANDROMEDA, also called M 31, is about two million light-years away and the nearest of the large regular galaxies. It is an intermediate (Sb) spiral that contains more than 100 billion stars and has a diameter of about 125,000 light-years.

formed, how they evolve and the relations among them. It is particularly important to look for critical distinctions among galaxies in trying to decide which ones belong to an evolutionary sequence and which ones perhaps belong to completely different "races" or "species" with innate differences.

The smoothest gradation of forms is from early ellipticals to late-type spirals. If spiral arms were added to ellipticals, they would somewhat resemble spiral galaxies; if arms were removed from spirals, they would superficially resemble ellipticals. For many years, therefore, the question was debated whether the passage of time saw the spirals evolving into ellipticals or the other way around.

The question has been pretty much settled by the patient work of many observers. For example, Thornton Page of Wesleyan University, by measuring the relative velocities of paired galaxies and assuming that they are in gravitationally bound orbits around each other, has been able to calculate the approximate masses of the pairs. He has found that the spheroidals and ellipticals are about 30 times more massive than the average spiral galaxy. It is clear that a spiral or elliptical galaxy aging in an undisturbed state could never generate or get rid of enough mass to pass from one form to the other. Mass is a meaningful physical measure and a stable criterion for arranging galaxies because it is difficult to transform mass into energy, or energy into mass, on a galactic scale. Another physical quantity difficult to increase or reduce on a galactic scale is angular momentum. This quantity is a measure of the rotational energy of a system. In order to change a galaxy's angular momentum, force would have to be applied from the outside.

In the diagram on pages 74 and 75 I have arranged the principal kinds of galaxies according to their approximate mass and angular momentum per unit of mass. (In order to specify the angular momentum of a galaxy accurately it would be necessary to measure the mass and velocity at all distances from the center and integrate them over the whole galaxy. Since such observations are not available, one can take the cross-sectional flattening of the galaxy as a qualitative measure of the relative amount of energy in the rotation at the time when the visi-

GALAXY IN URSA MAJOR, M 81, is a magnificent spiral about nine million light-years away. M 81 and M 31 are near enough so that their distance can be measured quite accurately. They indicate about how our galaxy would look if seen from the outside.

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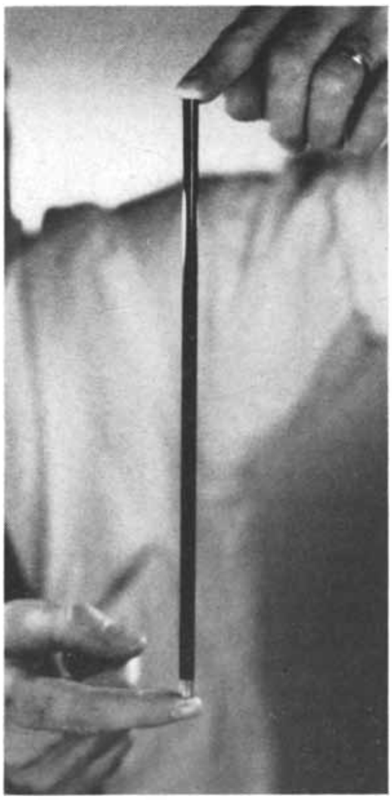

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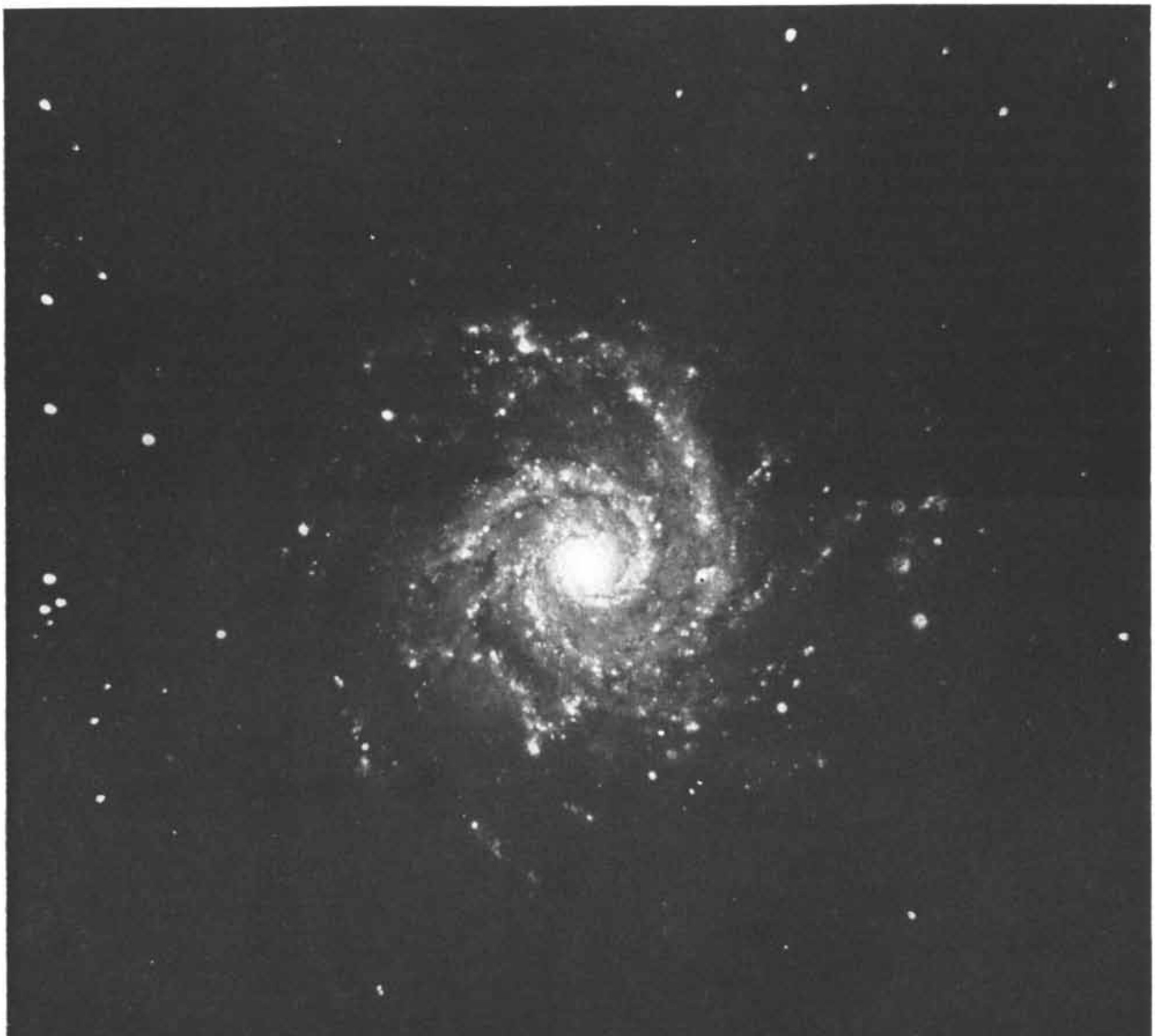
ble stars in the galaxy were formed.) If no outside forces act, one sees that the differences in mass and angular momentum are so great that the galaxies cannot evolve along either co-ordinate of the diagram. Therefore it is extremely unlikely that ellipticals evolve into spirals or vice versa. By extension, if this analysis is correct, most of the distinctively different types of galaxies represent different species and are not one species seen in different epochs of aging.

The Relation of Rotation to Form

Let us now see how one might account for the different galaxy types, accepting the hypothesis that the universe, as we see it, began with a cosmic "explosion" about 10 billion years ago. Immediately after the explosion space was filled with a homogeneous expanding gas. As the gas cooled, local irregularities in density developed and these slowly contracted under the force of gravitation. These clouds of contracting gas were protogalaxies—galaxies in the process of formation. Simply by chance the clouds would have different masses, and most of them could be expected to have at least a small net rotation. As a cloud shrank it would have to spin faster to conserve angular momentum, just as a figure skater spins faster when he draws his arms closer to his body. My belief is that if the shrinking cloud exceeded a certain speed, not all the mass would be able to contract. The galaxy might break in two, or it might throw several fragments out into space. Alternatively it might eject masses of gas along its rapidly rotating equatorial edge. Those protogalaxies that were not rotating, or that were rotating only slowly, could contract without losing mass until the gas became compressed enough to form stars. These became the massive spherical and elliptical galaxies we see today. More rapidly rotating systems presumably would not be able to contract all their mass. Mass in excess of a certain amount would be



GALAXY M 74 is a late-type (Sc) spiral about 20 million light-years away. There is no way to tell in which direction a galaxy is rotating when seen in this orientation. Although the arms probably trail, this cannot be established with certainty in all cases.

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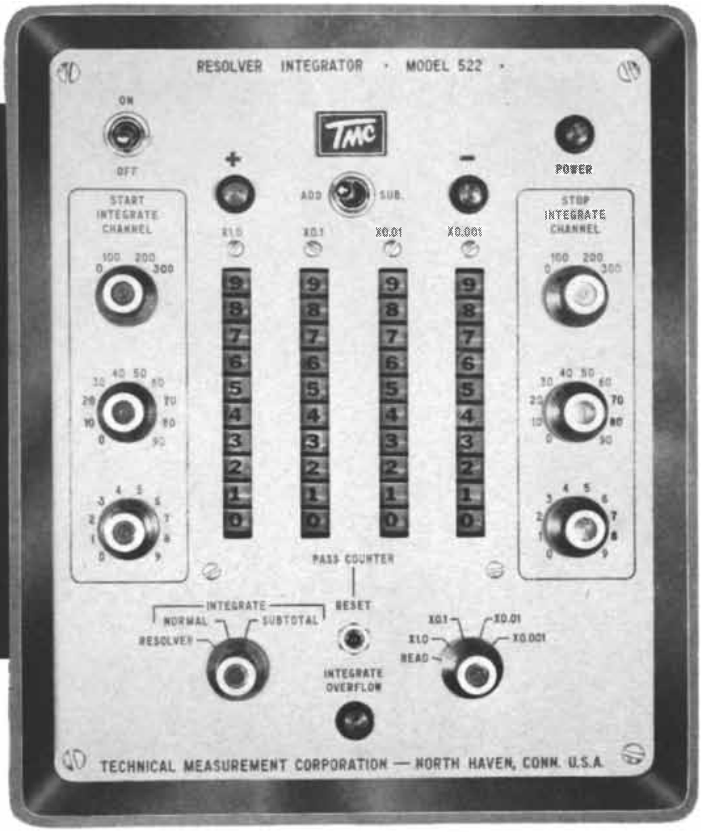

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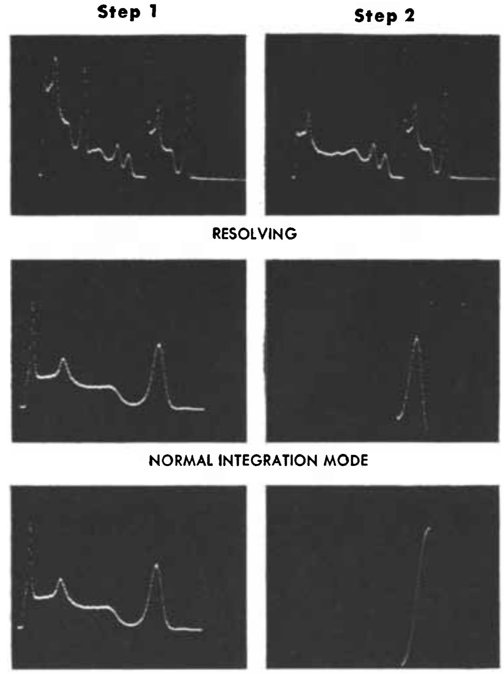

RESOLVING

NORMAL INTEGRATION MODE

SUBTOTAL INTEGRATION MODE

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% Resolved..........100%, 10%, 1% or 0.1%
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SMALL CLOUD OF MAGELLAN, visible in the Southern Hemisphere, is a small irregular galaxy, rich in gas, about 200,000 light-years away. Its diameter is about 30,000 light-years.

DWARF GALAXY is several hundred thousand light-years away in constellation Leo. Approximately 2,000 light-years in diameter, it contains faint stars and little or no gas.

thrown off. The result would be exactly the relation diagramed on pages 74 and 75, which shows that the slowly rotating kind of galaxy can be very massive, but that the faster a galaxy rotates, the smaller its maximum mass can be.

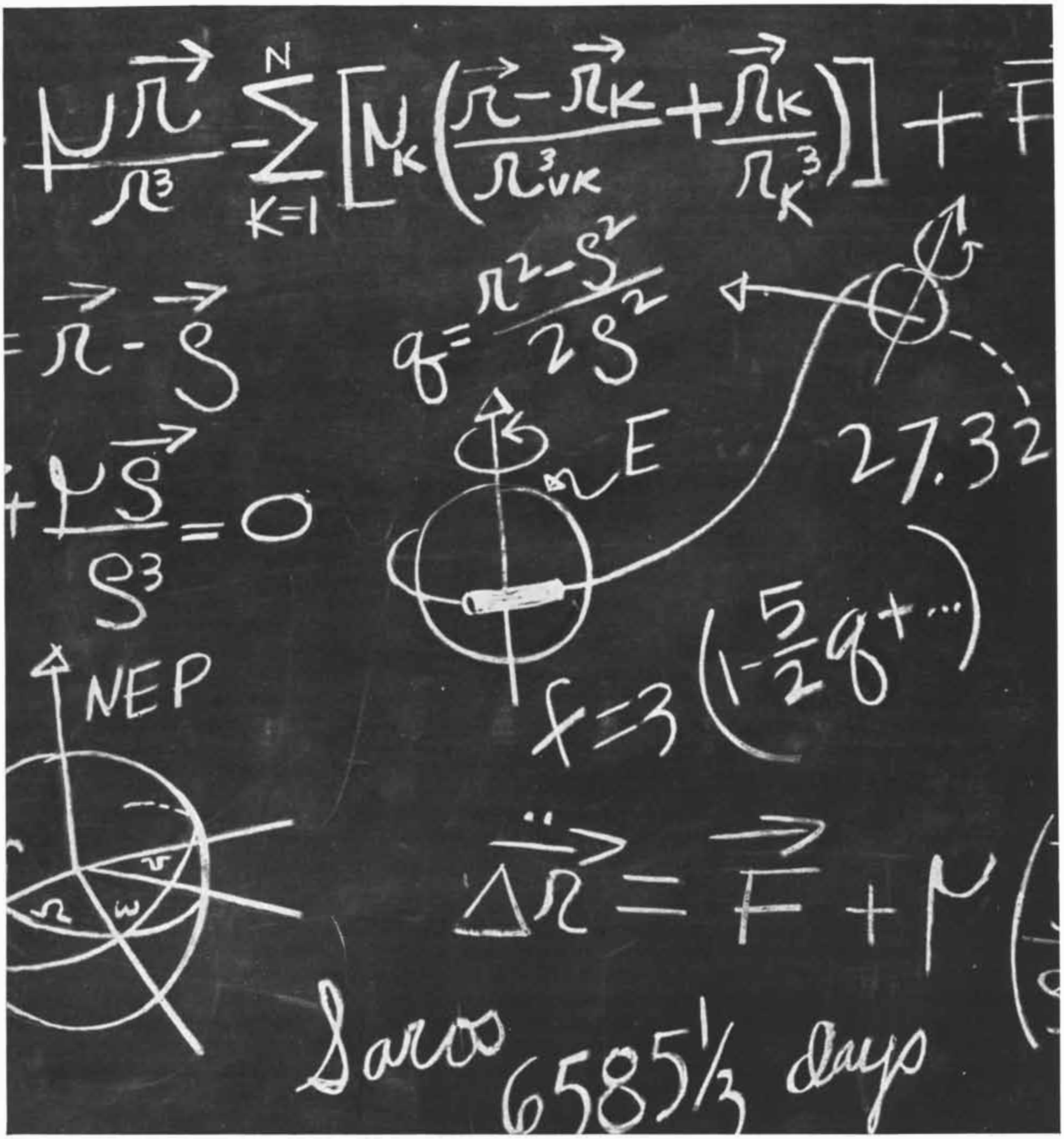
Purely as a bonus, we get a natural explanation of the spiral galaxies. Since they are rotating rapidly, they should be losing considerable matter around their sharp peripheral edges. It is precisely such an outflow of matter along the spiral arms that is needed to explain the riddle of their permanence.

Of course, the scheme just suggested is an oversimplified and tentative explanation for the origin of different kinds of galaxies and their subsequent development. It has by no means gained general acceptance. The hypothesis accomplishes the objective, however, of unifying all the important observational facts into the simplest possible structure. More important, it gives a definite picture that can be tested and discarded if found wanting, or expanded and modified if it continues to be basically satisfactory.

Since there is more going on in the spiral galaxies than in the more massive spherical and elliptical ones, the spirals offer more opportunities for testing the hypothesis. If the spirals are shedding mass at their edges, there are two general possibilities. The ejected matter may leave the galaxy and not be replaced or there may be some replacement. In fact, the matter may be in continuous circulation, flowing out at the edges of the galaxy and back in at the poles. Material (either new or recirculated) could be guided in at the poles by a magnetic field that is also directed inward at the poles.

Regardless of whether the spiral galaxies are ejecting matter or recirculating it, there should be a good deal of observable material immediately outside fast rotating spirals. Indeed, it is in the vicinity of such galaxies that we observe smaller galaxies, irregular galaxies and satellite systems. Around our own galaxy there are the irregular Magellanic clouds and many other small and fragmentary systems. Around other nearby spirals, down to the limit of visibility, one can also observe irregular and satellite companions. These searches are observationally difficult since they involve faint dwarf galaxies around relatively distant systems, but it is fair to say that galactic "remnants" are not so conspicuous about the elliptical and spherical galaxies as they are about the nearby spirals.

Consider, finally, the observation that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GIANT SPHEROIDAL GALAXY, M 87, is a member of the Virgo cluster of galaxies, about 45 million light-years away. M 87 contains about 30 times as many stars as our own galaxy.

ELLIPTICAL GALAXY, also in the Virgo cluster, is designated E5, which stands for "elliptical, Type 5" in Hubble's galactic classification scheme. It is flattened by rotation.

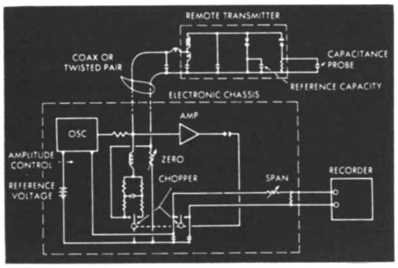
galaxies frequently occur not just in pairs but in groups, or clusters. The top diagram on page 76 shows the rather surprising result that the clusters of galaxies that are the densest contain almost exclusively elliptical galaxies and the armless disks known as SO galaxies. Evidently low rotational motion in individual galaxies is accompanied by relatively little random motion of the sort that would tend to disperse a cluster of galaxies. Conversely, it would appear that the higher rotational motions in spiral galaxies are matched by a higher degree of random, or translational, motion. This would explain the observation that the less dense the cluster, the higher its content of spiral galaxies. When the mean estimated density of the universe is reached, "clusters" are found to consist entirely of single galaxies, which are almost 100 per cent spirals. It was Hubble who originally observed that in general the spiral galaxies appear to be field objects rather than cluster objects.

The solution of the problem of the formation and evolution of galaxies may eventually help us to understand why some galaxies are strong emitters of radio waves [see "Radio Galaxies," by D. S. Heeschen; SCIENTIFIC AMERICAN, March, 1962]. For example, the Soviet astronomer I. S. Shklovsky has suggested that certain elliptical galaxies are strong radio sources because matter is still falling into them. This is not unlike the view presented here that matter may be falling into spiral galaxies. If matter is still falling into the galaxies, it is important to discover how it is coming in. For example, one would like to know if it can add angular momentum to a system or if it can add mass without angular momentum.

If the latter were possible, one can conceive that more and more mass could be added to the nucleus of a spiral galaxy until it eventually turned into an elliptical or spheroidal galaxy. Such a phenomenon would require a modification of the picture I have presented. But if it became necessary to consider such massive infall of material, one might argue that one should not even speak of galactic evolution, because the galaxies are in a sense still in the process of formation. In any event, it now seems likely that magnetic fields may strongly control the structure of galaxies, the flow of matter in the vicinity of galaxies and perhaps even the relative motions of the galaxies themselves. In a subject as young as the study of magnetic fields in galaxies, we can be sure only that there will be many surprises.

Research and Engineering at Sun Oil Company

An Improved Capacitance Probe System



Circuit diagram of Sun's new capacitance probe measurement system.

Capacitance probe instrumentation is one of the most promising measurement and control techniques available to the process industries today.

In the past, this technique has enjoyed only limited use. One deterrent was the difficulty of placing capacitance probes, together with their complex instrumentation, in and around hazardous processing areas. Another was the fact that these instruments required alterations in their electrical circuitry for different applications and different transmitting cable characteristics.

In order to use the full potential of capacitance probes in difficult-to-control processing applications . . . applications involving high temperatures, corrosive fluids, explosive atmospheres, and erosive solids . . . Sun's engineers have developed a capacitance probe system that is not plagued by these restrictions.

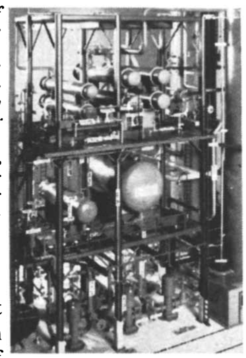
This new system consists of the following elements: a rugged, stationary probe having no moving parts that is permanently installed in the vessel or pipe line; a transmitter of passive elements in a totally-enclosed, explosion-proof housing that is mounted near the probe; and an electronic chassis that may be located in a control center up to 2000 feet away.

In operation, the probe acts as one plate of a condenser, the vessel or piping as the other, and the material under measurement as the dielectric. Changes in characteristics of the material alters the electrical capacity of this "condenser" and provides the basis for measurement.

For some years, Sun has used capacitance probes for such things as: liquid level measurement of hot sulfuric acid in pilot plant vessels; moisture determination down to parts per million in non-aqueous solutions and certain granular materials; continuous indication of aromatic content of hydrocarbon streams; interface measurement of different petroleum products passing through pipe lines; and measurement of catalyst levels in moving bed catalytic cracking units where catalyst pellets are extremely abrasive and temperatures reach 1000 F.

The U.S. Patent Office has issued a patent to Sun Oil Company on its new capacitance probe instrumentation system and the Company has concluded a license agreement with American Meter Company for the production and commercial sale of these units.

Designing High-Purity Propylene Plants



This scale model of the new high-purity propylene plant recently completed by Sun Oil shows precise locations of such equipment as super de-ethanizer, splitting towers, pumps, valves, piping, instruments and other essential components.

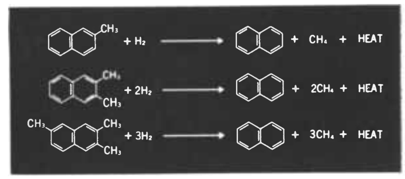
Propylene, a light hydrocarbon with a boiling point of minus 54 F, is the building block for polypropylene. It is also a raw material essential to the manufacturer of a host of other chemicals.

To makers of polypropylene, who require high purity propylene, Sun Oil consistently delivers 99.7 per cent propylene. This is not a simple task, since the utmost engineering sophistication is required to design a plant to meet these specifications.

Recently completed at Sun's Marcus Hook Refinery is a new 180 million lb/yr plant embodying features that enable it to deliver propylene of this purity. The design of this plant includes a super de-ethanizer, which precedes the "splitter" towers, to reduce the amount of hydrocarbons lighter than propylene in the feed from 2 per cent to less than 150 parts per million. Treating and drying facilities complete the purification process so that Sun is able to supply a product free of moisture, sulfur compounds, CO_2 and oxygen—a product that is ready for use in any process.

With this new plant, Sun Oil now has facilities to produce 300 million lb/yr of high-purity propylene and is one of the largest producers in the country.

Producing Naphthalene From Furnace Oil Aromatics



Fuel Oil Aromatics + *Hydrogen* → *Naphthalene* + *Gas* + *Heat*

Several years ago it became apparent that there would be a naphthalene shortage in the United States because the principal source of naphthalene at that time was coal tar, a by-product of the steel industry. The supply of naphthalene was not keeping up with demand. Petroleum then became the best potential source for the required additional supply.

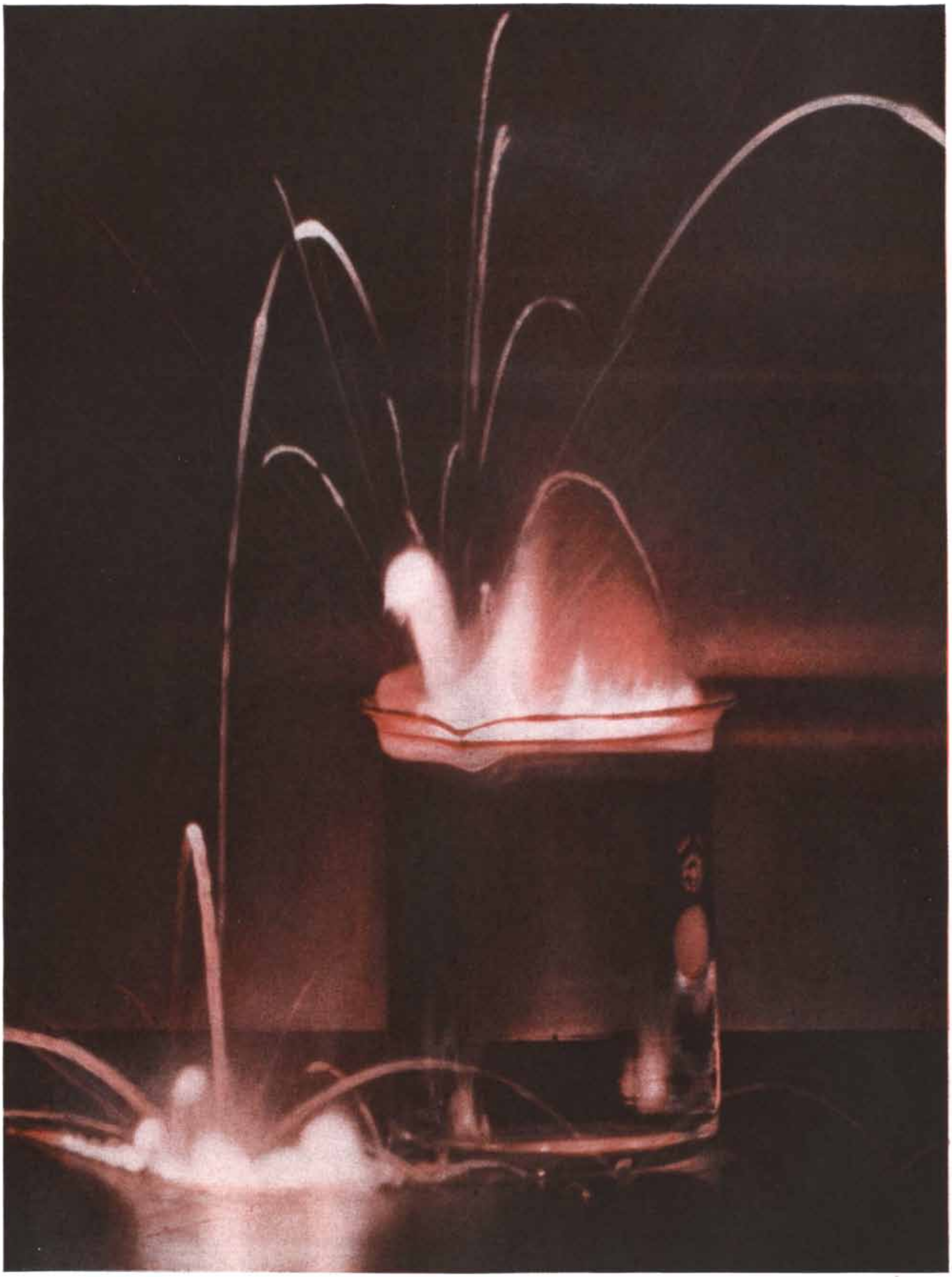
Fantastically large quantities of naphthalene formers are burned every day in furnace oil. For that reason Sun R&D engineers decided to capitalize on this source. It is essential that the aromatics so desirable for naphthalene production be separated from their source oil in better than 95 per cent purity, with a high recovery. Existing separation processes could be expected to produce aromatics at 90 per cent purity, with only fair recovery.

Faced with these rather unsatisfactory methods, Sun R&D developed a unique aromatic separation process that produces an aromatic concentrate of better than 99 per cent purity with over 85 per cent recovery of the critical naphthalene formers. And this process employs safe, readily-available chemicals to do the job. In addition to producing this highly desirable basic commodity, the process yields a higher quality furnace oil or a high cetane diesel fuel.

SUN OIL COMPANY
1608 Walnut Street Philadelphia 3, Pa.

SUNOCO

PROMOTING PROGRESS THROUGH RESEARCH



LITHIUM REACTS VIGOROUSLY with water, as do other alkali metals. This photograph was lighted by the reaction between a small amount of pure lithium metal and the water into which it was dropped. Both the electron structure of lithium and the highly concentrated positive electric charge that emanates from the nucleus of the lithium atom play important roles in such reactions.

LITHIUM

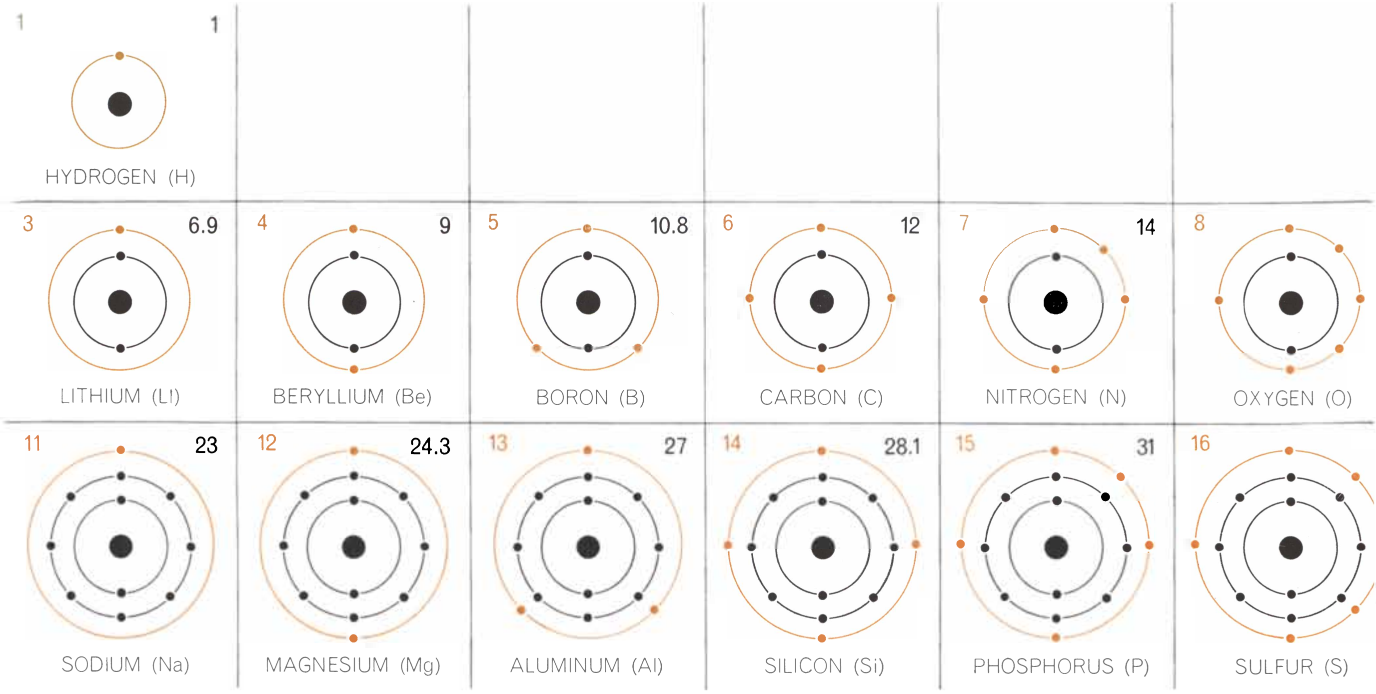
The unusual nuclear and electronic properties of this light element give it a variety of new uses. One of the most interesting stems from the fact that its compounds promote the synthesis of large molecules

by Henry Gilman and John J. Eisch

The name "lithium," from the Greek *lithos,* meaning stone, was conferred on an elusive constituent of the rocks early in the last century, when chemists were still primarily engaged in identifying the elements and working out their family relations. Until some 20 years ago lithium largely remained in the rocks; it found its way into technology almost entirely in the mineral form, as a ceramic glaze. Today, as the lightest of all metals, indeed as the lightest of all the elements that can exist in the solid and liquid state on earth, and above all as an atom endowed by its peculiar nuclear and electronic constitution with a surprising catalogue of properties, lithium is coming into use in the most advanced enterprises of technology. In nuclear technology it furnishes a fuel intermediate for the hydrogen bomb and for thermonuclear power reactors not yet on paper, serves as a radiation shield and holds great promise as a coolant and heat-exchange medium for fission reactors. As a metal it joins with magnesium in alloys that have the highest strength-weight ratio of all structural materials. In chemical technology lithium displays a special virtuosity, being able to form both covalent and ionic bonds. It lends its special properties to such diverse modern compounds as lubricants that remain effective at extreme temperatures and dehumidifiers that have a remarkable water-absorbing capacity. More significantly, it gives chemists a precision tool for the synthesis of large or complex molecules. Certain organic compounds of lithium, and indeed lithium metal, act almost, but not quite, in the manner of catalysts to "initiate" the reactions that produce, for example, regularly arranged molecules of the plastic polyethylene and synthetic molecules of the natural rubber polyisoprene.

It may seem odd that an element with such imposing capacities should have been ignored for so long. Part of the explanation is that lithium was so well concealed in nature that it was for a long time thought to be rare. Thanks to diligent prospecting, lithium can now be classified as a relatively abundant element. To complete the explanation, it must be admitted that the chemical individuality of lithium was almost equally well concealed in the thought processes of chemists. Early investigation showed that the chemical behavior of lithium was similar to that of the "alkali metals" such as sodium and potassium. By 1869 the recognition that other elements could also be grouped according to resemblances in their chemical behavior brought order out of the chaos of accumulated empirical data. Working independently, the Russian chemist Dmitri Mendeleev and the German chemist Lothar Meyer charted the known (and unknown) elements in the now familiar periodic table, arranging them by atomic weight and by the similarities in their chemical and physical properties. In the conventional layout the vertical columns of the table display the chemically similar families, each headed by its lightest member: the alkali metals by lithium, the alkaline earths by beryllium, the halogens by fluorine, and so on. One of the triumphs of 19th-century empiricism, the periodic table demonstrated the great power of the intuitive principle of chemical analogy, perhaps at once the most useful and the most precarious concept in chemistry. For a generation or two it had the unfortunate effect of encouraging chemists to minimize the differences among members of a particular family of elements. Given the scarcity of lithium, chemists found it tempting to draw conclusions about this element by analogy with the more accessible alkali metals.

Actually the chemical individuality of lithium was the key to its discovery. An analysis in 1801 of the silicate mineral spodumene by the French chemist Louis Nicolas Vauquelin failed to account for nearly 10 per cent of the mineral's chemical composition. In 1817 Johan August Arfwedson, a young worker in the laboratory of the Swedish chemist Jöns Jakob Berzelius, was perplexed when his analysis of the newly discovered mineral petalite could identify the elements composing only 96 per cent of its substance. Soon Arfwedson was able to show that the mysterious element was a metal that resembled sodium and potassium in some reactions but not in others. Eventually he succeeded in isolating salts of the element, and he and Berzelius named the element lithium. Within a few years the presence of lithium had been detected in about 150 different minerals. The isolation of the metal itself in quantities sufficient for study was accomplished in 1855 by Robert Bunsen of Germany and Augustus Matthiesen of England. Bunsen's sensitive spectroscopic techniques, employing his celebrated burner, not only led to the discovery of the new alkali metals rubidium and cesium but also disclosed the presence of lithium (by the magenta color it gives to the flame) in the tissues of tobacco, sugar cane and seaweed. This belied the exclusive occurrence of the element in the mineral kingdom, as implied by the name given to it by Berzelius and Arfwedson. The detection of lithium salts in the waters of spas in England and Germany helped to popularize the discovery of the new element, and finally the identification of lithium in the spectrum of the sun



FIRST PART OF PERIODIC TABLE of the elements has lithium, third lightest of all the elements, in the third box. Rings and dots on them represent electron shells and electrons. Valence electrons, which are responsible for chemical reactions, and their shells are in color. Atomic numbers are in color; black numbers represent atomic weights. The third member of the alkali-metal family, after

showed that the element is not restricted to the crust of the earth.

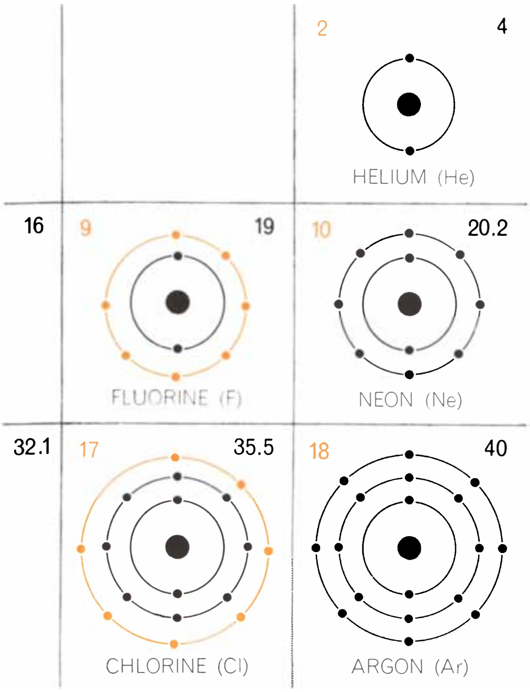
Present estimates of the average lithium content of the earth's crust indicate that the element is fairly common, ranging from .002 to .0075 per cent by weight. (The abundance of its atoms is even greater, because its atomic weight is so low.) In comparison the more familiar metal lead constitutes only .0016 per cent of the crust, and zinc only .0001 per cent. Lithium-containing ores, however, are widely scattered; the most important are associated with pegmatite dikes, masses of granitic material forced in the molten state into fissures in older rocks. Pegmatites often contain spodumene, the object of Vauquelin's analytical frustration and the principal source of lithium in North America. In some pegmatites gray-white crystals of spodumene 20 to 30 feet long are common; such deposits have been found at Kings Mountain in North Carolina and in the Black Hills of South Dakota. The silicate lepidolite and certain brine deposits, notably at Searles Lake, Calif., are also valued for their lithium content. The Republic of the Congo, Leopoldville, so rich in other minerals of igneous origin, probably possesses the largest lithium reserves in the world. Some transparent lithium minerals contain tinges of impurities that cause them to rank as gems: hiddenite (green), kunzite (purple) and triphane (yellow).

Lithium occupies the third box in the periodic table because the three protons in its nucleus give it three units of electric charge and an atomic number of three. Its atomic weight (6.94) makes it the third lightest element after hydrogen and helium. The atomic weight is not a whole number because on earth the element is normally a mixture of two isotopes: lithium 6, the nucleus of which consists of three protons and three neutrons, and lithium 7, with three protons and four neutrons. The two isotopes occur in the ratio of 7.39 (lithium 6) to 92.61 (lithium 7).

It is lithium 6 that plays the key role in thermonuclear technology. It enters into this realm, however, by a somewhat roundabout route. The most feasible and efficient thermonuclear reaction involves the fusion of a nucleus of tritium (hydrogen 3, containing one proton and two neutrons) with a nucleus of deuterium (hydrogen 2, containing one proton and one neutron). In a hydrogen bomb the reaction is ignited by the enormous temperatures generated in the explosion of a charge of fissionable material. The fusion yields one nucleus of helium 4 (two protons and two neutrons) plus one free neutron and 17.6 million electron volts of energy [see "The Hydrogen Bomb: II," by Hans A. Bethe; Scientific American, April, 1950. "The Hydrogen Bomb: III," by Robert F. Bacher; Scientific American, May, 1950]. Deuterium exists in nature and can be isolated from water; tritium is an unstable and hence a rare isotope and must be manufactured in order to obtain it in quantity. Both isotopes of hydrogen are supplied to the thermonuclear reaction of a hydrogen bomb in the form of the solid compound lithium 6 deuteride. Upon absorption of a neutron, provided in the first instance by the fission reaction, lithium 6 fissions, yielding a nucleus of ordinary helium 4 and a nucleus of tritium. The latter fuses with the deuterium compounded in the lithium 6 deuteride [*see illustration on page 100*].

The propensity of lithium 6 to absorb neutrons makes it an effective shield against the neutrons given off by a nuclear reactor. Nuclear-powered aircraft, if any are ever built, would probably have to employ a lithium 6 shield rather than one made of more ponderous lead or concrete. In its metallic form the isotope is already used to shield patients exposed to the neutron beam from a nuclear reactor adapted for medical purposes. A layer of paraffin is interposed between the lithium shield and the beam in order to slow down the speed of the neutrons for absorption by the lithium.

Another quality of lithium that interests the designer of nuclear reactors is its great heat capacity. The solid metal becomes liquid at 180 degrees centigrade, but the liquid does not boil over into the gaseous state until it reaches 1,326 degrees C. In the liquid form lithium commends itself as a heat-transfer or cooling



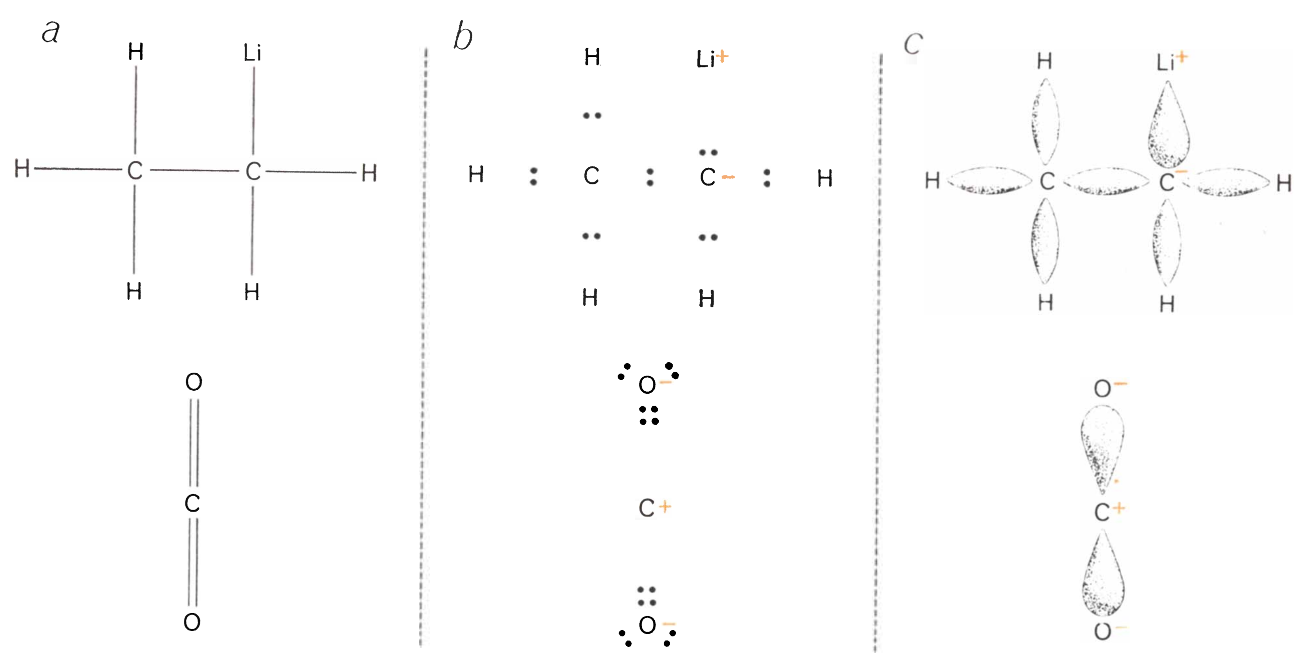
lithium and sodium, is potassium. If it were shown, it would be below sodium because it has one more complete electron shell.

agent at the high temperatures available in a nuclear reactor. The major obstacle to this application recalls the problem that plagued the alchemists seeking the universal solvent: a suitable container. Molten lithium, like other molten alkali metals, reacts with most materials.

The chemical reactivity of lithium derives from the arrangement of its electrons and the high density of the positive charge on its nucleus. Of the three negatively charged electrons that balance the positive charges of the three protons in the nucleus of the atom, two occupy and complete the innermost shell around the nucleus. In the second shell, which is completed when it contains eight electrons, lithium has only one electron [*see top illustration on these two pages*]. As readers of this magazine are well aware, chemical reactions occur and elements join into compounds because atoms "seek" to have a full outer electron shell. The "noble" gases such as helium, neon and argon, having full outer shells, are so inert that until recently no one succeeded in making them react with anything. Each of the alkali metals, on the other hand, bears a single electron in its outer shell (the third shell in the case of sodium, the fourth shell in the case of potassium and so on). They seek to give away or to share this electron with another atom. Their complements are the halogens, which have seven of eight possible electrons in their outer shell and just as avidly seek another electron to fill the gap. When one atom gives up an electron to another, or accepts one, the two are said to be joined by an ionic bond. The atom that gains the electron thereby acquires a negative charge, and the atom that donates the electron becomes positively charged—hence the mutual attraction between the two atoms. When lithium gives up its electron in forming such a bond, it acquires a positive charge, but one that is "dense," or concentrated because it is shielded from its surroundings only by its single electron shell. The same positive charge correspondingly acquired by a sodium ion or by a potassium ion is shielded by two or by three electron shells. All of this explains why lithium is so reactive, why free lithium does not occur in nature and why in many organic-chemical reactions lithium does not act like sodium and potassium.

To pry lithium from its natural compounds the chemical engineer brings the mineral into solution with a molten salt, decomposes the resulting lithium salt (in which lithium has displaced one of its alkali-metal cousins) by running an electric current through the solution and collects the lithium metal at the negative electrode. The metal must be kept immersed in kerosene, oil or some other material with which it does not react. Like metallic sodium and potassium, lithium reacts violently with water.

The salt lithium chloride provides a simple table-top demonstration of the higher positive charge-density of the lithium ion: the crystals will immediately absorb water vapor from the air and soon accumulate a puddle large enough to dissolve them. Sodium chloride does not



CHEMICAL BONDS are represented in several ways. A straight line (*a*) indicates a covalent bond, or pair of electrons shared by two atoms. Dots for electrons (*b*) can show that in ethyl-lithium (*top*) the electrons in the carbon-lithium bond are nearer carbon, giving carbon a slight negative charge and lithium a slight positive charge. (A "slight charge," in this context, means a charge smaller than that carried by one electron.) Lithium does not give up its outer electron to carbon, as sodium does, because carbon does not attract the electron with enough force to overcome the opposing attraction from the positive charge-density from the lithium nucleus. In carbon dioxide (*bottom*) the electrons are nearer oxygen because the oxygen nucleus has a higher charge than the carbon does. Electron "clouds" (*c*) are more like the actual situation; a cloud is thickest where the electrons spend the most time.

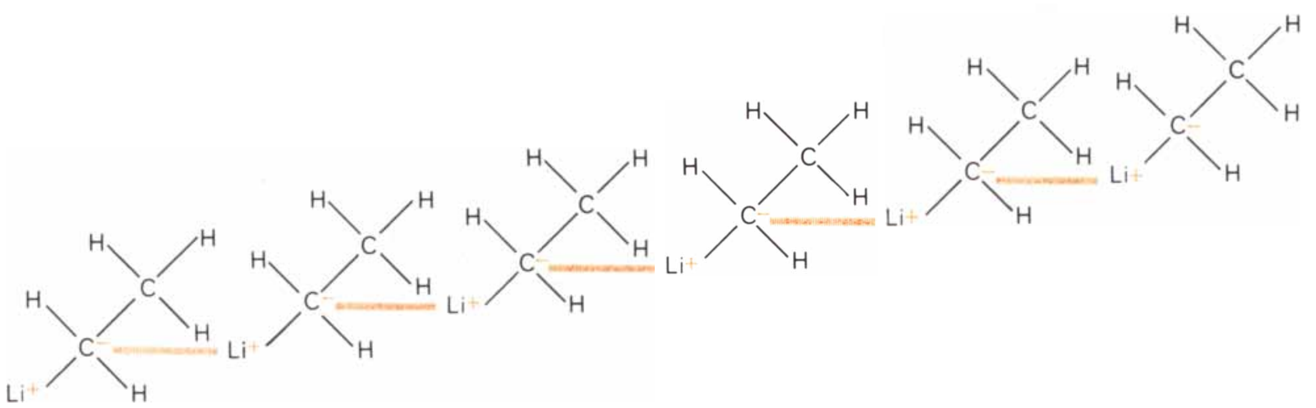
attract water at all; table salt fails to pour in damp weather due to the hygroscopic action of impurities that it contains. Because it is so hygroscopic lithium chloride is often employed as a dehumidifier. The avidity of lithium metal for oxygen and nitrogen is similarly turned to advantage in scavenging trapped air from molten metal; such treatment of molten copper prior to pouring improves the electrical conductivity of the metal. A small amount of lithium metal in the welding flux enhances the welding of alloy steels.

When it is alloyed, lithium metal loses most of its reactivity. The new lithium-magnesium alloys, with their high strength and low weight per unit volume, are proving increasingly attractive in aircraft and space-vehicle design. Lithium is entering space technology in another function: compounded in lithium aluminum hydride ($LiAlH_4$), it is employed as a reagent in the synthesis of boron hydride, a promising high-energy fuel. The lithium-containing lubricants, based on the compound lithium stearate, also hold interest for the space technologist. They keep their integrity over a range from 52 degrees below zero centigrade to 138 degrees above; other lubricants congeal or break down toward extremes of this range.

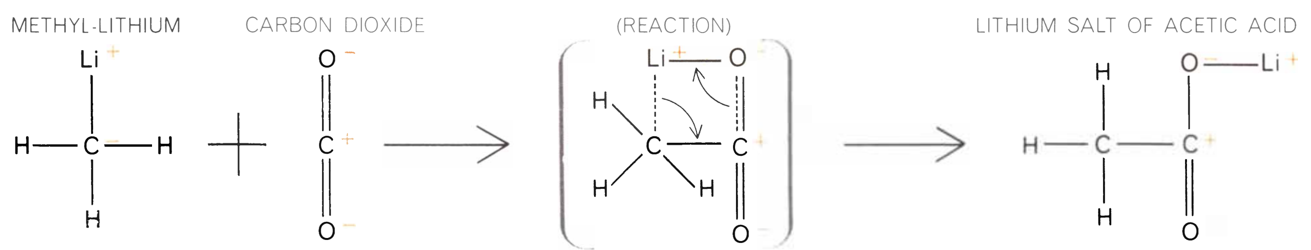
When lithium enters the realm of organic chemistry, its behavior is more like that of an alkaline earth than of an alkali metal. Sodium and the other alkali metals form ionic bonds with carbon. The alkaline earths, having two electrons in their outer shell, are less eager donators of electrons and form covalent bonds with carbon. Each partner in such a bond contributes an electron, and the electron pair is shared between them. Lithium also forms a covalent bond with carbon, but it is a covalent bond that has a peculiar configuration, as will be seen.

Organometallic compounds have held great interest for chemists ever since 1900, when the French chemist Victor Grignard devised a practical technique for preparing organomagnesiums. Their importance as reagents for promoting and controlling synthetic reactions was recognized as early as 1912 by the award of a Nobel prize to Grignard. The organolithiums have proved to be even more reactive. Like the metal, they must be protected from moisture, oxygen and even carbon dioxide; some spontaneously catch fire in air. Unlike the metal, however, they do not react with nitrogen and so can be put to work in an atmosphere of this gas.

The departure of lithium from the behavior of other alkali metals in organic compounds is well illustrated by the contrast between ethyl-sodium (C_2H_5Na) and ethyl-lithium (C_2H_5Li). Ethyl-sodium resembles sodium chloride in that it has a high melting point, high electrical conductivity and low solubility in certain organic solvents. The compound can therefore be classified as a salt, in which the sodium is bound by an ionic bond and for which the formula is more correctly written as $Na^+ (C_2H_5)^-$. Ethyl-lithium, on the other hand, has a low melting point and low electrical conductivity and dissolves readily in various organic solvents. This and other pieces of evidence suggest that the compound consists of molecules rather than ions, with lithium joined to carbon by a covalent rather than an ionic bond. The outer lithium electron fills one of the four empty spaces in the outer shell of the carbon, and one of the four outer carbon electrons fills one of the seven empty



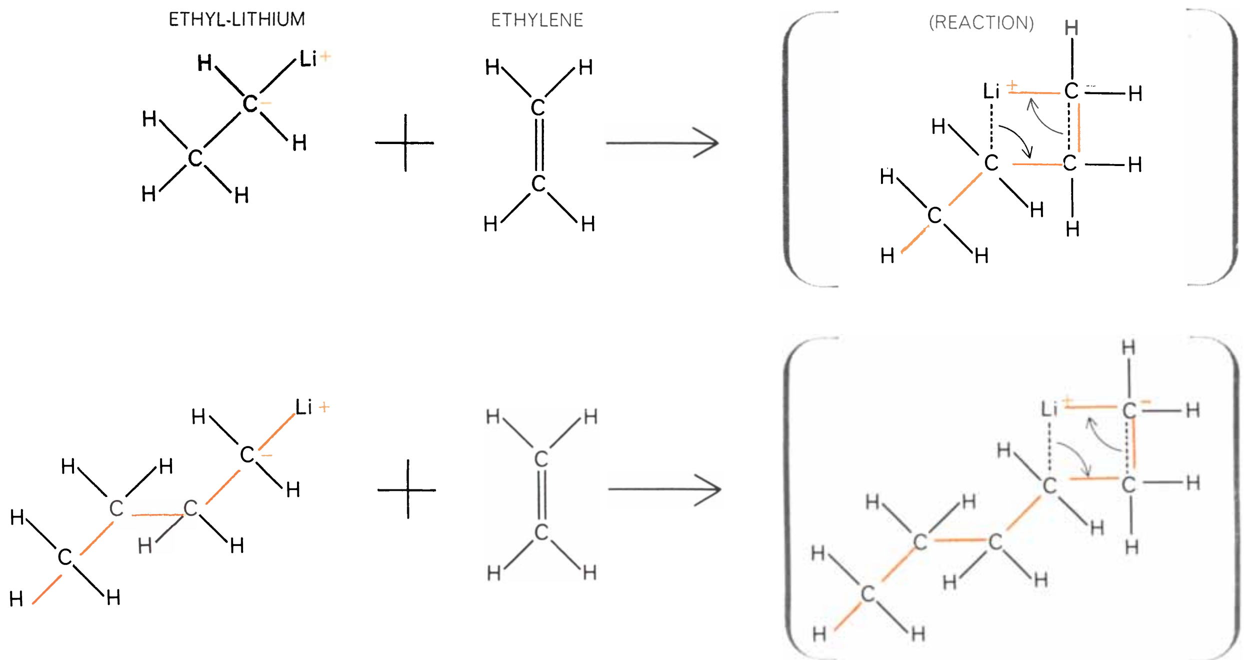
ATTRACTIVE FORCES (*colored hatching*) **between molecules of ethyl-lithium arise because of incomplete electron shell and slight electric charge on lithium, and the small charge on one of the carbon atoms of each molecule. The bond represents the action of lithium in sharing part of the electron cloud of an adjacent molecule. On the average six such molecules group together in solution.**



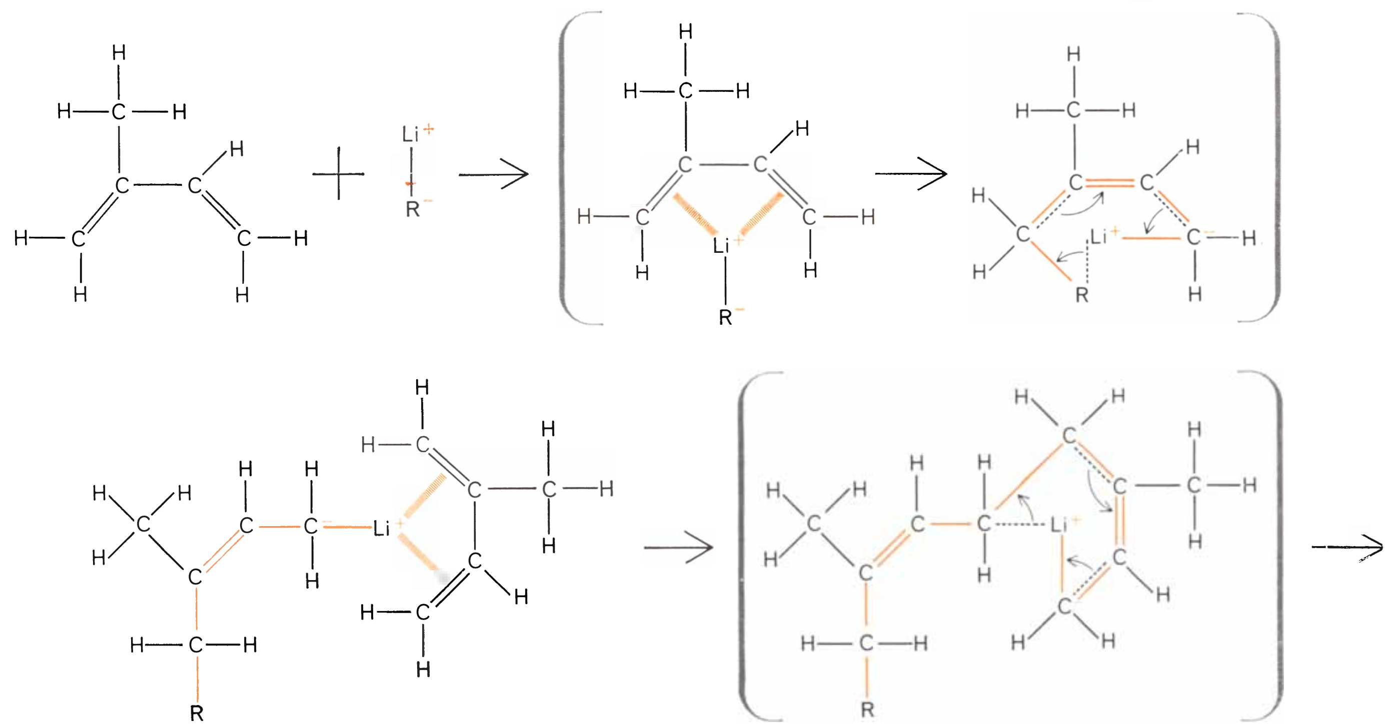
TYPICAL REACTION of organolithium compound and an "unsaturated" compound (which has one or more double bonds) takes place between methyl-lithium and carbon dioxide. Lithium, with its slight positive charge, attracts the mobile electrons of one of the double bonds. A great many organic compounds have double bonds, which will react just as readily with organometallic substances.

spaces in the outer shell of the lithium. Because the two electrons tend to associate more closely with the carbon atom, this covalent bond shows ionic properties: the carbon atom is endowed with a slight negative charge and the lithium is left with a slight positive charge.

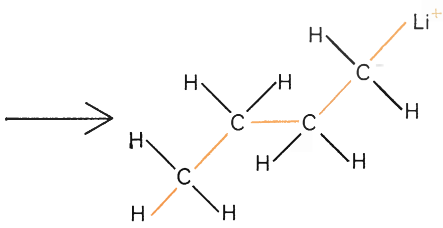
On closer analysis ethyl-lithium presents an even more interesting structure. Given the masses of its eight constituent atoms, it should have a molecular weight of 36. Yet measurement of its molecular weight when it is dissolved in benzene gives as much as six times the expected value. One may deduce that on the average six C_2H_5Li units are bound in a cluster or chain. Since the single outer electron of lithium is in each case engaged in the carbon-lithium bond, the question is: What holds the six units together? This and similar situations in chemistry,

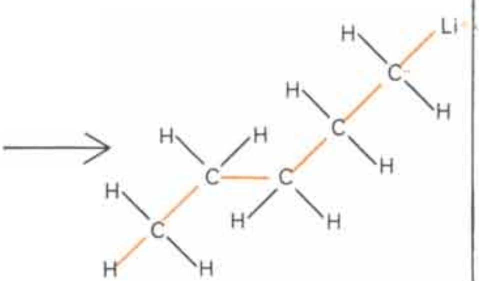


POLYMERIZATION OCCURS in ethyl-lithium–ethylene reaction. Linking of first units (*top*) leaves lithium out on one end of new, longer molecule. There it can react easily with double bond of next ethylene molecule that approaches (*bottom*), again ending up at the far end of the chain. In theory process should produce tremendously long molecule of polyethylene, but side reactions interfere.

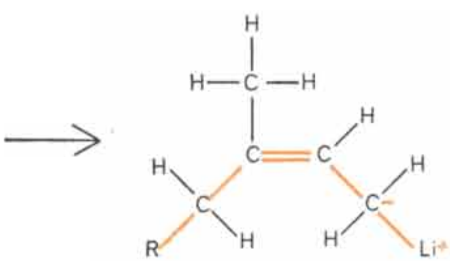


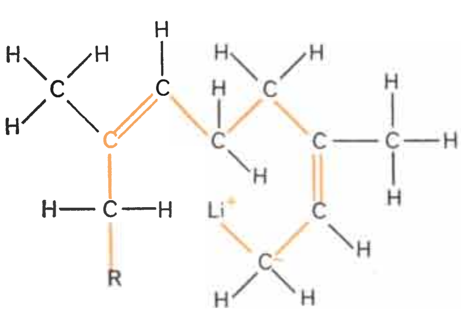
SYNTHETIC "NATURAL" RUBBER is created by organolithium reaction that first places isoprene monomers in proper position and then adds them to growing long-chain molecule. Colored hatching represents attraction between lithium and mobile electrons. "R" is the radical, or organic portion, of the organolithium reagent. Colored bonds make up the main chain, or backbone, of the molecule. It actually has a three-dimensional structure; true angles between various bonds are not given in this two-dimensional where there are not enough electrons to go around to form the ordinary type of covalent bond, require a less rigid and restrictive model of the function of the electrons in establishing chemical bonds. The electrons may be thought of as existing in clouds that have the greatest





By using the titanium tetrachloride as a cocatalyst with an organolithium, chemists have overcome problem of side reactions.





representation. The coiled structure of the real molecule is indicated at bottom right. Lithium lies at one end of the coil, ready for next reaction; the radical, at the other end.

negative charge-density where the electrons, which are always moving, spend most of the time.

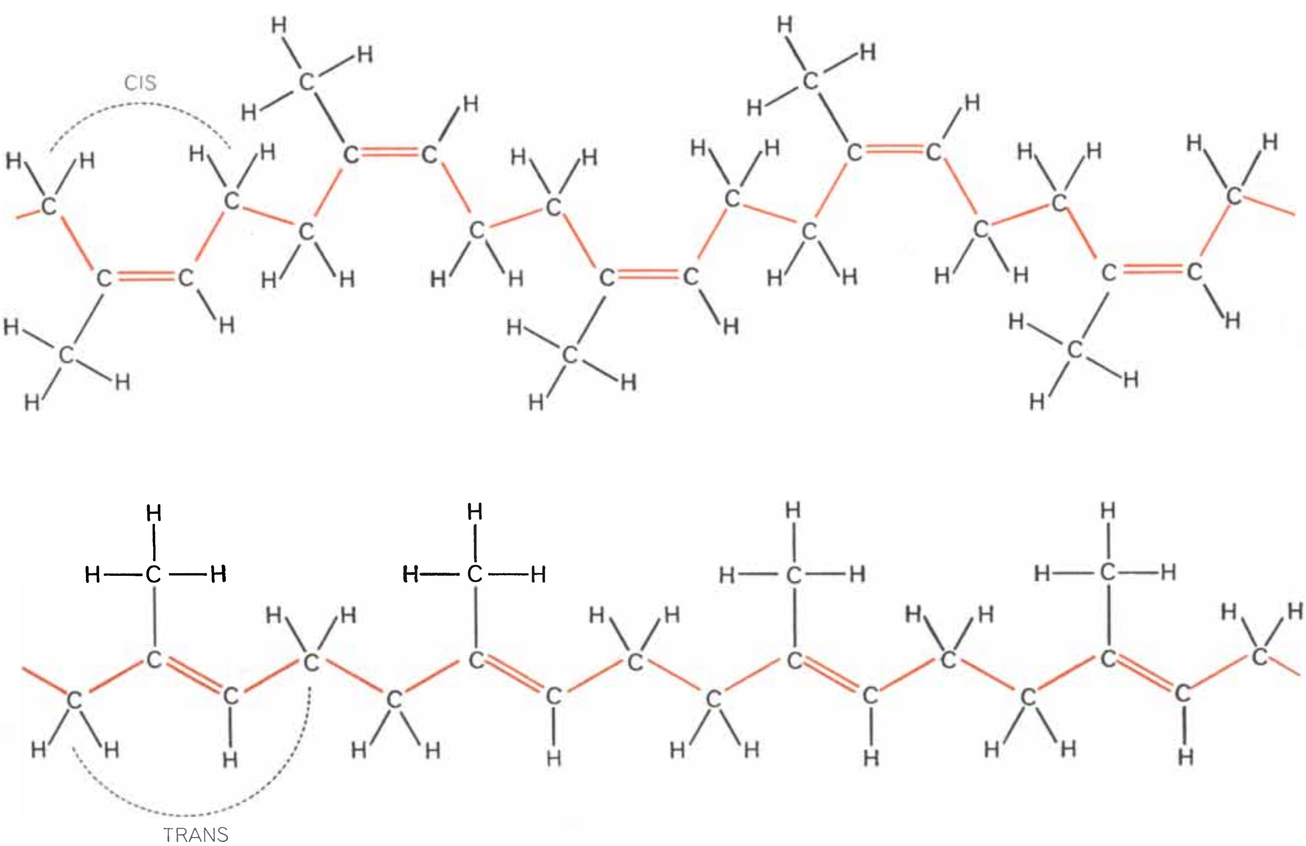
In ethyl-lithium, the slight positive charge on the lithium atom and the six empty spaces in its outer shell cause it to pre-empt a share of the electron cloud of the carbon atom of an adjacent molecule as well as of its "own" carbon. The electron cloud can thus be pictured not just between two nuclei, as is suggested by classical valence theory, but as pressed into service to hold three atoms together (C–Li–C). The discovery that some atoms that are already combined in molecules, and that have unfilled electron shells, can attract the electron cloud from other molecules has enhanced the chemist's understanding not only of compounds containing lithium but also of the behavior of organolithium compounds in interaction with other substances.

Organic chemistry abounds in molecules that have electrons available for interaction with organolithium compounds. Many organic compounds are "unsaturated": they have double or triple bonds between two atoms, which involve not one but two and three shared pairs of electrons. The electrons that make up the second and third bonds are mobile compared with those in the single bond and are ready to be attracted by lithium, preparing the way for reactions with it. Carbon dioxide (CO_2), which has two double bonds between the oxygen atoms and the carbon atom, reacts readily with organolithium and other organometallic substances. The higher nuclear charge of oxygen (eight, from its eight protons) compared with that of carbon (six) causes the oxygen to draw the electrons closer to itself. Thus the oxygens each gain a slight negative charge and the carbon a slight positive charge.

In methyl-lithium (CH_3Li), as in ethyl-lithium, lithium carries the slight positive charge and the carbon the slight negative charge. This sets the stage for interaction of the lithium and one of the oxygens in carbon dioxide. The electron pair in one of the double carbon-oxygen bonds in effect swings over to form a covalent bond with the lithium. At the same time, the carbon-lithium bond moves around to form a covalent bond with the carbon of CO_2 [*see lower illustration on page 92*]. The product is the lithium salt of acetic acid.

It was Karl Ziegler, director of the Max Planck Institute for Coal Research in Germany, who first recognized a few years ago that organolithium compounds react with common unsaturated hydrocarbons. His discovery has already had far-reaching consequences. In a very important application ethyl-lithium is made to react with ethylene (C_2H_4), a gaseous petroleum product with a double bond between its carbons. The reaction leaves the lithium atom, with its slight positive charge, out on the end of the new, longer molecule, ready to react with the next ethylene molecule that approaches. The lithium attaches this ethylene unit to the molecule and again occupies the end position, where it can repeat the operation [*see top illustration on preceding two pages*].

Actually in this particular reaction the build-up of the carbon chain is rather slow and side reactions soon interfere with the formation of a long chain. Ziegler and his colleagues were able to circumvent these difficulties by combining organolithium (or organoaluminum)



CIS AND TRANS CONFIGURATIONS are different linkages of the monomers, or units, in polyisoprene. The *cis* form (*top*) is natural rubber. *Cis* means that the two CH_2 groups of each unit are on the same side of the double bond of that unit. The CH_3 side group is on the tail part of a unit and the single hydrogen bonded to a carbon is on the head. The *trans* configuration (*bottom*) is gutta-percha, a gum. In the *trans* structure the two CH_2 groups are on opposite sides of the double bond of unit to which they belong.

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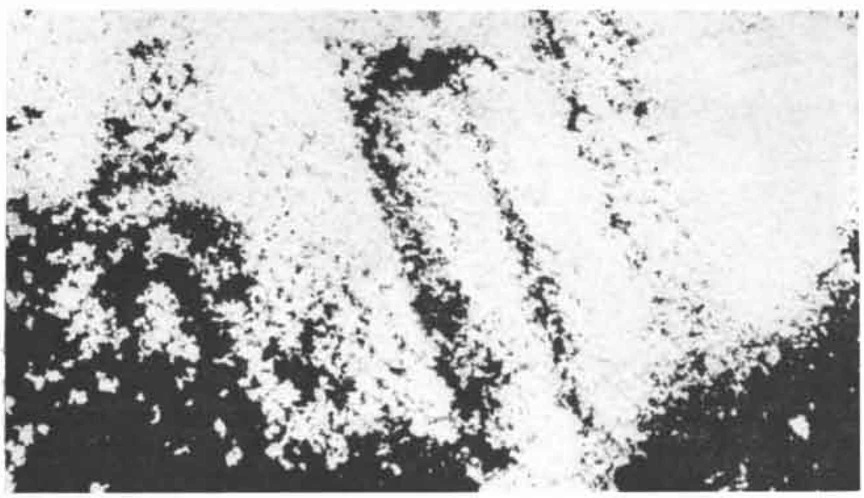
compounds with the fuming liquid titanium tetrachloride. The combination yields a brown solid that, in a solution containing ethylene molecules, promotes the polymerization of tens of thousands of ethylene units into individual long-chain molecules of polyethylene. This plastic is now the most versatile and inexpensive staple of the plastics industry.

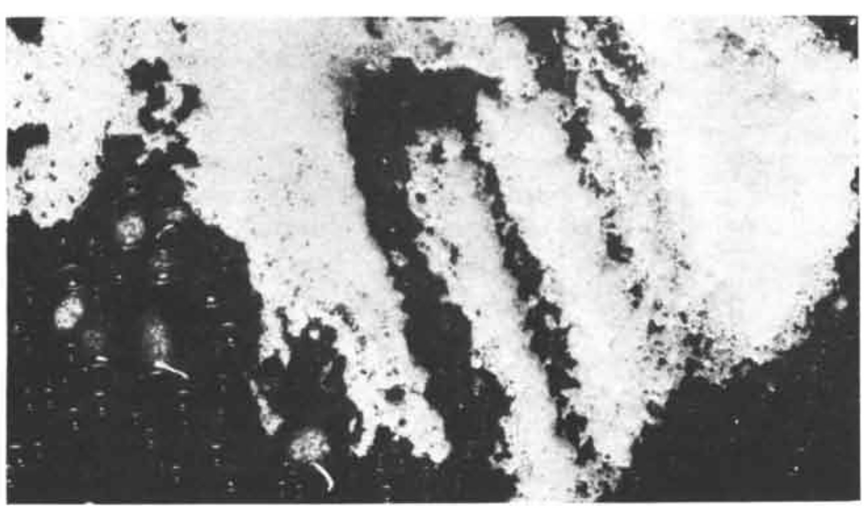
Giulio Natta of the Institute of Industrial Chemistry in Milan extended the utility of these organometallic reagents by altering them so that they construct polymers with a high degree of regularity in three dimensions [see "Precisely Constructed Polymers," by Giulio Natta; SCIENTIFIC AMERICAN, August, 1961]. Such organization of the molecular chains produces plastics with greater density, a higher melting point and more tensile strength.

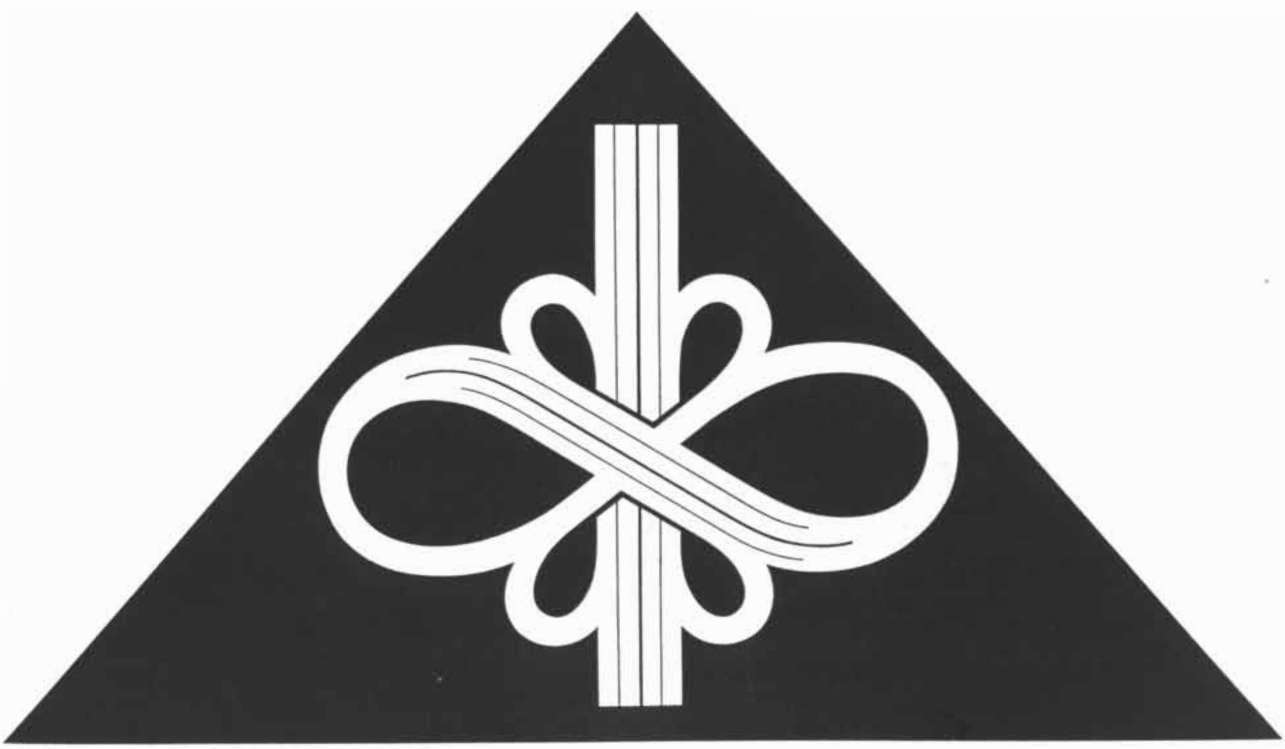
There are several theories as to how the organolithium reagents work. Strictly speaking the reagents cannot be classified as catalysts because they are consumed in the reaction, the organic portion of the molecule being incorporated into the polymer. Thus in the reaction between ethyl-lithium and ethylene the ethyl portion becomes a part of the polyethylene chain. For this reason the term "initiator" has been coined. In spite of the incompleteness of present theory, the organolithiums have gone on to new successes in high-polymer chemistry. The latest is the synthesis of the molecule of "natural" rubber.

Natural rubber is obtained as an exudate from the tropical rubber tree *Hevea brasiliensis.* It has long been recognized as a polymer of isoprene; that is, isoprene is the simple repeating unit, or monomer, of natural rubber, just as ethylene is the repeating unit of polyethylene. Nature is highly selective in linking these units together. Out of eight possible modes of linkage, as seen



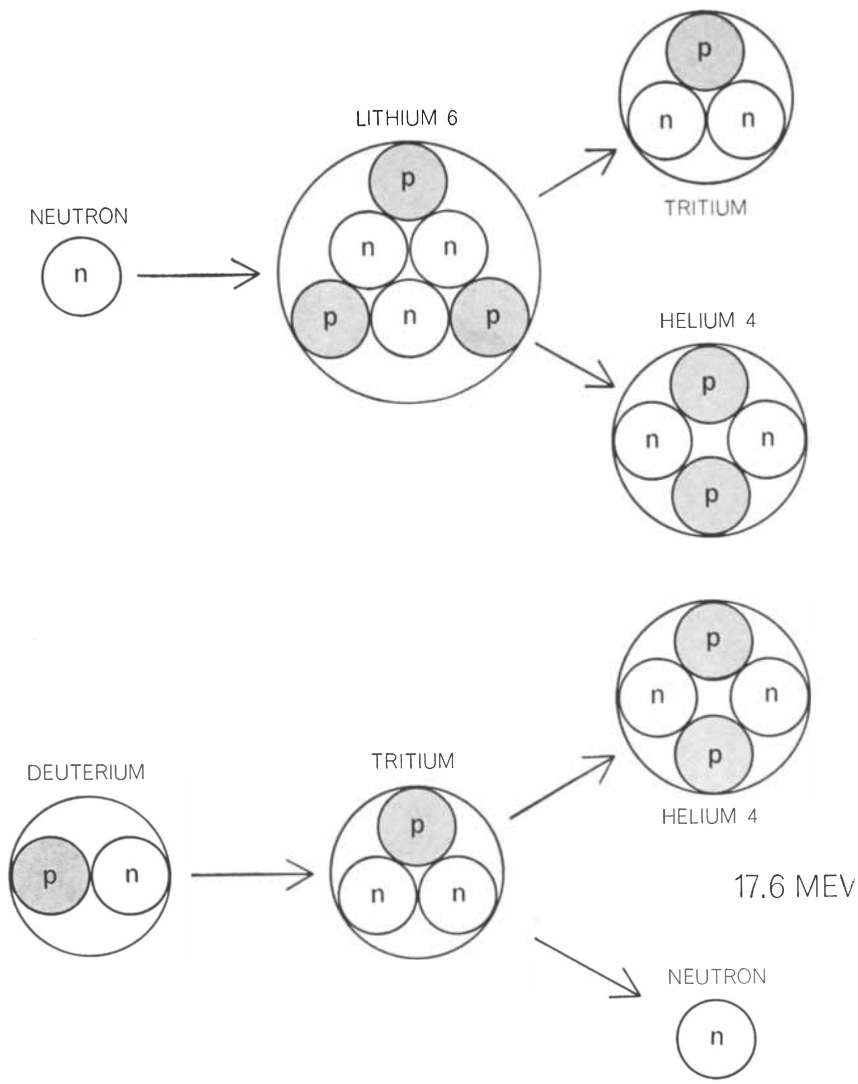
CRYSTALS OF LITHIUM CHLORIDE (*above*) **resemble the cubical crystals of the analogous sodium compound, table salt. Unlike table salt, however, they absorb so much water from moist air that they can create a puddle** (*below*)**, in which they dissolve. This is because high charge-density of positive lithium ion attracts oxygen atom of water molecule.**





in three dimensions, the arrangement termed *cis*-1,4, in which the monomers are linked up head to tail, characterizes natural rubber [*see illustration on page 96*]. Chemists learned some time ago to achieve a polymerization of sorts with isoprene; they could convert the monomer, a volatile liquid, into a solid polyisoprene. In fact, treatment of butadiene, a relative of isoprene, with sodium yielded one of the first commercial synthetic rubbers, known as Buna rubber. This product is neither so resilient nor so resistant to wear as natural rubber. Recently, with the help of organolithium compounds and with lithium metal itself, investigators at a number of research centers have succeeded in imitating closely the *cis* head-to-tail structure of natural rubber.

One good explanation of these reactions holds that the lithium in the organolithium initiator mobilizes two unsaturated bonds in the isoprene monomer; the organic portion of the initiator becomes bound to a carbon on the "tail" of the isoprene and the lithium to a carbon on the "head" of the monomer. The lithium is now in position to perform the same operation on the next isoprene, attaching the tail of this molecule to the head of the first and attaching itself to the head of the now incipient chain [*see lower illustration on pages 94 and 95*]. The chain therefore grows in the desired *cis*-1,4 configuration. Lithium performs this feat better than sodium does because of its higher charge-density and because of its smaller size. It can fit more easily between the two double-bonded units of the original isoprene molecule, so that the concentrated positive charge attracts



NUCLEAR REACTION when lithium 6 absorbs a neutron produces tritium and helium 4 (*top*). In hydrogen bomb enormous heat from explosion of a charge of fissionable material then causes the tritium to fuse with deuterium (hydrogen 2), which had been chemically combined with the lithium. The fusion yields helium 4, a neutron and 17.6 million electron volts of energy (*bottom*). The lithium 6 reaction is the easiest way to make tritium.

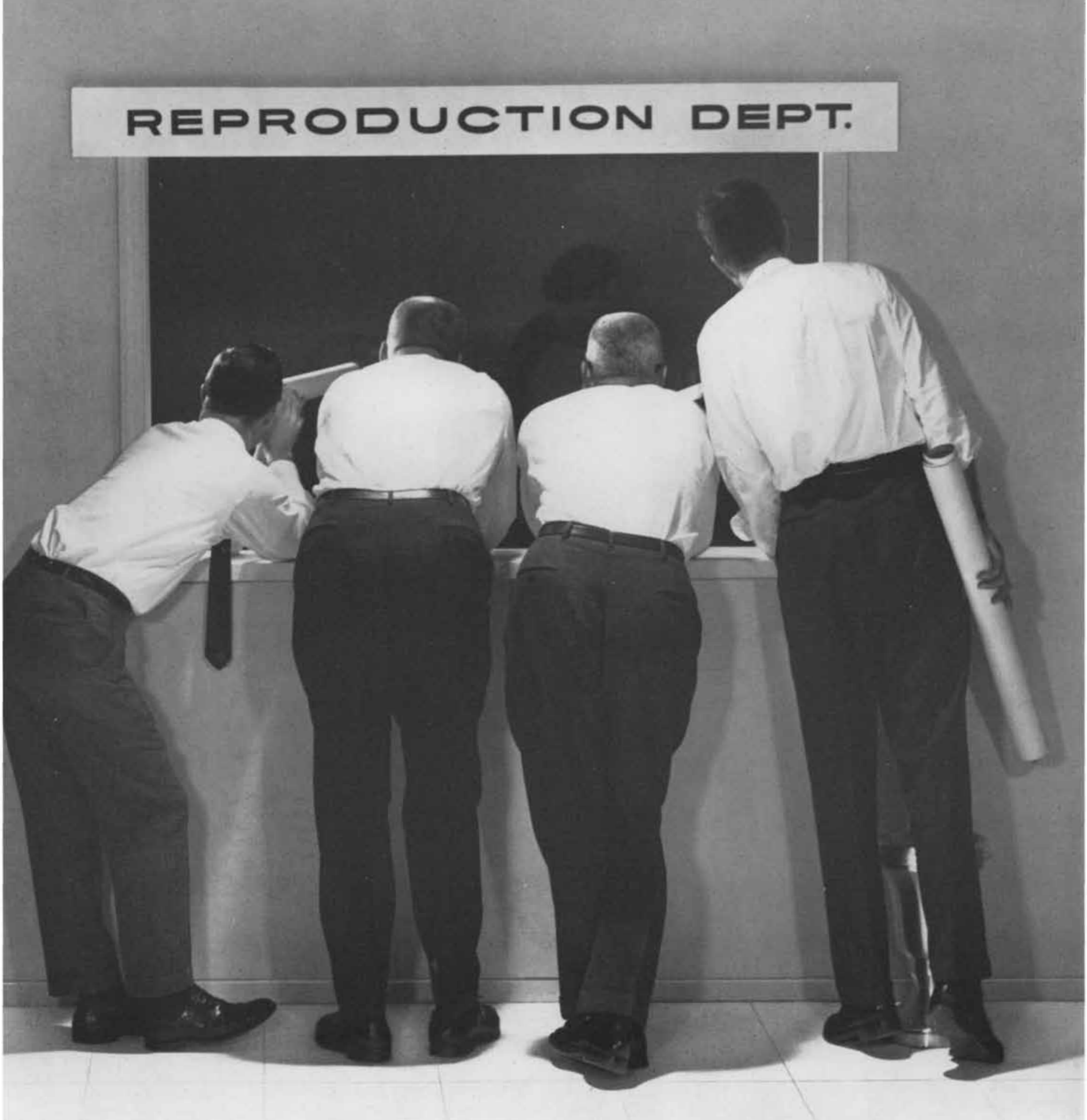
the mobile double-bond electrons, holding the molecule in the proper position for producing the *cis* structure as each unit is added to the chain.

When the isoprene and the lithium compound are dissolved in a solvent such as ether $[(C_2H_5)_2O]$, which has an unshared electron pair on the oxygen atom available for interaction with the lithium atom, the driving force for the *cis* polymerization is weakened. The unshared electron pairs in ether react with lithium and diminish its ability to attract electrons. As a consequence the lithium cannot position the isoprene units for *cis* polymerization. The product then has a predominantly *trans* arrangement [*see illustration on page 96*] and resembles not rubber but the resinous rubber-like material called gutta-percha. This gum, a natural product of Malaysian trees, has few of the desirable properties of natural rubber.

When lithium metal is used to polymerize isoprene, a somewhat different pathway of reactions produces the *cis*-head-to-tail structure. The other alkali metals, however, give rise predominantly to gutta-percha when used as catalysts for the polymerization of isoprene.

Although polymer chemists now have a fairly good general idea of how lithium acts to produce a polymer with a regular arrangement, the task of solving the puzzle of organic catalysis has only begun. With deeper understanding it should be possible to construct catalytic agents that will produce every possible configuration of a particular polymer. Eventually increasing facility in the construction of synthetic molecules may help to clarify how biological organisms create natural polymers of specific, regular structure, such as carbohydrates and proteins. Indeed, the idea of selective chemical reagents, designed to attack one out of several possible sites on a molecule—as lithium does with isoprene—is beginning to permeate all of organic chemistry.

The other lesson that can be learned from lithium and its reactions is that elements have great chemical individuality even though they belong to families. Theoretical or empirical generalizations cannot long suppress these differences. Because so many factors combine in unknown proportions to determine the chemical behavior of an element, more detailed conclusions drawn from the periodic table will continue to require experimental substantiation. It is just this unpredictable aspect of nature that makes chemical research so rewarding.



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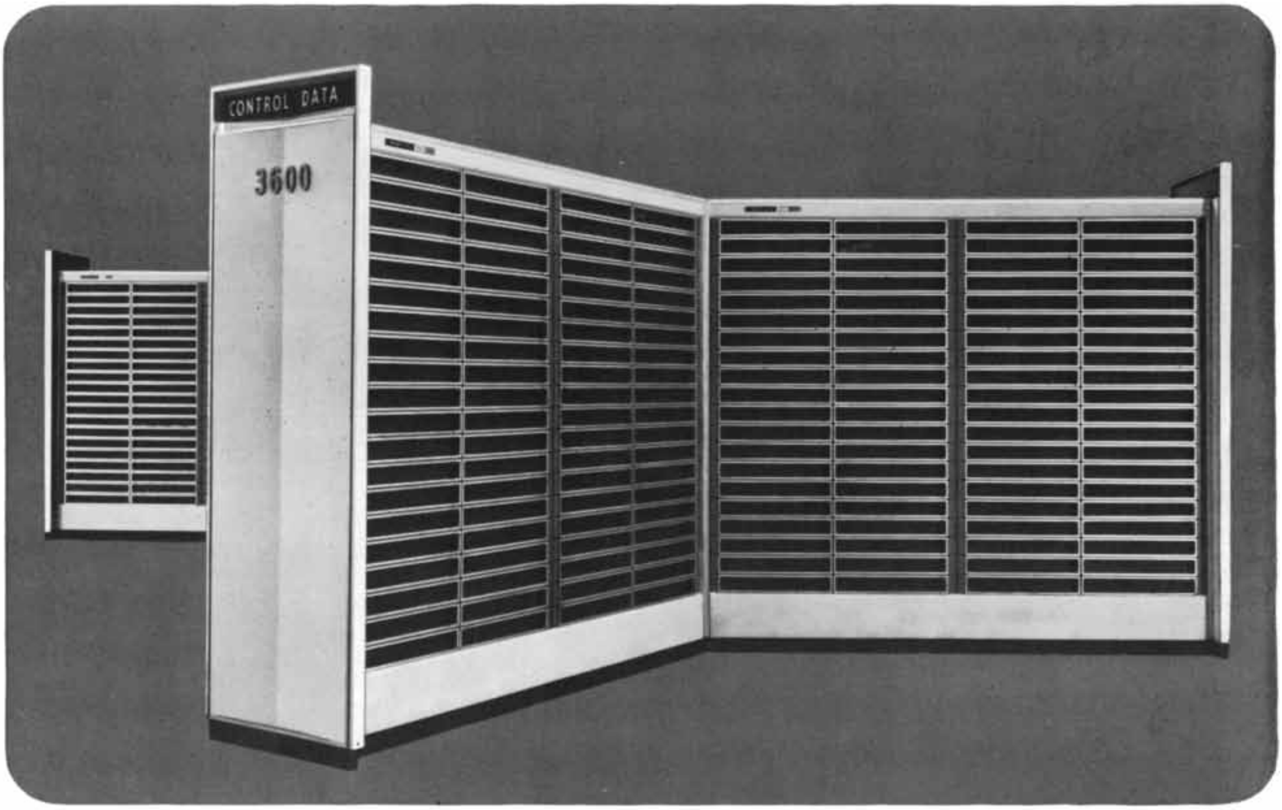

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The Perception of Neutral Colors

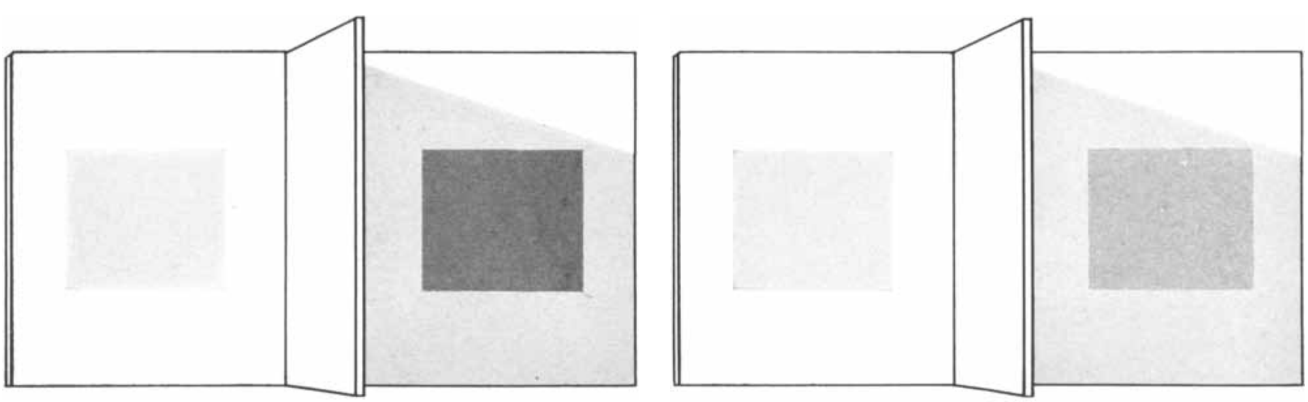
What makes a surface gray and why does it stay gray even when the illumination changes? Apparently the ratio between adjacent light intensities governs the perceived lightness of an achromatic color

by Hans Wallach

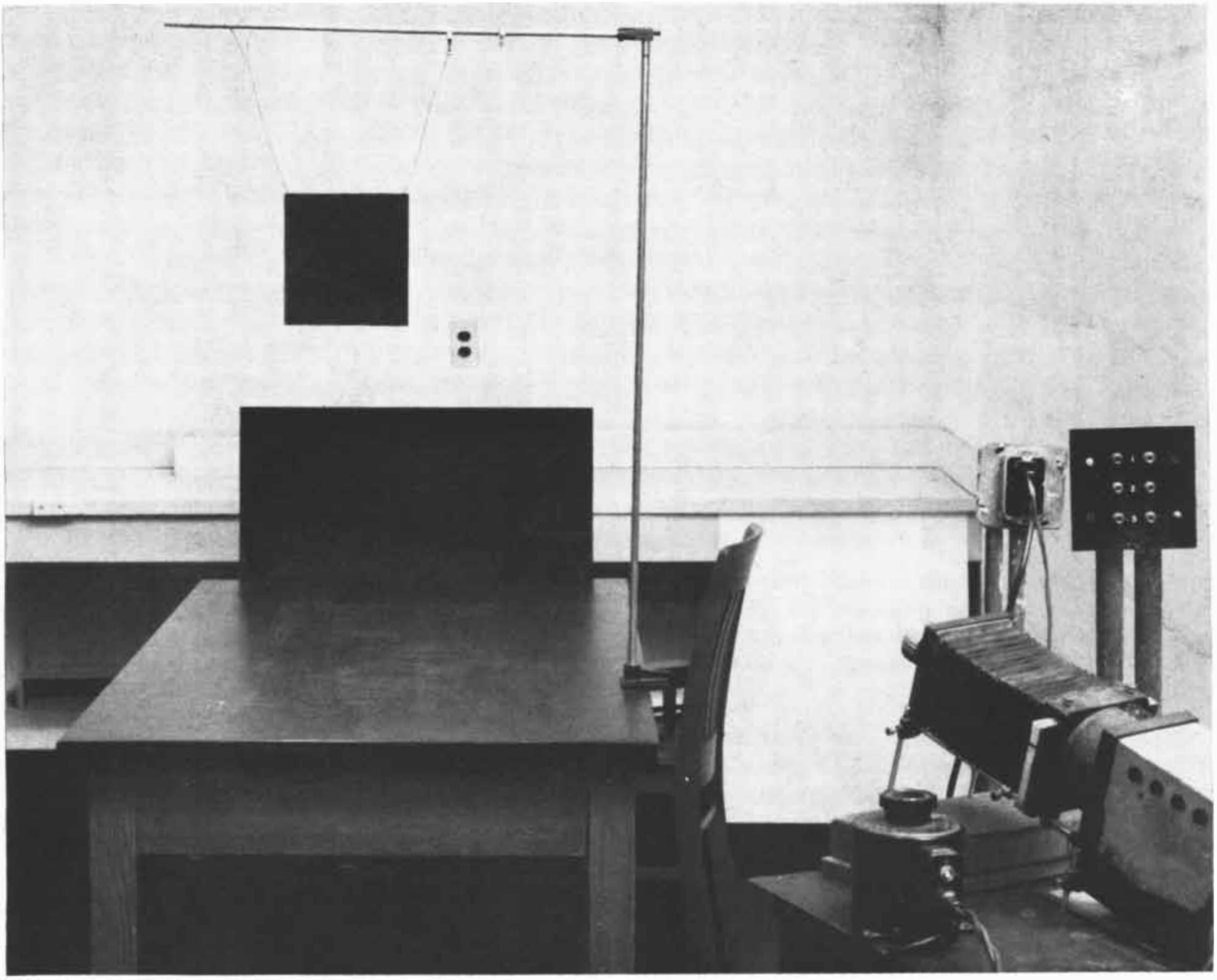
Most investigations of color perception deal with the relation between the spectral composition of light—the assortment of wavelengths in it—and the color sensations it evokes. But there is a family of colors the quality of which does not depend on wavelength or combinations of wavelengths. These are the achromatic, or neutral, colors—white, the various grays and black—which differ from one another only in degree of lightness or darkness. The scale of lightness, in other words, is the only dimension of the neutral colors, although it is one dimension (along with hue and saturation) of the chromatic colors as well. The perception of neutral colors is therefore a basic problem in visual perception that needs to be understood in its own right and that at the same time has implications for color vision in general.

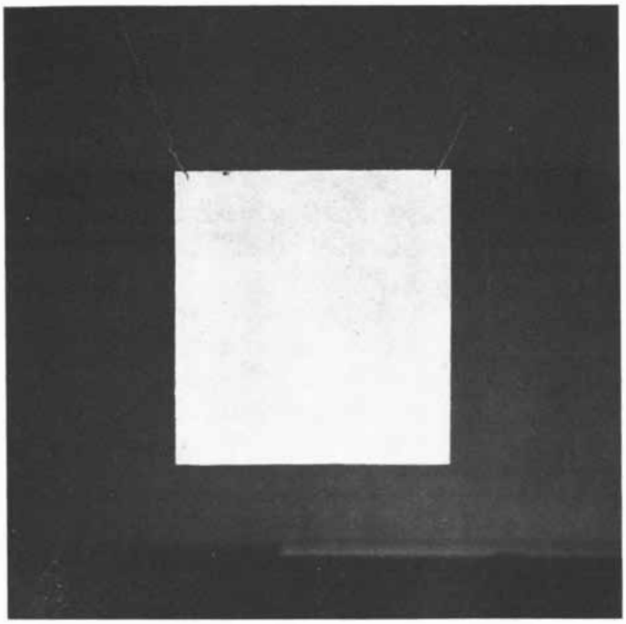
The fact that lightness does not depend on a property of light itself is not only a semantic paradox but also a major complication in the study of neutral-color perception. Light can appear dim or bright but not light or dark. It can be blue or yellow or red but not gray. Lightness or darkness is a property of surfaces, and the investigator of neutral-color perception must concern himself with white or gray or black surfaces. Now, the physical property of a surface that corresponds to a perceived neutral color is reflectance. A surface deserves to be called white if it reflects diffusely about 80 per cent of the visible light of any wavelength that falls on it, and it is called black if it reflects only 4 or 5 per cent of the incident light. The various shades of gray range between these extreme reflectance values. The big problem in understanding the perception of neutral colors is that the amount of light reflected by a neutral surface depends not only on its reflectance but also on the intensity of the illuminating light. As the illumination varies over a broad range, the intensity of the light reflected by a surface of a given neutral color will vary just as much. The light message that is received from a reflecting surface is therefore an ambiguous clue to its reflectance—to its "actual" color.

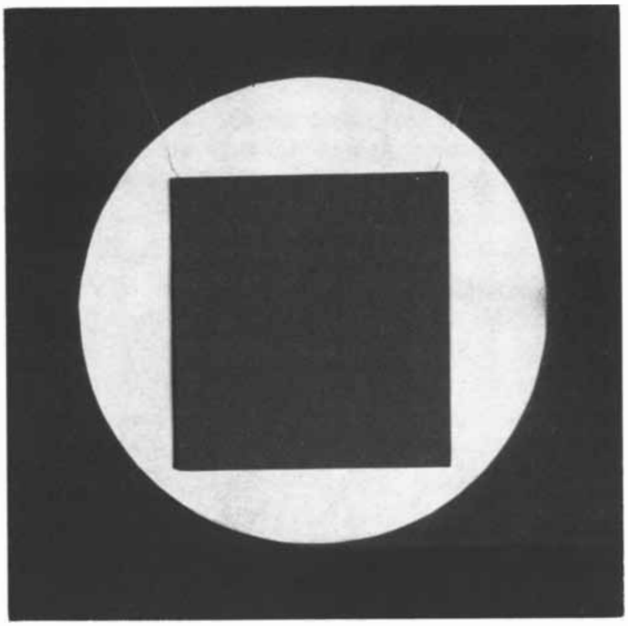
How then can one account for the fact that perceived neutral colors are usually in good agreement with the reflectance of the surface on which they appear—that a dark gray object, for example, tends to look dark gray in all sorts of light? This "constancy" effect, as psychologists call it, can be simply demonstrated by an experiment that David Katz, a German psychologist, devised more than 30 years ago. Two identical gray samples are fastened to a white background and a screen is so placed that it casts a shadow on one of the samples and on its surround [*see illustration below*]. The sample in the shadow does indeed appear to be a somewhat darker gray than the sample in direct illumination. That is to say,



CONSTANCY of neutral colors is demonstrated by this experiment. When one of two identical gray samples is placed in shadow, it looks to an observer only a little darker than its brightly illuminated counterpart although, as the drawing shows, it reflects a lot less light (*left*). The color of the shadowed sample is then lightened until it looks the same as the well-lighted one; it still reflects much less light (*right*). In each situation constancy is at work, making the grays appear more equal than the actual light intensities they reflect would warrant. The drawing reproduces these actual light intensities, not the apparent colors of the samples.







IMPRESSIVE DEMONSTRATION of constancy can be given with the setup illustrated in the top photograph. A dark gray sample suspended before a light-colored wall is illuminated by a projection lantern. When the sample hangs alone, any change in room illumination or lantern intensity changes its apparent color. At the bottom left, for example, it appears almost white. But if a white surround is placed behind the sample within the lantern beam, the sample immediately looks gray again (*bottom right*). It stays gray in spite of changes in the lantern intensity or room illumination. The bottom photographs simulate the apparent colors of the sample.

constancy is not complete. But the shadowed sample by no means looks as much darker as the difference in the actual light intensities reflected by the two samples would warrant, which is to say that there is a constancy effect. When the shadowed sample is replaced by a patch of lighter gray so chosen that the two surfaces appear to be the same in spite of their different illuminations, the shadowed sample will still reflect a good deal less light than the directly illuminated one. This difference in the actual light intensity compatible with apparent equality of color represents the constancy effect. Any explanation of this effect must account eventually not only for its presence but also for its incompleteness as demonstrated in the first part of the experiment.

For a long time the standard explanation of constancy has been that the viewer takes illumination into account when he evaluates the intensity of the light reflected by a surface. The difficulty with this is that illumination is never given independently. It manifests itself only by way of the light that the various surfaces in the visual field reflect. One variable, the intensity of the reflected light, depends on both the incident illumination and the reflectances of the surfaces—and is in turn the only direct clue to both of these factors.

The Katz demonstration had the virtue of simulating the conditions under which constancy occurs in everyday life, but it is not amenable to as much manipulation as an experimental situation worked out by Adhémar Gelb of the University of Frankfort. In my laboratory at Swarthmore College some 15 years ago we undertook to explore with Gelb's setup some of the inconsistencies of the orthodox explanation of constancy.

We suspend a dark gray sample some distance from a light-colored wall and illuminate it with a projection lantern so placed that the bright spot formed where the beam hits the wall is concealed behind a door or curtain. With the room nearly dark, the dark gray sample appears brightly luminous, provided that it is perfectly flat and evenly illuminated so that no shiny high lights show. As the general illumination—and hence the illumination on the light wall behind the suspended sample—is raised, the luminous appearance of the sample disappears and it becomes a white surface. Remember that the sample is really dark gray; in this situation constancy is clearly absent. A further increase in room illumination changes the appearance of the sample to a light gray. Obviously the wrong illumination is being taken into account! The light reflected by the dark sample is being evaluated in terms of the general illumination on the wall; the strong light from the projector is being ignored. The reason for this, proponents of the standard explanation would say, is that the strong light from the lantern is visible on only one object, the dark gray sample, the surround of which reflects only the dimmer general illumination; constancy would be restored if the light from the lantern showed in the surround. And so it is. When a piece of white cardboard, somewhat larger than the sample but small enough to fit into the beam, is hung behind the dark sample, the sample looks dark gray. The orthodox explanation is that the white cardboard surround makes it possible to take into account the effect of the lantern light on the intensity of the light reflected by the dark sample.

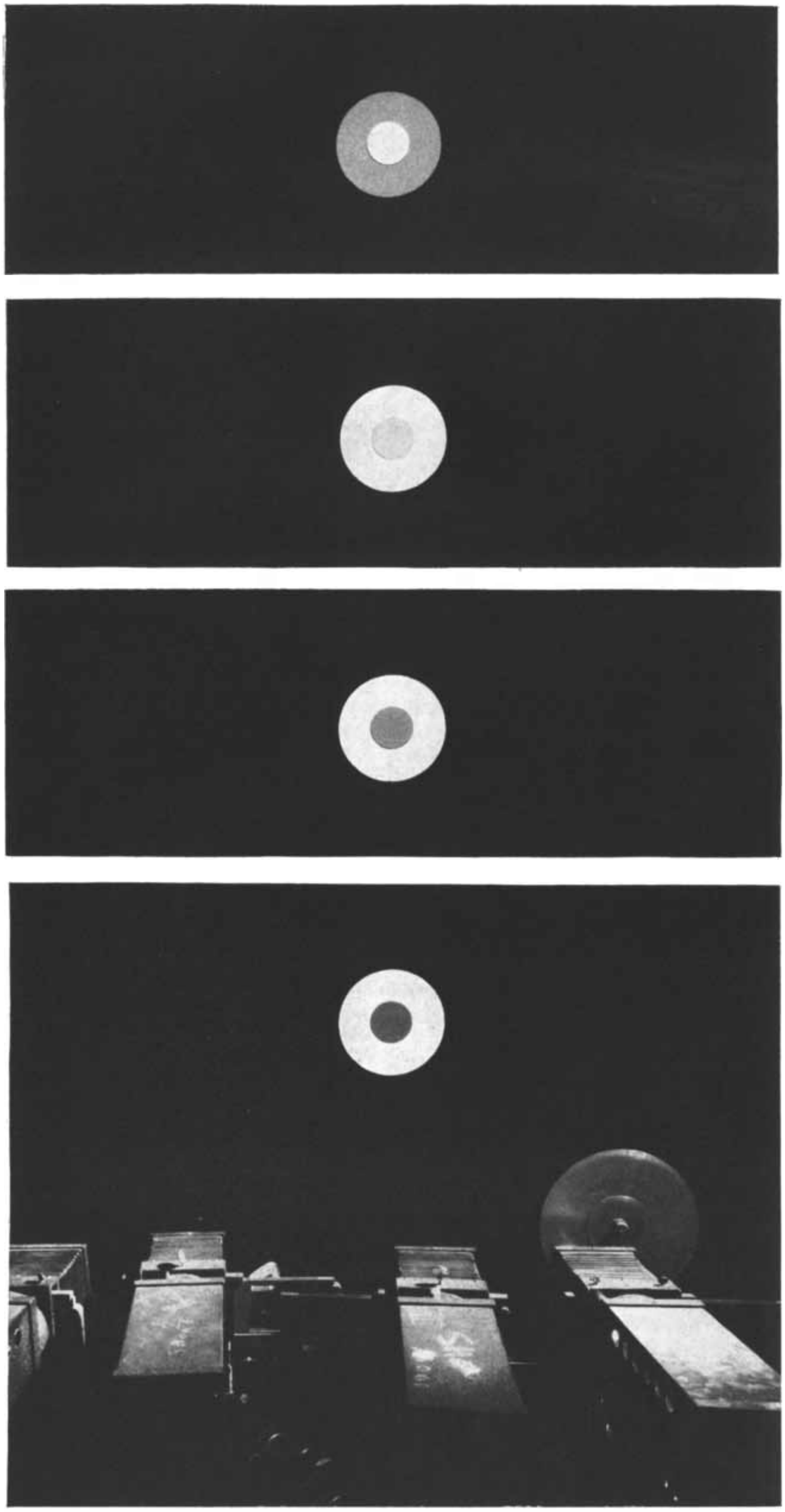
What happens when we vary the intensity of the lantern beam? With the gray sample alone intercepting the beam, every reduction in the intensity of the light causes a change in the apparent color of the sample, which can be altered in this manner all the way from white to dark gray. With constancy restored by the addition of the white cardboard, however, the same changes in light intensity hardly affect the color of the sample and its surround. The sample remains dark gray and the surround white, although the latter looks more or less strongly luminous as the lantern light is varied. This "luminousness" is a special aspect of neutral-color perception, as will be seen; in so far as the neutral colors as such are concerned, however, the combination of dark gray surface with white surround is resistant to changes in illumination.

It is difficult to see how this demonstration of constancy can be explained by any mechanism that takes the illumination into account. The amount of light the white cardboard reflects, after all, gives information about the intensity of the illumination only when the cardboard is correctly assumed to be white. But there is no cue for such an assumption. What if the cardboard were not white? As a matter of fact a surround of any other color fails to produce constancy, that is, to cause a dark gray sample to be perceived as dark gray. If, with the walls of the room dark, the white cardboard is replaced by a medium gray one, the surround again appears luminously white in the lantern beam, whereas the dark gray sample looks light gray. Although the color is now incorrectly perceived, the combination of sample and surround is still resistant to illumination changes. The intensity of the beam can be moved through a broad range and the sample remains light gray.

If taking illumination into account is not the explanation of constancy, what is? Some years ago Harry Helson, then at Bryn Mawr College, proposed an entirely different approach, invoking the mechanism of adaptation by which the eye adjusts itself to wide variations in the amount of light available. To account for the fact that constancy prevails when different illuminations are visible simultaneously, he suggested that incoming light intensities are evaluated in terms of a "weighted average" of stimulation in different parts of the retina, the light-sensitive screen at the back of the eye. It seems to me that there is implicit in this notion of regional adaptation an assumption of some sort of interaction of processes arising in different parts of the retina, and such interaction would appear to be a requirement in any explanation of constancy. Helson's explanation was advanced as part of a general theory of sensation that has been quite successful, and he did not describe a specific mechanism for interaction.

Speculating on the observations just described, in which the combination of gray sample and cardboard background proved resistant to changes in illumination, I wondered if a ratio effect might be at the heart of the matter. Since any neutral surface reflects a constant fraction of the available illumination, the light intensities reflected by two different surfaces under the same illumination should stand in a constant ratio no matter how the illumination is changed. If one could demonstrate that perceived neutral colors depend on the ratio between the light intensities reflected from adjacent regions, all the foregoing observations, and in fact neutral-color constancy in general, would be explained. The following experiments show that this is indeed the case.

The first experiment calls for a darkened room, a white screen and two identical slide projectors the light intensity of which can be altered by measured amounts. In an otherwise dark room one lantern projects a disk of light on the screen and the other lantern a ring of light that fits closely around the disk. The light intensity of the disk is



NEUTRAL-COLOR PERCEPTION depends largely on the ratio between two different light intensities in adjacent regions, as demonstrated with a ring-and-disk pattern projected by two lanterns in a dark room. In this experiment the light in the disk is kept constant but the ring light is increased, changing the appearance of the disk from white to dark gray. The ring-to-disk ratios are (*top to bottom*) one to three, two to one, four to one and eight to one. These photographs show how the ring and disk colors appear to an observer.

kept constant; variation of the intensity of the ring then changes the appearance of the disk through the entire range of neutral colors. When the ring intensity is half or a quarter that of the disk, the disk looks white. When the ring intensity is higher than that of the disk, the disk becomes gray. Its shade deepens from light to medium to dark gray as the ring light is made first twice as intense as and then four and eight times more intense than the light in the disk. When the relative intensity of the ring is raised still further, the disk even appears black. This experiment shows clearly that the neutral color of an area does not depend on the intensity of the reflected light as such, because with the intensity of the illumination of the disk held constant its color nevertheless ranges all the way from white to black as the intensity of its surround is increased. Obviously what matters is the relation of the intensity of the light reflected from the disk to the intensity of the light reflected from the surrounding ring.

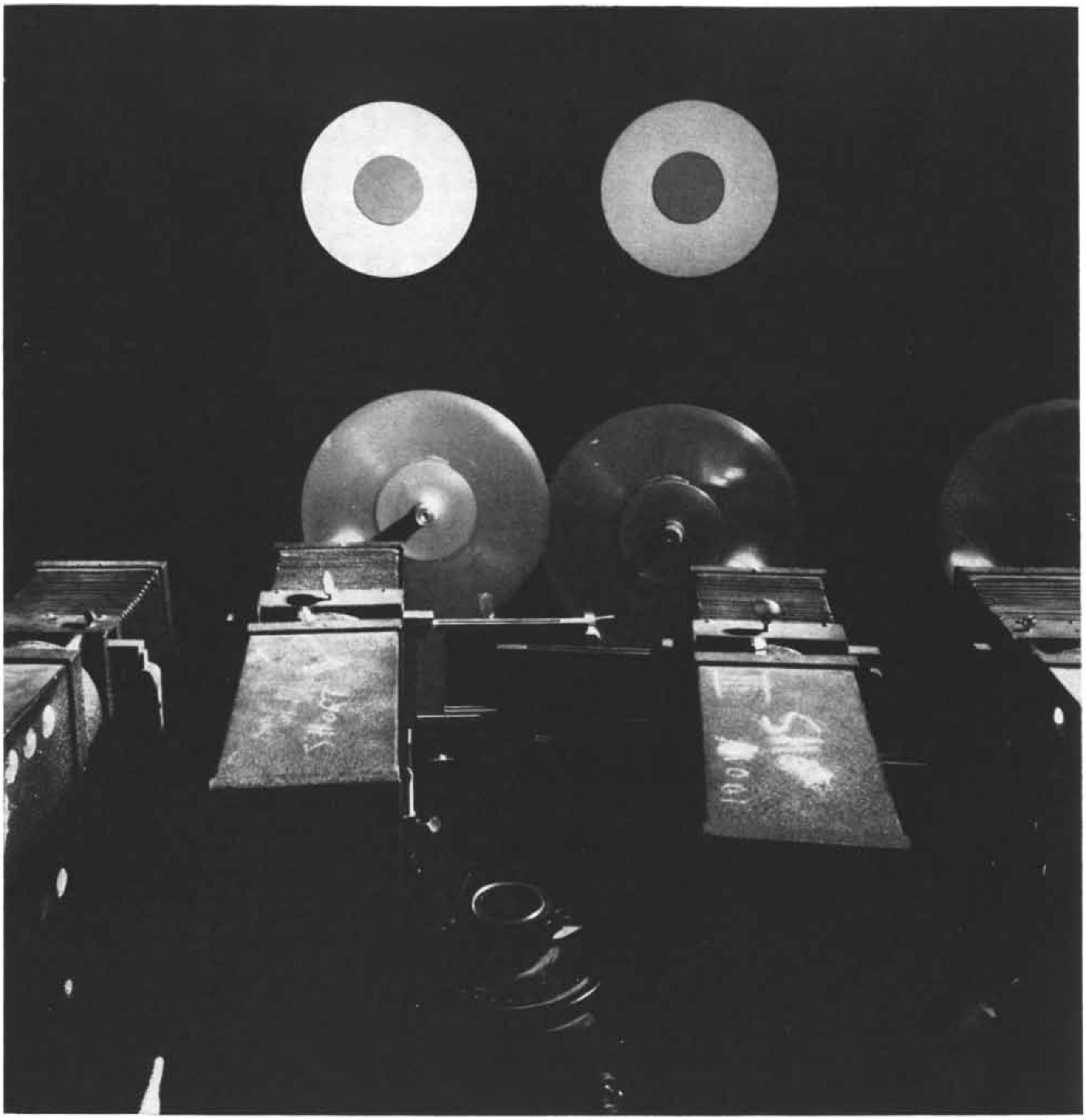
Another experiment demonstrates that a particular gray is produced largely by a specific ratio between the intensity of the ring and that of the disk. A second pair of lanterns is added to project an identical ring-and-disk pattern on a second screen. If the ring and disk in each pattern are illuminated with the intensities in the same ratio but with the absolute intensity in one pattern reduced to, say, a third or a quarter of the intensity in the other, almost the same gray is perceived in both disks. Whenever the intensity of one of the disks is varied until the grays of the two disks appear to be truly equal, the disk intensities turn out to be almost equal fractions of the intensities in their respective rings.

The discovery that the various gray colors depend approximately on the ratio between light intensities stimulating adjacent regions of the retina goes a long way toward explaining neutral-color constancy in general. The ratio principle can account for the observed constancy in the Katz experiment, where a sample in shadow is compared with one in direct illumination. The combination of sample and background is resistant to differences in illumination because the ratio between the intensities reflected by sample and background is constant. It will be recalled, however, that constancy was not complete in the Katz experiment. A ring-and-disk demonstration explains this also. The ratio principle operates best only when the ring and disk are presented against a dark background or when the ring is enlarged to fill the whole visual field. If, instead, the ring is surrounded by an area of still higher intensity, the disk assumes a darker color. And this is in essence what happens in the Katz setup: the gray sample and background in the shadow correspond to the disk and ring, and the portion of the background that remains under direct illumination corresponds to the outer region of still higher illumination that makes a disk appear darker. It is largely because the shaded region and the area under direct illumination are adjacent that constancy is incomplete. Were they widely separated, as they are in the presentation of two ring-and-disk patterns, much better constancy would result, because the ratio principle would then operate as nearly perfectly as it did in the projector experiments.

Although perception of illumination may not be very accurate and does not account for the constancy of neutral colors, it cannot be denied that people do perceive conditions of illumination. A room looks generally brighter near the window than it does far from the window; there is a bright area on the wall near a lighted table lamp and there are shadows on other walls; one side of the house across the street appears brightly illuminated by the sun. How, in view of the ratio principle, is one to account for the fact that the shadow on the gray wall does not look exactly like a darker gray or black but has a somewhat translucent appearance; that the wall near the lamp does not seem to be lighter in color but merely looks brighter and less opaque; that the sunlit wall of the house looks outright luminous? All of these examples have one thing in common: the typical quality of a surface of neutral color is either completely replaced by a luminous appearance or is modified in the direction of what can be considered a partially luminous quality. The two-projector experiment, as already noted, also produces examples of this luminousness and of a translucent quality in the grays that is the low-intensity counterpart of the same effect.

When the intensity of the light reflected from the disk is two to four times higher than the intensity of that reflected from the ring, the disk looks white; when the intensity of the disk is lower than that of the ring, the disk looks gray or black depending on the ratio between the two intensities. If the intensities of ring and disk are reversed, however, the appearance of the ring is very different from that of the disk under corresponding conditions. Under illumination of the higher of the two intensities, the ring appears not white but plainly luminous, like the glass globe of a not too bright lamp. Under illumination of the lower intensity the ring does look gray, but the gray has a peculiar quality. It lacks the opaqueness of an ordinary surface; it seems rather to be somewhat translucent, as if there were a light source behind it. As a matter of fact it resembles an extended shadow, which also lacks the opaqueness of a dark surface color, although to a lesser degree. With the ring eliminated altogether, the dark region surrounding the disk does not look like an opaque black surface but like a dark expanse. The distinction between the two kinds of darkness is pointed up vividly when the disk is eliminated and a ring of light is projected alone on a dark field. The area inside the ring has a black surface color quite different from the dark expanse outside the ring.

Several factors seem to account for the sensation of luminosity. The larger of two contrasting areas, in the first place, tends to appear luminous. In our experiments the ring was usually larger than the disk. With the ring reduced in



RATIO PRINCIPLE is confirmed by projecting a second pattern from two more projectors. The ratio between ring and disk light intensities is made the same in both patterns but the absolute intensities in the pattern at the left are four times greater than those at the right. In spite of the variation in absolute intensity, the grays perceived in the two disks look remarkably similar to an observer. The photograph, however, approximately reproduces the true light intensities rather than the apparent disk colors.

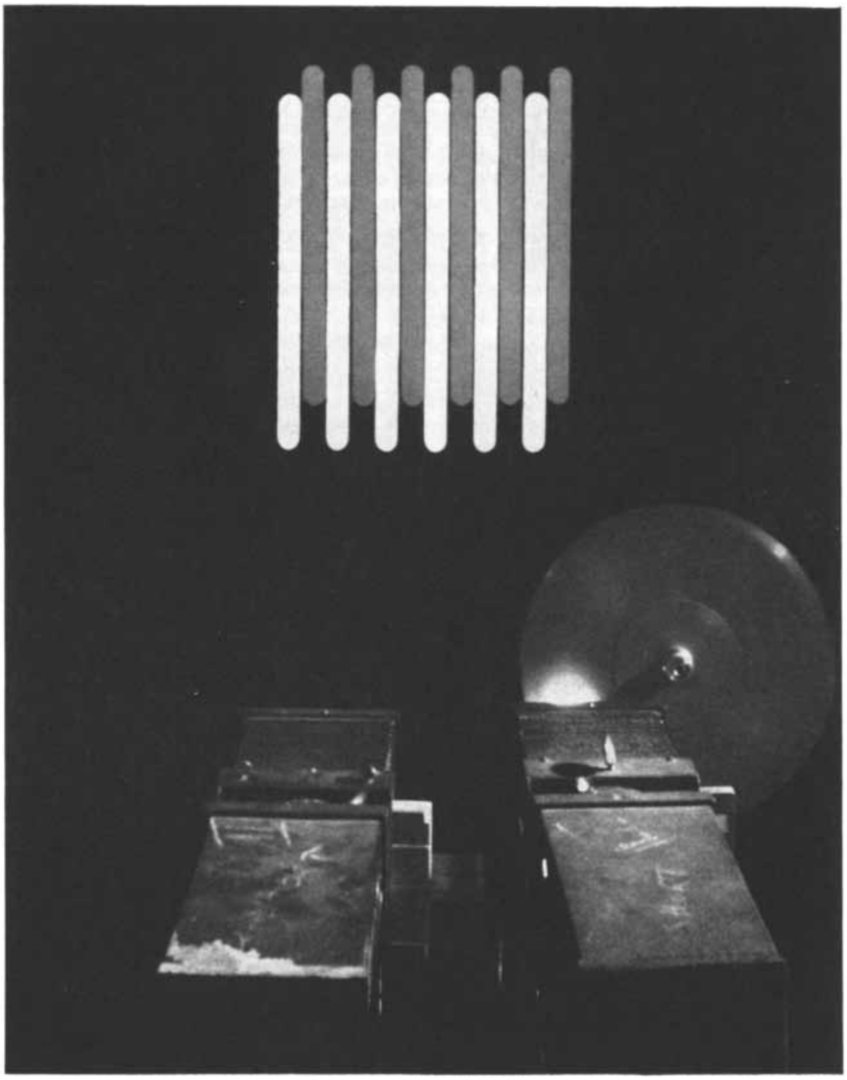
width so that its area is smaller than that of the disk, the appearance of luminosity and translucence transfers to the disk. The degree of contact between two surfaces reflecting different light intensities also plays a part in this effect. Surrounded completely by the ring, the disk tends to look more like an opaque surface. The ring, which tends to assume the luminous quality, is in contact with the disk on one side only and is bordered on its outer perimeter by the darkness of the room, from which there is minimum stimulation. Lack of contact also explains the luminousness or translucence observed when the disk or the ring is presented alone.

To isolate the effect of difference in contact we have projected two sets of bars, one from each lantern, so that bars of high and low intensity alternate in the pattern on the screen. The two outside bars, one white and one gray, appear somewhat luminous, whereas all the other bars show opaque colors. Since the areas of each bar and of each intensity are exactly equal, the luminous look can only be attributed to the diminished contact of the outer bars with areas of different intensities. A special case of reduced contact occurs when an intensity gradient replaces the sharp border between two areas of different intensities. Such gradients appear in the penumbrae of shadows, where the grays assume the quality of translucence that belies the opacity of the surface under inspection.

Regardless of size or degree of contact, when the intensity difference becomes greater than about four to one, the area of higher intensity becomes somewhat luminous as well as white; with very large differences it loses all whiteness. An illuminated disk in an otherwise dark field never looks white or gray; depending on its intensity, it is brightly or dimly luminous. The most familiar illustration of this laboratory finding is the contrast between the appearance of the moon by day and by night. In a bright blue sky the moon looks white. As the setting of the sun reduces the intensity of the blue sky the moon's light becomes relatively more intense and the moon appears more and more luminous, even though the intensity of the light arriving from the direction of the moon certainly does not increase.

It can be concluded, therefore, that a region reflecting the higher of two light intensities will appear white or luminous, whereas an adjacent region of lower intensity will appear gray or black. Every change of the intensity ratio causes a change in the color of the area of lesser intensity along the scale of grays. As for the area of higher intensity, it appears white when the intensity ratio is small and becomes luminously white and finally luminous as the ratio is increased. If the contact between surfaces of different intensities is reduced, neutral colors become less dense and opaque and even somewhat luminous. The same effect is seen in a region that is larger than an adjacent one of different intensity.

It seems to me that these facts can be explained by considering that stimulation with light gives rise to two different perceptual processes. One process causes luminousness and the other produces the various opaque colors. The first process is directly dependent on intensity of stimulation and the state of adaptation of the eye. The second is an interaction process: an area of the retina that receives a higher intensity of stimulation induces a sensation of gray or black in a neighboring region of lower intensity, with the particular color roughly dependent on the ratio of the two intensities; conversely, the region stimulated at a lower intensity induces a white color in the region of higher intensity. If the intensity ratio is too high, however, if the relative size of the inducing surface is too small or if the contact between two regions of different intensities is too small, the interaction process may give way to the process that gives rise to the sensation of luminosity, or the sensation of color and luminosity may be experienced simultaneously.

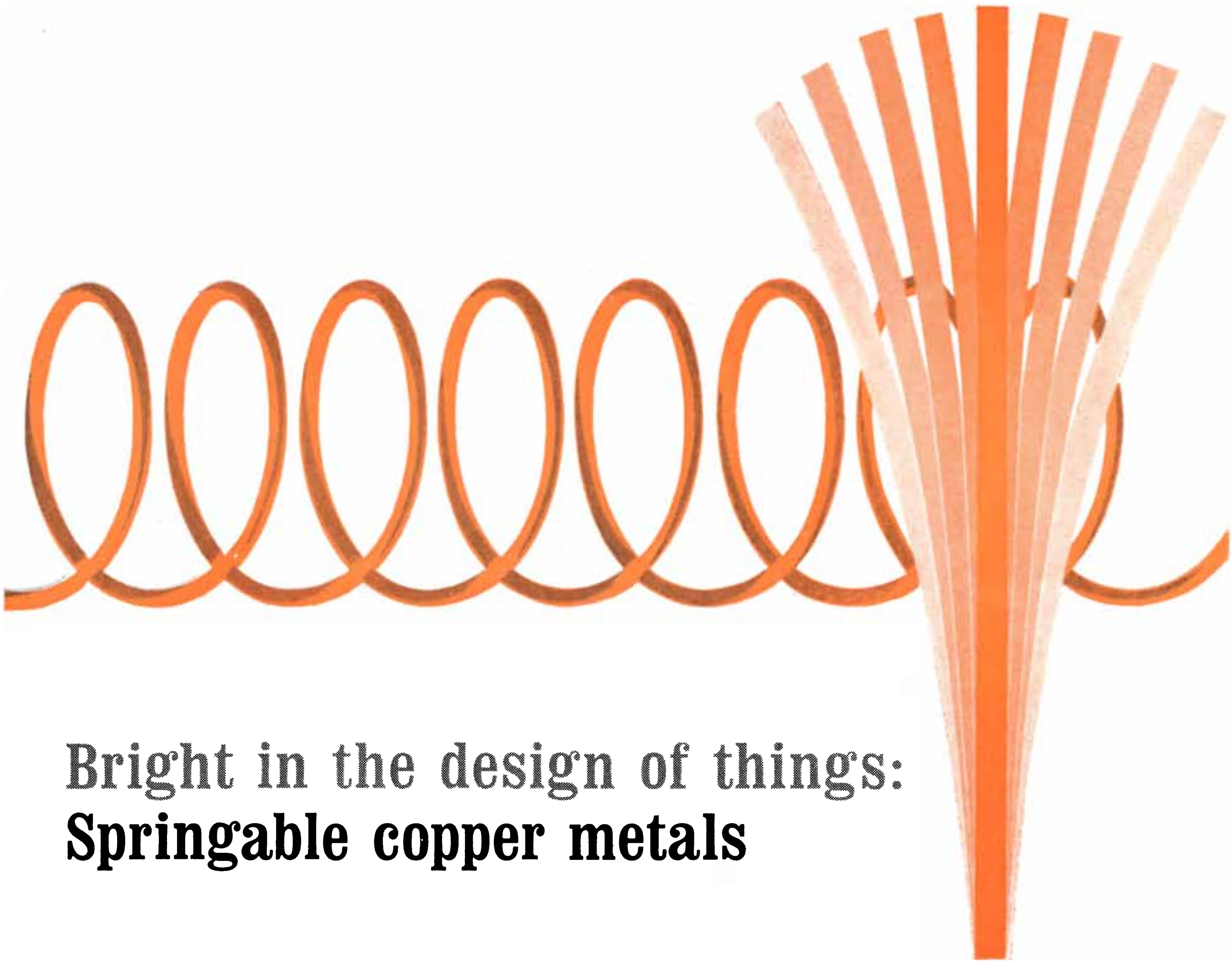


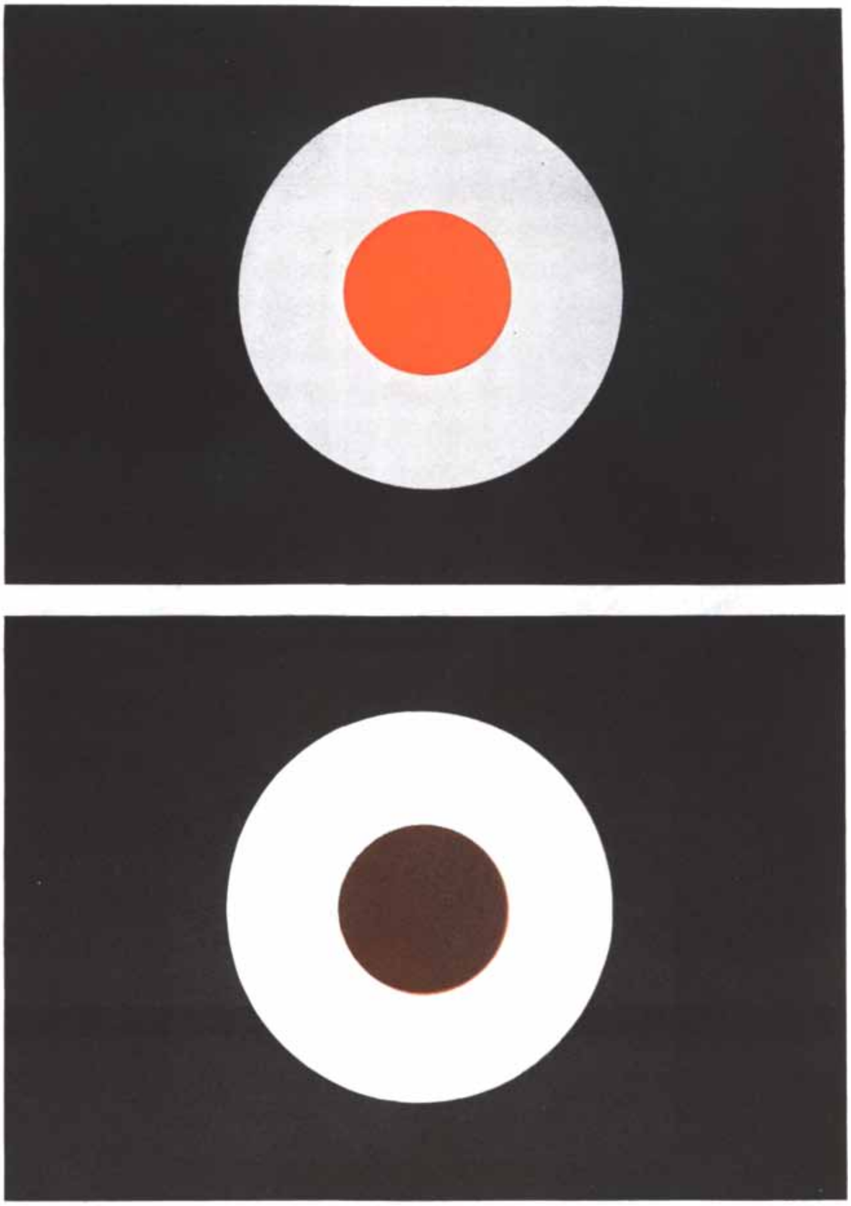
LUMINOUS QUALITY is produced by a reduction in the degree of contact with an area of contrasting light intensity. In this pattern of bars of alternating high and low intensity, the two outside bars look somewhat luminous to an observer (the effect is not apparent in a photograph) because they have only half as much contact with contrasting bars.

The processes of neutral-color perception have their counterparts in the perception of chromatic colors. This is not surprising; the neutral colors are continuous with the chromatic colors: for any sample of a greatly desaturated chromatic color a closely similar gray can be found. A final experiment with the two projectors demonstrates that the lightness of chromatic colors depends on a relation between the intensities of stimulation in neighboring regions. When a disk of chromatic light is surrounded by a ring of white light, variation in the intensity of the latter changes the lightness of the chromatic color in the disk. In this way a bright pink, for example, can be changed to a dark magenta. The same experiment performed with a yellow or orange disk yields a surprising result: surrounding the disk with a ring of high-intensity white light transforms the disk into a deep brown. This serves to demonstrate that brown is a dark shade of yellow or orange. It also dramatizes the point that the shades and tints of chromatic colors, as well as the neutral colors, are the result of an interaction process.

Even the luminous appearance that results from stimulation with light from a neutral surface has its counterpart in the sensation of chromatic colors. For many years psychologists have distinguished a number of "modes of appearance" of chromatic colors, including surface colors, expanse colors and aperture colors. Surface colors are the opaque colors of objects, the hued counterparts of the neutral surface colors. Expanse colors, of which the clear blue sky is a good example, occur in extended homogeneous regions and lack the density and opaqueness of surface colors. That is, expanse colors have a luminous appearance, which may be caused by a relatively high intensity of stimulation or because they are greatly extended in relation to an adjacent region of different intensity. Aperture colors are observed when one looks through a hole in a screen at a chromatic surface some distance beyond the screen. Under these conditions the surface is transformed into a seemingly transparent chromatic film stretched across the hole.

The aperture mode has been attributed to the peculiarities of the laboratory arrangement in which it is usually observed. It can be shown, however, that this effect too is a product of specific ratios of stimulation intensities. The

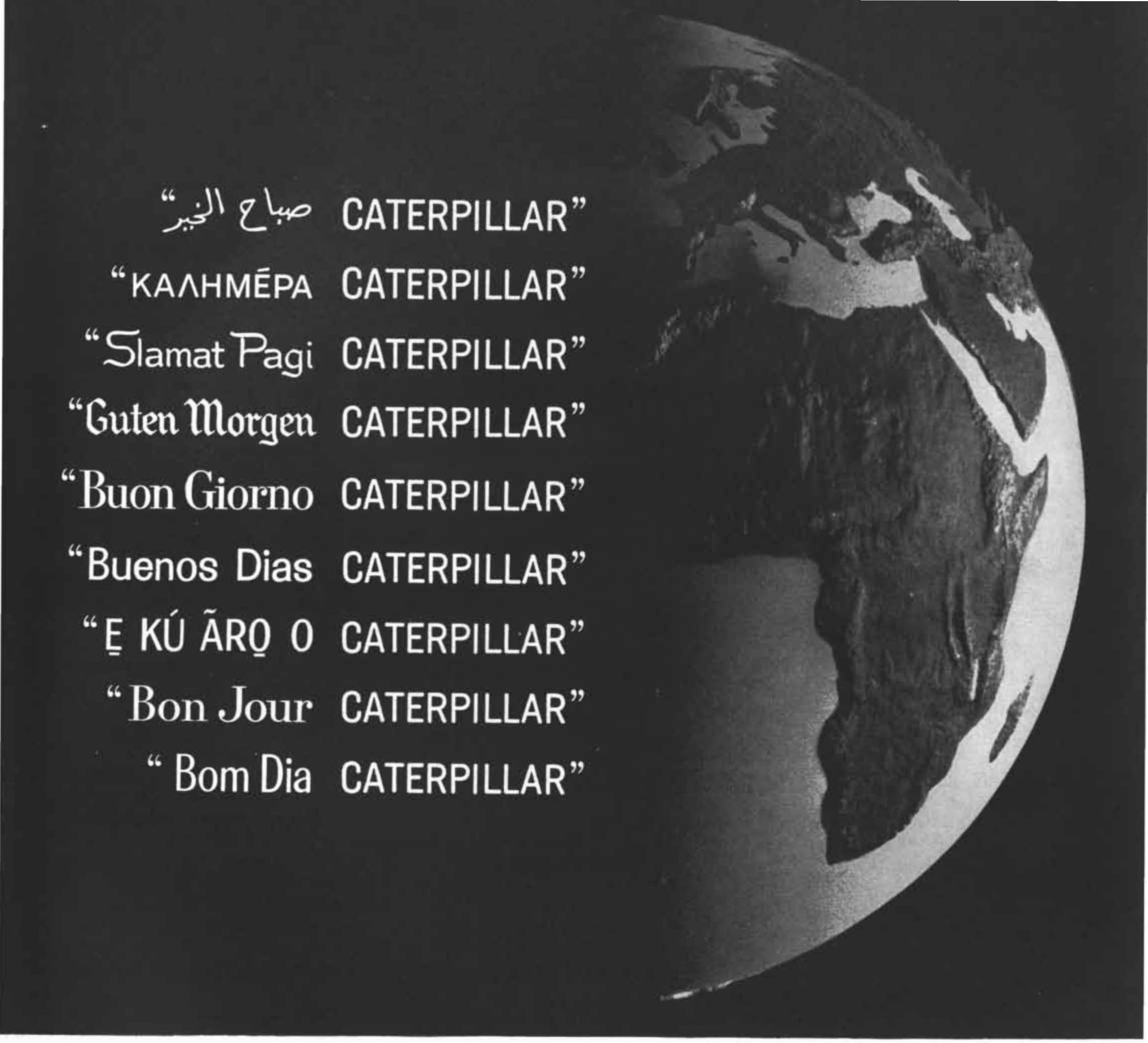




CHROMATIC COLORS also vary in lightness depending on the intensity of the illumination in an adjacent region. The experiment simulated here shows how the appearance of a disk of orange light changes with the intensity of a neutral surround. In this case increasing the intensity of the ring changes the apparent color of the disk to brown.

"transparent film" appears only when the intensity of the light reflected from the chromatic surface seen through the hole is high in relation to that of the light reflected from the screen. Raising the illumination on the screen transforms the film into a surface color, so that the hole comes to look like a piece of colored paper attached to the screen.

Such a change can be observed easily out of doors on a clear morning. Cut a small hole in a large sheet of white cardboard. Hold the sheet up so that the sky is visible through the hole. The sky will appear in the hole as a blue transparent film. Now turn until the white cardboard reflects the direct light of the sun. When the cardboard is brightly illuminated, the hole seems to be replaced by an opaque bluish-gray patch, notable for its lack of saturation. This transformation of the strongly saturated expanse color of the sky into a surface color of medium lightness by the provision of a relatively large surface of contrastingly high light-intensity shows how desaturated the blue of the sky really is. It suggests that the sky looks very blue not only because the blue wavelengths of sunlight are scattered by the atmosphere but also—and perhaps largely—because the sky is so bright.



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Skin Transplants and the Hamster

This familiar laboratory rodent is an anomaly of the animal kingdom in several respects, not least of which is the unique hospitality it shows to many kinds of foreign-tissue grafts

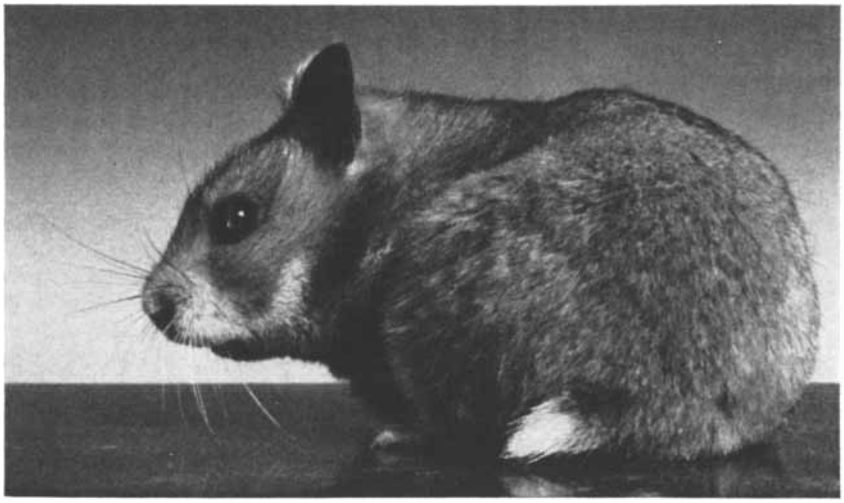
by Rupert E. Billingham and Willys K. Silvers

A fairly recent addition to the select number of small mammals that have been domesticated for laboratory use is the Syrian, or golden, hamster. About midway between the mouse and the rat in size, reasonably placid, clean and prolific, it is easy to maintain and handle. These virtues alone would account for its growing population and numbers, now estimated at 100,000, in laboratories around the world. The hamster does special service, however, in those lines of investigation that involve the transplanting of tissue from one animal to another: studies of cancer, aging, endocrine function and, of course, the immunological reaction that ordinarily brings about the rejection, or "sloughing off," of a tissue graft. To make other species serve this purpose requires the mating of brothers to sisters over many generations to produce at last a stock of individuals with the genetic compatibility of identical twins; decreasing fecundity of the breeding line is only one of the hazards that can bring such an inbreeding program to a halt. Among the members of any laboratory colony of hamsters, in contrast, one usually finds that a high proportion of individuals will exchange tissue grafts. In addition, it is fairly easy to inbreed a strain for full compatibility. More remarkable still, the cheek pouch of the hamster, in which it collects and transports food in nature, will accept grafts not only from other hamsters but also from other mammals and even from animals as alien as the frog.

Plainly the hamster is deserving of investigation in its own right. At the Wistar Institute of Anatomy and Biology in Philadelphia we have over the past several years established the genetic basis of the animal's remarkable receptivity to homografts—grafts from genetically unrelated members of its species. Our findings show that the hamster presents one of the simplest instances of the working of one of the many different genetic mechanisms that underlie the uniqueness of the individual at the biochemical level. The cheek pouch is another matter entirely. The receptivity of this tissue environment to heterografts—grafts from members of other species—as well as homografts is not yet explained in full or with certainty. It may hold a clue to the nature of the barriers that insulate tissues and glands that have distinctive biochemical constituents from one another in the body—barriers that break down in certain rare cases of autoimmunological disease.

Although the Syrian, or golden, hamster has come to be known as "the hamster," it is one of three species—along with the European black-bellied hamster and the Chinese gray hamster—that have been brought into the laboratory. In nature it is one of 66 varieties or subspecies distributed over the Eurasian continent. Belonging to the mouse group in the large order of rodents, hamsters are formally designated as the family Cricetidae. They dwell in deep, chambered burrows in which they hoard grain and other vegetable foodstuffs foraged from the field at night. As a result of their short gestation period of 16 days, the large size of their litters and the early sexual maturation of the female, at four weeks, these animals have a remarkably high rate of reproduction and are considered a pest in agricultural lands.

Of all the hamsters, the Syrian is one of the most narrowly restricted in natural habitat, being confined to the Mediterranean side of Asia Minor. It was first identified as a species (*Mesocricetus auratus auratus*) in 1839 by the British naturalist George R. Waterhouse, who obtained a single characteristically fawn-colored specimen from Aleppo in Syria. It was not until 1930, when I. Aharoni



GOLDEN HAMSTER is a relative newcomer to the laboratory. All domesticated hamsters are descended from a single litter found in Syria in 1930. As a result of their recent common ancestry different laboratory stocks of hamsters may be very closely related genetically.

of the Hebrew University in Jerusalem captured a litter from a deep burrow, that this hamster began to attain a more cosmopolitan distribution. All the domestic stocks of the animal are descendants of one male and two females of Aharoni's original litter.

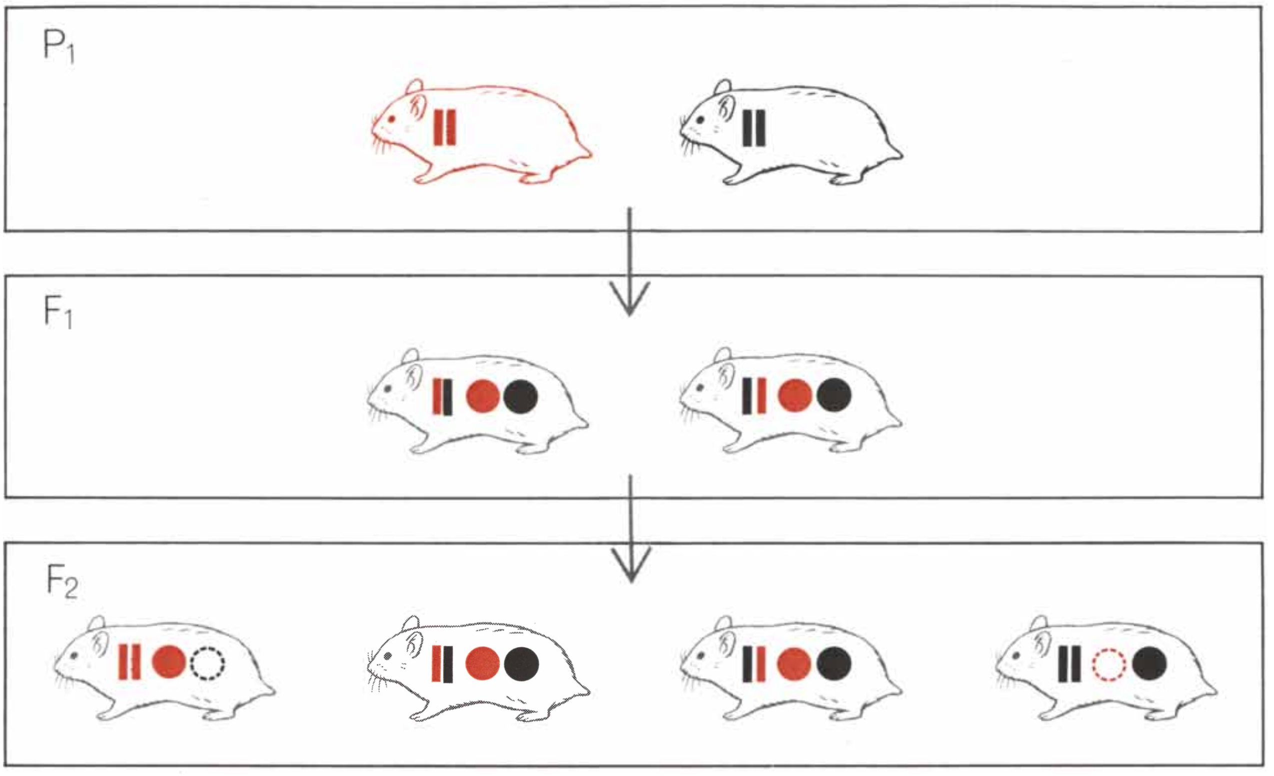
The Adam-and-Eve-like origin of the laboratory hamster suggests itself as the first explanation for the animal's acceptance of homografts. As recent successes in surgery have advertised, tissue grafts and even organ grafts have been successfully exchanged between identical twins [see "The Transplantation of the Kidney," by John P. Merrill; SCIENTIFIC AMERICAN, October, 1959]. Identical twins, in consequence of their derivation from a single fertilized egg cell, have exactly the same genetic and biochemical constitution. Grafts exchanged between them are more properly termed isografts. Foreign tissue in the form of a homograft or heterograft, on the other hand, elicits the build-up of a state of specific resistance in the host's body—an immunological reaction—and the total destruction of the graft as a living entity follows. Not being represented in the host's own body, certain constituents of the foreign tissue are antigenic, just as foreign blood proteins and pathogenic organisms are. The tissues of the host—specifically the tissues of the host's lymphatic system—respond by producing the complementary proteins, called antibodies, that neutralize the antigens.

In the case of the heterograft the foreign proteins are more diversely and powerfully antigenic and provoke a correspondingly powerful antibody response. Skin grafts exchanged between adult mice and rats or between hamsters and rabbits normally heal in feebly, acquire a poor and transient blood supply and suffer complete cell death within a week. Although homografts also provoke antibodies in the host, these do not appear to play any significant role in the destruction of the graft. The transplanted tissue develops a better blood supply and gives the appearance of "taking" before it breaks down. The agents that attack and destroy the homograft seem to be lymphocytes: white cells produced by the lymph nodes and carried to the site of action in the blood. In this respect homograft immunity appears to be related to the similar immunity (here meaning sensitivity) that is built up in the human body in response to poison ivy and certain chemical agents [see "Delayed Hypersensitivity," by Alfred J. Crowle; SCIENTIFIC AMERICAN, April, 1960].

Recent research indicates that the transplantation antigens liberated by homografts are lipoproteins—proteins with a lipid, or fatty, molecular constituent—and that they are associated with membranous structures of the cell. Furthermore, like the antigens involved in blood-group incompatibilities, transplantation antigens are determined by multiple dominant genes, termed histocompatibility (tissue compatibility) genes. The tedious and uncertain process of inbreeding, which must be carried through at least 20 consecutive generations, is necessary to produce uniform populations for transplantation experiments. In such a stock, or strain, every member has the same genetic constitution, including, of course, identical complements of histocompatibility genes. Obviously the distinctive genetic constitution of an inbred strain will depend on the genetic constitution of the particular base-line breeding pair from which it was initially derived. Thus members of different inbred strains of entirely independent origins may differ from one another just as much as do randomly selected individuals from an outbred, or wild, population.

The discovery that members of an ordinary breeding colony of hamsters would exchange tissue grafts successfully was made quite by accident in 1939, when the animal was still a newcomer to the laboratory. Investigators at the Imperial Cancer Research Fund Laboratories in London were surprised to find that they could transplant tumors from one animal to another with a high degree of success. Independent studies by Richard A. Adams and his colleagues at Boston University and by William H. Hildemann and Rupert E. Billingham, coauthor of the present article, confirmed that homograft rejection occurred far less frequently in the hamster than in other species. They found, in fact, that the majority of grafts exchanged among members of noninbred stocks were usually accepted for long periods, if not permanently, in perfectly healthy condition. It looked almost as though the hamster's immunological machinery for reacting against homografts was not fully developed. This possibility was set aside, however, by the observation that homografts exchanged between some donor-recipient combinations were rejected in a prompt and orthodox manner. The high degree of compatibility to homografts displayed by these animals was therefore to be regarded not only as a

CHEEK POUCHES of the hamster in this photograph have been stuffed with cotton wool to demonstrate their great storage capacity when fully distended. Normally the pouches are used to transport large quantities of food to the rodent's elaborate underground burrow. The hamster's parsimonious habits are the source of its common name: *hamstern* in German means "to store or to hoard."



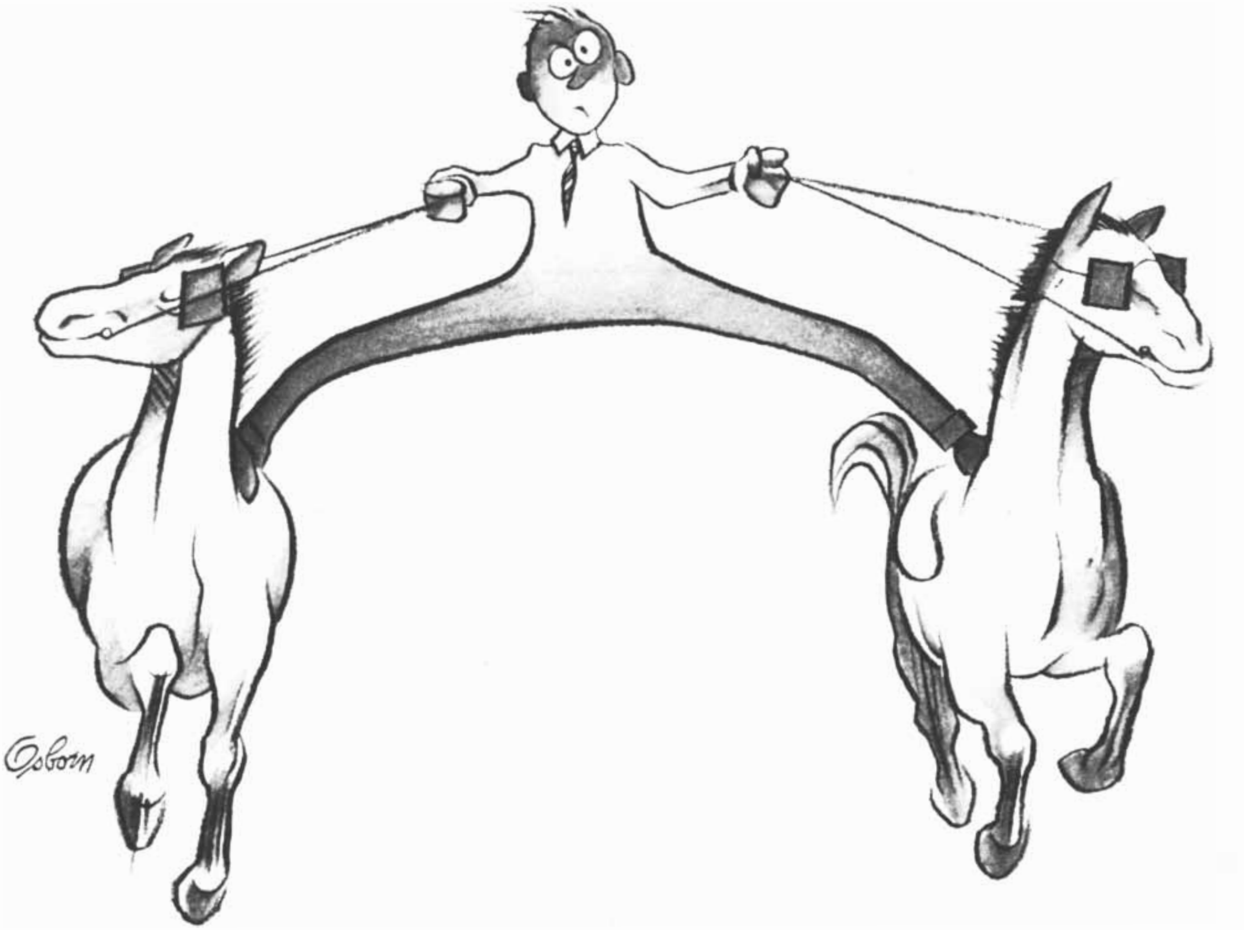
DIFFERENCE OF ONE GENE between an original (P_1) breeding pair will result in four possible genetic combinations in the chromosomes of the second-generation (F_2) hybrids. Of these, three will receive at least one specific antigen-producing gene from one of the P_1 grandparents and consequently will tolerate a skin graft taken from any member of the inbred strain to which that grandparent happened to belong. The fourth will reject such a graft, since the antigens received from it would be foreign to this hybrid's own genetically determined set. The same situation of course holds true for grafts taken from the other P_1 strain. Regardless of the number of genes by which any P_1 pair differs, all first-generation (F_1) offspring will accept a graft donated by a member of either P_1 strain.

convenience for the investigator but also as a question for investigation.

The most obvious hypothesis was that the genetic constitutions of the laboratory hamsters are differentiated at relatively few histocompatibility loci—these being locations on the chromosomes at which alternative histocompatibility genes may occur in different individuals. Work in our laboratory has recently confirmed this hypothesis. We have found, in fact, that the laboratory hamsters, at least, have only three such loci.

The making of such a determination for any laboratory animal begins with the crossing of two isogenic lines. The members of each such line have two identical sets of chromosomes (44 chromosomes in all), so that each histocompatibility gene is present in duplicate. When the lines are crossed, the first-generation hybrids (F_1) inherit one complete set of chromosomes, including all the histocompatibility genes, from each parent. Since these genes are codominant, the histocompatibilities of both lines are expressed in the make-up of the offspring. The F_1 hybrids will accordingly accept grafts from either parental strain. When the F_1 hybrids produce their sperm and egg cells, however, they likewise pass on only a single set of chromosomes (22 altogether). Each chromosome of this set will be an exact replica of each of the chromosomes present in one or the other of the original isogenic parental strains, but which chromosome will come from which strain is a matter of chance. The second-generation offspring (F_2) produced by the matings of the F_1 individuals are thus genetically heterogeneous, in particular bearing all possible combinations of the histocompatibility genes present in the two original parental strains. Some percentage of F_2 offspring will inherit all the histocompatibility genes of one or the other original strain. This percentage is predictable and depends on the number of histocompatibility genes by which the strains differ from each other. If they differ by only a single gene, as, for example, when one is AA and the other A′A′, then out of the four possible combinations into which the original pairs of genes can be reassorted, half will bear the codominant histocompatibility genes of both parental strains (AA′) and a quarter each will bear the gene of one or the other (AA or A′A′).

As a result 75 per cent of the F_2 generation will accept grafts from either strain—a different 75 per cent in each case. If two loci are involved, 56 per cent will show histocompatibility with one or the other strain. Provided that each gene is passed on independently and provided that the antigen determined by each is singly sufficient to elicit the immune reaction to the homograft in a host that lacks this gene, the percentage of F_2 individuals that will accept grafts from one or the other parental strain can be shown by the laws of probability to be equal to $(.75)^n$. The exponential n is simply the number of histocompatibility loci at which the parental strains differ. By challenging a fairly large number of F_2 animals with grafts from their parental strains and determining the percentage that accept them, the value of n can be calculated from the equation. Since $(.75)^2$ equals .56, for example, the finding that 56 per cent accept grafts from one or the other strain can be taken as an indication that two histocompatibility loci are involved. It is apparent that this procedure can only give some idea of the minimum number of histocompatibility loci present in a species. Experiments conducted with inbred strains of mice and rats have indi-

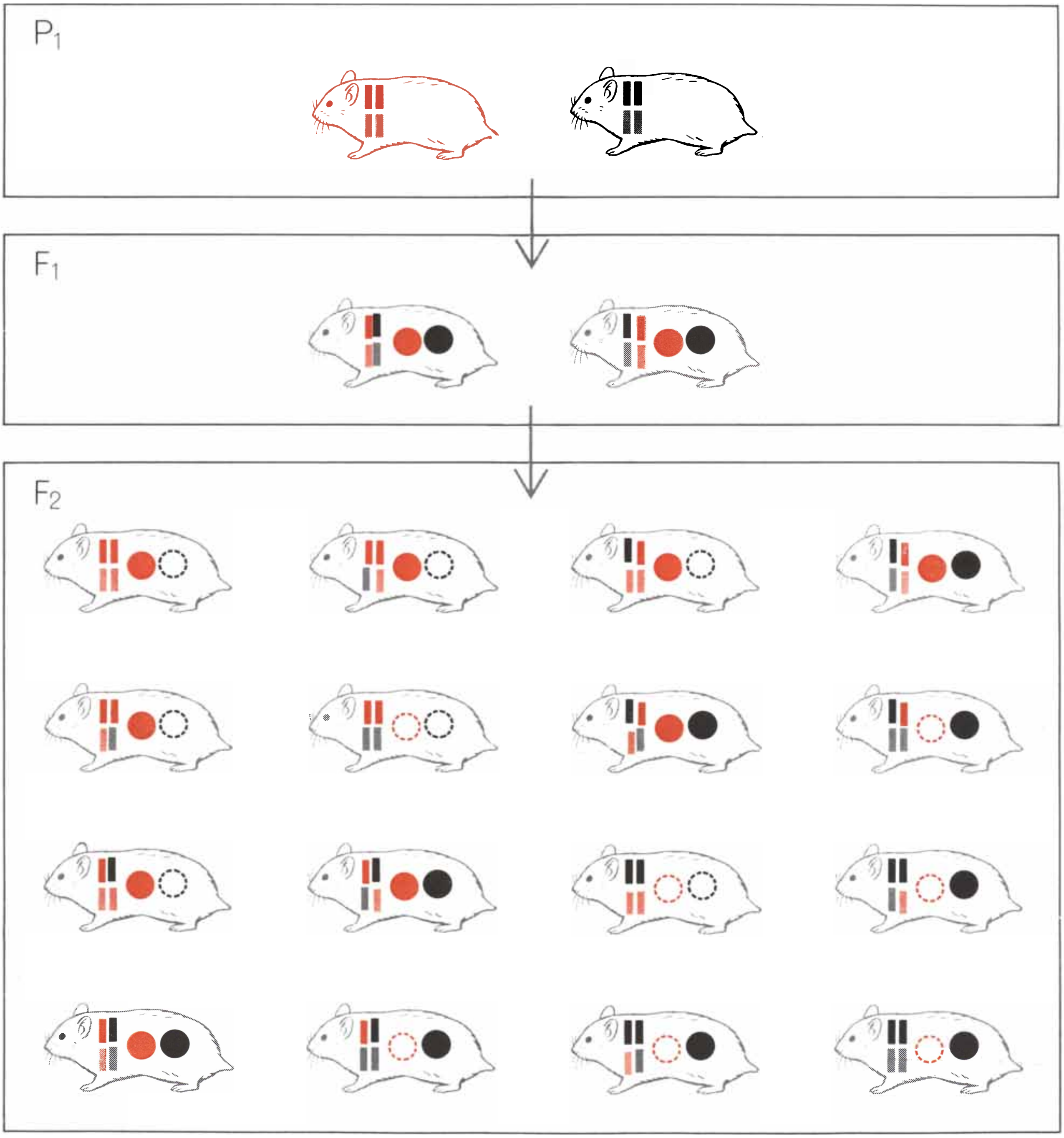


cated that these species have at least 15 such loci.

For our work with hamsters we inbred three strains, bringing each in a few generations to complete histocompatibility, as evidenced by the consistent, long-term acceptance of intrastrain homografts. What is more, the invariable rejection by each strain of grafts from the other two showed that these strains differed from one another with respect to their histocompatibility genes.

When we carried out grafting tests of F_2 hybrids in different combinations of these strains, the results indicated that tissue-graft incompatibility between the three strains depended on differences in genes present at no more than three loci. The alternative genes at only one of these loci appear to be of major importance in that they determine the production of antigens strong enough to cause the rejection of a graft within two weeks.

One obvious explanation for the paucity of histocompatibility genes in the hamster is that Aharoni's original breeding trinity was almost, if not completely, uniform at least with respect to their



DIFFERENCE OF TWO GENES between P_1 progenitors will result in 16 possible genetic combinations in the F_2 generation. In this case nine of the 16, or 56.2 per cent, will accept a graft from one of the P_1 strains. Four will accept a graft from either P_1 strain and two from neither. The F_1 generation will again accept either P_1 graft. By working backward from the observed percentage of successful P_1 to F_2 transplants, the authors have been able to determine a maximum possible histocompatibility gene difference between random combinations of P_1 hamsters equal to only three factors. By contrast, mice and rats differ by at least 15 factors.

complement of these genes. Even if this were the case, however, one might have expected that a number of histocompatibility mutations would have occurred during the domestic history of the species. An appreciable number of mutations affecting eye and coat color have been observed in laboratory colonies. Current experiments with hamsters of a different subspecies, *Mesocricetus auratus brandti*, captured for us in Kurdistan, suggest that a high degree of compatibility to homografts may be a characteristic of this subspecies as well as of *M. auratus auratus* and perhaps of other members of the Cricetidae family too. The paucity of histocompatibility genes in the domesticated Syrian hamsters would thus reflect the situation in wild populations. The only other mammal that is known to show a tolerance approaching that of the hamster is the Mongolian gerbil (*Meriones unguiculatus*), a rodent only recently recruited to the laboratory.

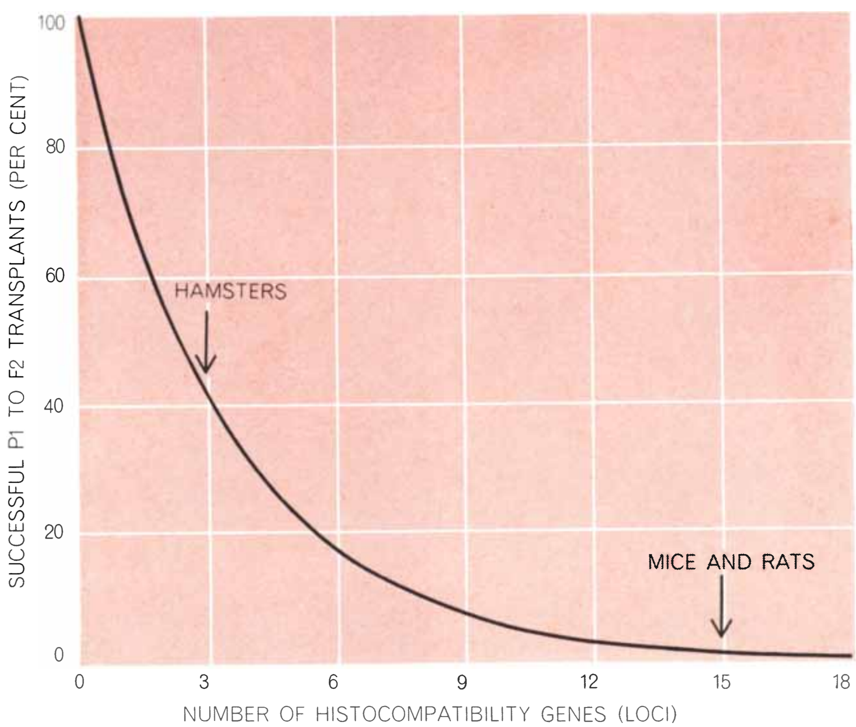
From early in the hamster's laboratory career investigators were attracted by the potential usefulness of its cheek pouches. These are tubular prolongations of the animal's cheek cavities that run backward beneath the skin of the shoulder regions. They are lined by a continuation of the mucous membrane of the mouth and have a rich blood supply. When empty, they are three to five centimeters long and a centimeter wide, but they can be distended by food to more than twice this size. Because of the loosely packed, highly elastic connective tissue that unites the wall of the pouch to the adjacent tissues of the cheek, one can easily evert the pouch by grasping its "blind" (inner) end with forceps. Stretched out on a block of glass and transilluminated, the relatively thin sheet of hairless skin provides an excellent preparation for studies of the blood circulation in its rich plexus of vessels. Indeed, it is almost as useful for such purposes as the web of the frog's foot, the wing of the bat or the tail of the tadpole. When released, the pouch returns to its normal position by muscular contraction.

Investigators soon found that the pouch tissue is a hospitable site for tissue grafts. Small pieces of tumor tissue from other hamsters rapidly acquire a blood supply and begin to grow upon insertion in a tiny incision in the pouch. Such grafts can readily be inspected *in situ* under the microscope, and specimens can be removed for study or transplantation to other hamsters. Even small numbers of dissociated tumor cells may give rise to a solid tumor mass upon simple injection into the pouch wall.

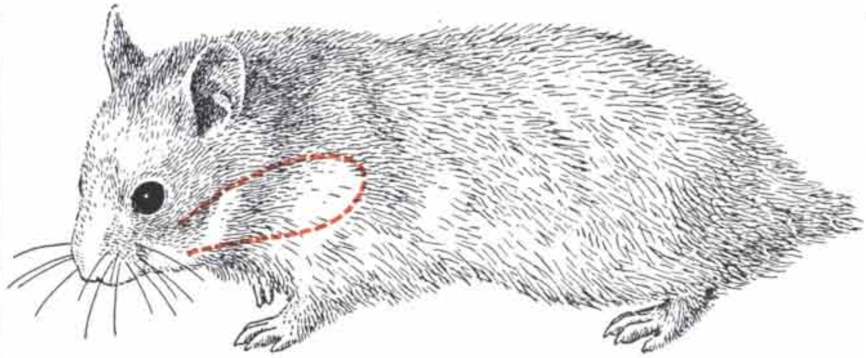
In the course of such experiments it was found that the pouch will invariably accept homografts without regard to the strain of the donor hamster and will not infrequently accept heterografts for experimentally useful periods of time. Since grafts of either type were rejected from other sites in the same animal or in others of its strain, some factor other than the hamster's paucity of histocompatibility genes was indicated. The cheek pouch was somehow immunologically privileged. It was clear that foreign-tissue grafts in this environment either were insulated from the consequences of the immunological response or failed to evoke a fully effective response. Examples of such immunological privilege are well known. Cartilage typifies privilege of the first sort; because it requires little by way of a blood supply and enters into minimal exchanges with the body of the host, a cartilage homograft is protected from whatever response it evokes in the host. The brain is an immunologically privileged site of the second kind. Grafts implanted in the cerebral cortex derive a rich blood supply from it but often fail to elicit an immune response. The reason for this, apparently, is that the brain has no lymphatic drainage system. In the absence of the pathway that carries the antigenic stimulus from other sites in the body to the lymph nodes—the seat of the immunological response—a graft in the brain does not excite the production of antibodies and immunologically activated lymphocytes.

Upon reflection we decided that the situation here might resemble that in the brain. We quickly found confirmation of this hypothesis. Homografts from an incompatible strain that had become well established in an animal's pouch could be destroyed by challenging the animal with a skin graft on the chest or simply with an injection of cells from the same strain. Furthermore, prior immunization of an animal by the same means would prevent a subsequent graft from becoming established in the cheek pouch. Once a state of immunity has been evoked, in other words, it can express itself just as effectively in the pouch as elsewhere in the body. The hospitality of the pouch to foreign tissue must therefore depend on some barrier that keeps the antigens liberated by a graft in the pouch from gaining access to the host's seat of immunological response.

In search of insight into the specific nature of the barrier, we now prepared

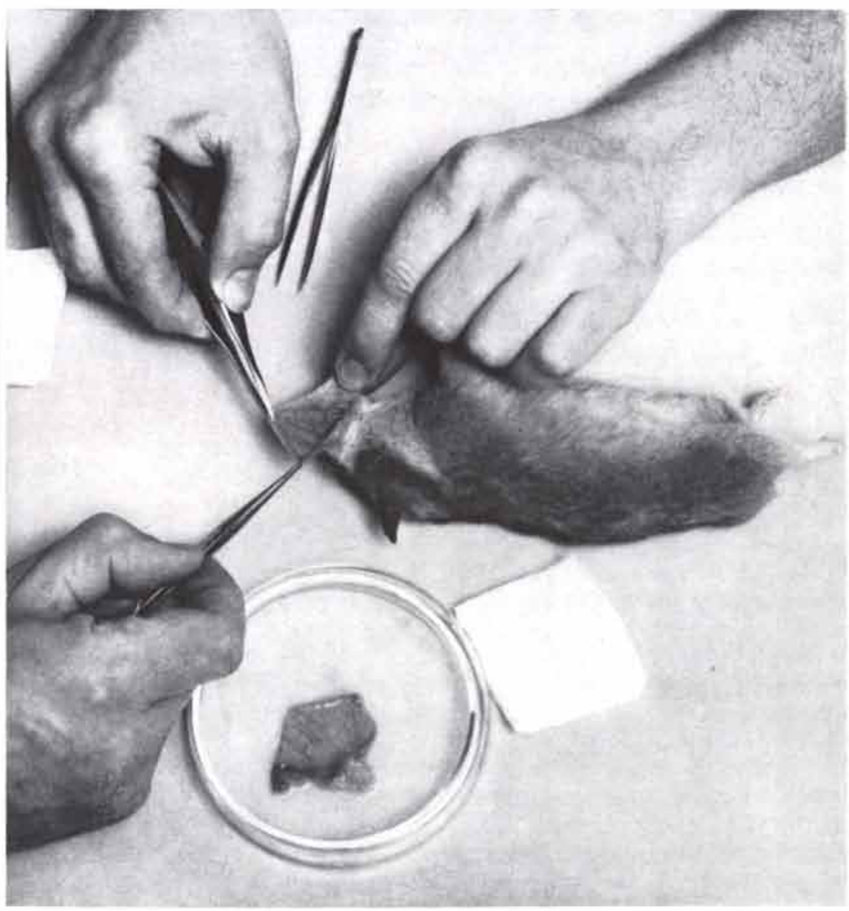


DISPARITY between the hamster's homograft compatibility and that of some closely related rodents is illustrated in this graph. At least 40 per cent of the hamsters tested accepted P_1 to F_2 transplants, whereas no more than 1 per cent of such grafts succeeded in the case of mice and rats. All higher mammals, including man, differ by more than 15 histocompatibility gene factors and accordingly accept fewer than 1 per cent of all P_1 to F_2 transplants.

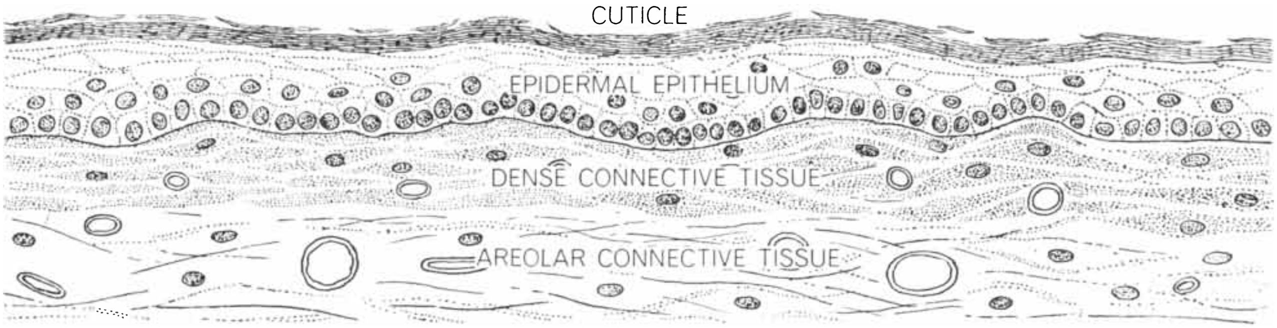


LOCATION OF EMPTY CHEEK POUCH is indicated in this drawing by the broken line. When full, as in the photograph on page 119, the volume of the pouch is more than doubled.

relatively large grafts of pouch "skin" and transplanted them to prepared sites on hamsters' chests. The grafts from donors to recipients of the same strain healed in rapidly, acquired a rich blood supply (indicated by their healthy pink color) and were permanently accepted, as one might anticipate. To our gratified surprise, pouch skin grafts between strains known to be incompatible for ordinary skin grafts healed in just as promptly. The majority outlived the ordinary grafts, some of them remaining alive and healthy for as long as 100 days after operation. As in the case of grafts to the pouch, these grafts could be destroyed by challenging the immunological mechanism of the host by "proxy": with a skin graft or an injection of cells from the donor strain. This was evidence again that the pouch skin barrier works in one direction only and by



CHEEK POUCHES ARE EVERTED by grasping their deep ends with a pair of forceps and withdrawing them through the hamster's mouth. In this position they are useful for studies of their rich blood circulation and also as convenient graft sites. Excised pouches, such as the one shown in the dish here, can also be test-grafted onto the bodies of other hamsters.



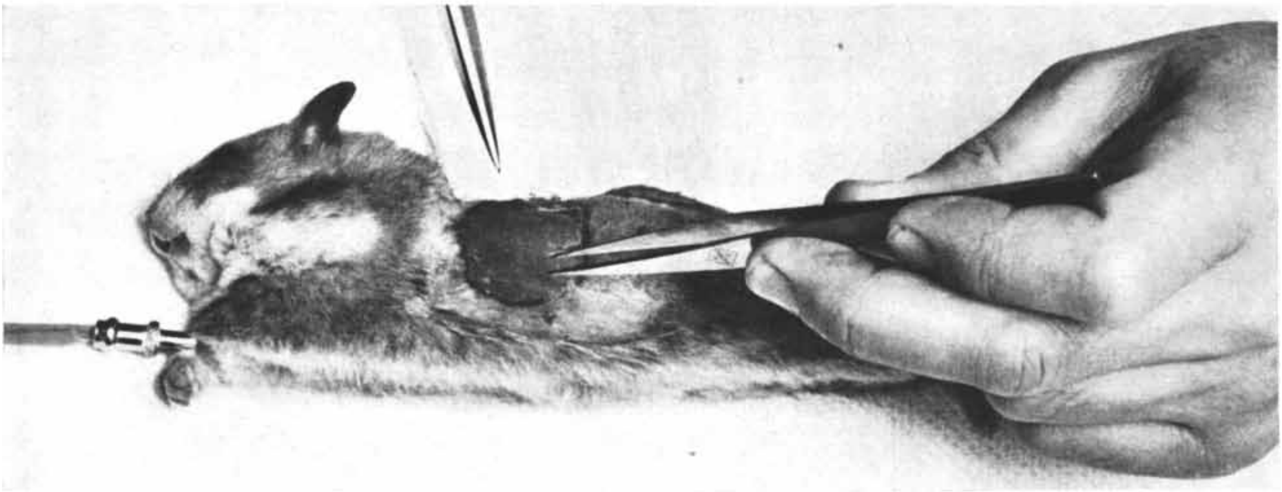
CROSS SECTION OF POUCH SKIN reveals its typical three-layer construction. Antigen-producing epithelial cells constitute the uppermost layer, which is covered by a very thin and compact cuticle. Underlying this is an intermediate layer of densely packed muscle fibers. Eversion of the pouch is made possible by the great elasticity of the loose areolar layer, which connects the pouch directly to the inside of the hamster's cheek. Antibodies and lymphocytes are able to circulate freely through the numerous blood vessels present in both connective-tissue layers, but lymphatic vessels, the ordinary avenues of antigenic dispersal, have not been detected in either.

some means blocks entry into the host's system against whatever antigens the pouch cells liberate, or against antigens liberated by grafts placed in the intact pouch wall.

Microscopic inspection of the structure of the pouch skin suggested a possible candidate for the barrier. Most of the living cells in the skin and so most of its biochemical activity are located in the epithelial, or outer, layer. It therefore occurred to us that the antigens liberated by these cells and, to a lesser extent, by the more sparsely distributed cells of the inner connective tissue layer might conceivably be prevented from reaching the host's body as a result of some sort of absorptive activity in the connective-tissue matrix. We explored this possibility in two series of experiments. From the centers of long-established isografts of pouch skin we excised the outer layer of epithelial cells, leaving intact almost the entire thickness of the pouch skin connective tissue. We then fitted small grafts of body skin from an incompatible strain into these prepared defects. The results were most encouraging. Instead of undergoing rejection within two weeks, as they would have done if placed in direct contact with host tissue, many of these "inlays" lived for a long time, regenerating crops of hair of normal density. Even heterografts of rabbit skin manifested some tendency to survive when grafted in this manner.

We then put the barrier hypothesis to a more direct test by stripping sheets of the rather slimy, elastic connective tissue from freshly excised pouches and spreading them over graft beds on the sides of hamsters' chests. On top of this layer of connective tissue we placed grafts of skin from an incompatible strain. The skin grafts soon acquired a normal blood supply without any apparent interference from the layer of connective tissue. The layer of connective tissue did, however, interfere with the capacity of the graft to elicit the immunological response of the host. This was evidenced in the prolonged survival of many of the grafts. Whether the cell population of the connective tissue was alive or not at the time of grafting did not appear to affect the outcome. Sheets of the tissue that had been repeatedly frozen and thawed under conditions known to be lethal for cells of hamster skin continued to demonstrate the barrier effect that protected the overlaid skin grafts. The barrier did not, of course, afford protection from the immune response of the host elicited by proxy.

The postulated one-way barrier is supported by still another series of experiments. We have attempted by various means (by the topical application of chemical irritants and by mechanical irritation) to stimulate the release of effective amounts of antigen from



POUCH SKIN GRAFT is shown being applied to a prepared site on the side of an anesthetized hamster. The unusually high degree of success attained with such grafts lends support to the authors' "barrier hypothesis," which was originally postulated to account for the behavior of the pouch as an immunologically privileged site for the transplantation thereto of many kinds of foreign tissue.

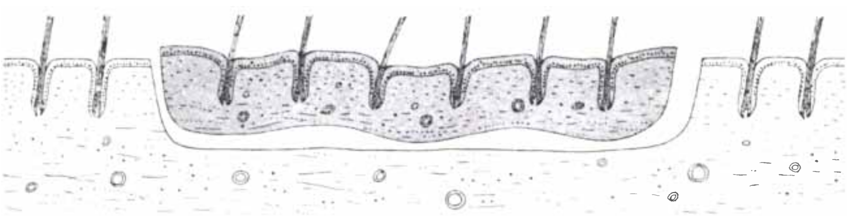
long-established pouch skin homografts. All of these efforts—including even superficial injection with hyaluronidase, an enzyme known to dissolve a component of the ground substance of connective tissue—have proved ineffective.

The evidence thus leads to the conclusion that the connective tissue of pouch skin presents a barrier to the escape of antigens from the graft into the body of the host. Whether this is due to some enzyme-mediated reaction, to absorption or simply to the failure of the host's lymphatic system to establish drainage vessels through the connective-tissue barrier are questions that remain to be investigated.

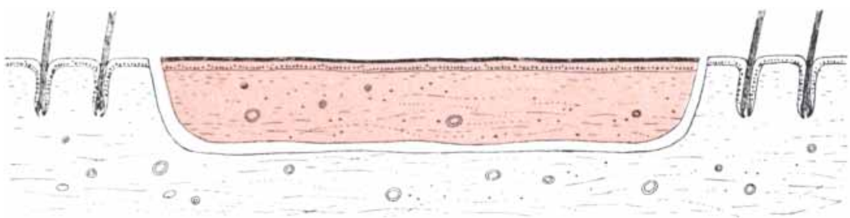
It is difficult to see what benefit hamsters can derive from the peculiar immunological properties of their cheek pouches. The barrier it presents to antigens may be merely a secondary consequence of the anatomical plan of these organs, which has been revealed by the unnatural act of grafting. The principles underlying the action of the barrier may nonetheless have general biological implications. May not such barriers play an important role in keeping individual organisms from reacting against certain substances in their own systems that are known to be potentially antigenic to the organism itself? Certain diseases of the thyroid gland, for example, appear to be the outcome of an immunological reaction against specific products of this organ that may have escaped as a result of the compromise or breaking of some sort of barrier. It is tempting to put another question: Is there any hope of finding a source of similar connective-tissue sheets in the human body or of being able to produce synthetically a material that has similar properties? Such a material, natural or synthetic, might facilitate the acceptance of human homografts in reparative surgery.

The hamster's contribution to a general understanding of the genetics and physiology of the immune reaction as it relates to the transplantation of tissues does not exhaust its interest for experimental biologists. Another curious faculty of the species may derive from an adaptation to its native habitat in Asia Minor. This is its high resistance to colchicine, a drug that inhibits cell division. The lethal dosage of colchicine is about one milligram per kilogram of body weight in rodents and eight milligrams per kilogram in man. But for the Syrian hamster it is nearly one gram per kilogram. This effect, first noted in 1952 by Margaret Ward Orsini and Ben Pansky at the University of Wisconsin, has recently been exploited by Alvin Midgeley, Barry Pierce and Frank J. Dixon at the University of Pittsburgh to investigate the arrest of cell division in human tumors planted in the cheek pouches of hamsters. It may be that the Syrian hamster acquired this tolerance because plants of the genus *Colchicum*, which are the source of the drug, have their center of distribution in Asia Minor and may form part of the hamster's diet.

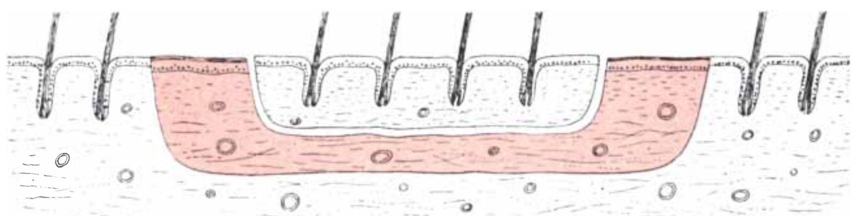
As hibernators, hamsters have also contributed to knowledge of the physiological mechanisms that enable some animals to withstand reduction of their body temperature to low levels. Finally, they have proved to be highly susceptible to the polyoma virus, a mammalian cancer virus, and to some adenoviruses, which cause respiratory disease in man. Altogether it appears that the position of the hamster in the laboratory is established, with tenure.



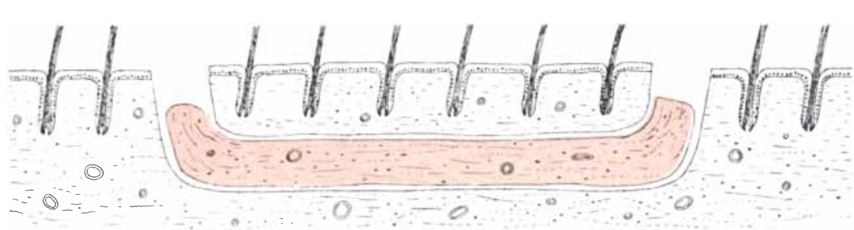
ORDINARY SKIN HOMOGRAFT, exchanged between two hamsters known to be incompatible, is promptly rejected. Antigenic stimulation of the host's immune mechanism results in the total destruction of the foreign tissue by an attack force of native lymphocytes.



POUCH SKIN HOMOGRAFT is accepted. Antigens emitted by the epithelial cells at the surface of the graft are prevented from entering the host's body by some sort of physiological barrier located near the upper face of the loose-fibered areolar connective-tissue layer.



SUPERIMPOSED SKIN HOMOGRAFT is isolated from the host by the long-established pouch skin graft underneath. Incompatible antigens from the inlaid skin cannot penetrate the pouch's protective barrier to provoke an immune response and both grafts are accepted.



SIMULTANEOUS APPLICATION of a skin homograft over a sheet of cheek-pouch connective tissue also results in the long-term survival of both. Any subsequent introduction of antigenic material by proxy into the host body will cause the rejection of all the above grafts.

WHY DO ROADS CORRUGATE?

Many explanations have been advanced for the "washboard" surfaces so often encountered on unpaved roads. Experiments show that these jarring ridges come from the rhythmical bouncing of vehicle wheels

by Keith B. Mather

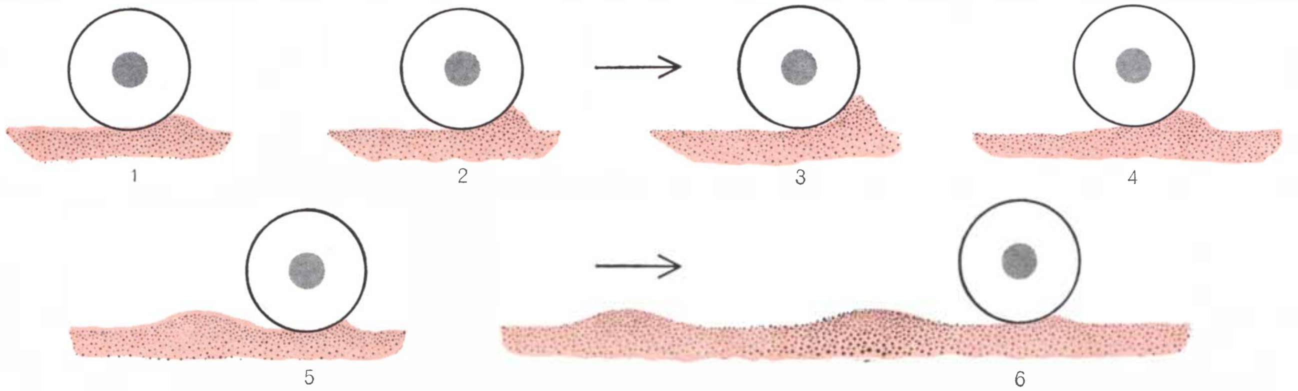
In the U.S. today the motorist can still find his way off the 2.5 million miles of paved highway onto the earth and gravel byways that total a million miles in length. On these roads, even in a well-sprung, shock-absorbered 1963 automobile, he will sooner or later experience shuddering vibrations generated by stretches of corrugated surface often called "washboard" or "corduroy." Over the smooth stretches his passage will, in dry weather, inevitably start the process that imposes on the surface a transverse pattern of parallel crests and valleys that may ripple along for a few yards or for miles on end. The problem of road corrugation has been solved in the sense that it can be cured by paving. It has also been solved in the sense that the corrugated surface can be shown to be the fully understandable result of the interaction of rolling wheels and unpaved roads. This still leaves the problem of road corrugation unsolved, however, in those regions where high cost and low traffic density keep roads unpaved. The problem may be a minor one for the U.S. motorist (and perhaps a welcome assurance of privacy in the outer reaches of suburbia), but it constitutes a major impediment to surface transportation elsewhere in the world, particularly in the developing countries where there are tens of thousands of miles of new earth-surfaced roads that are unlikely to be paved in the foreseeable future. So from a practical standpoint, as well as to satisfy scientific curiosity, the physical mechanism of road corrugation warrants investigation.

Our studies at the University of Melbourne have gathered a fair sampling of the folklore that surrounds the question. In the dry "outback" of Australia, where the roads for hundreds of miles are beautifully corrugated, the condition is attributed to the peculiar soil. In the course of inquiry I have found that the soil is equally "peculiar" in most parts of Australia and in New Zealand, India, Pakistan, Alaska, the Sahara and Nigeria. One local expert says there are too many coarse particles; another says there are too many "fines." Someone else blames the wind generated by the vehicles, another their exhausts and yet another their pneumatic tires. One whole school of theorists postulates "regular impulses delivered by a reciprocating engine." Among the marvels of contrivance is an explanation offered in a textbook on road engineering that was reprinted as late as 1952. When the front wheels strike a bump in the road, this author said, the rear axle is made to oscillate about the front axle, with the result that the rear wheels rise from the ground and fall back. The road surface therefore has to resist two reactions: the vertical one due to the weight of the vehicle and a tangential one due to the forward motion of the vehicle. The latter causes loose material to be thrown forward toward the crest of the bump that the front wheels have just passed.

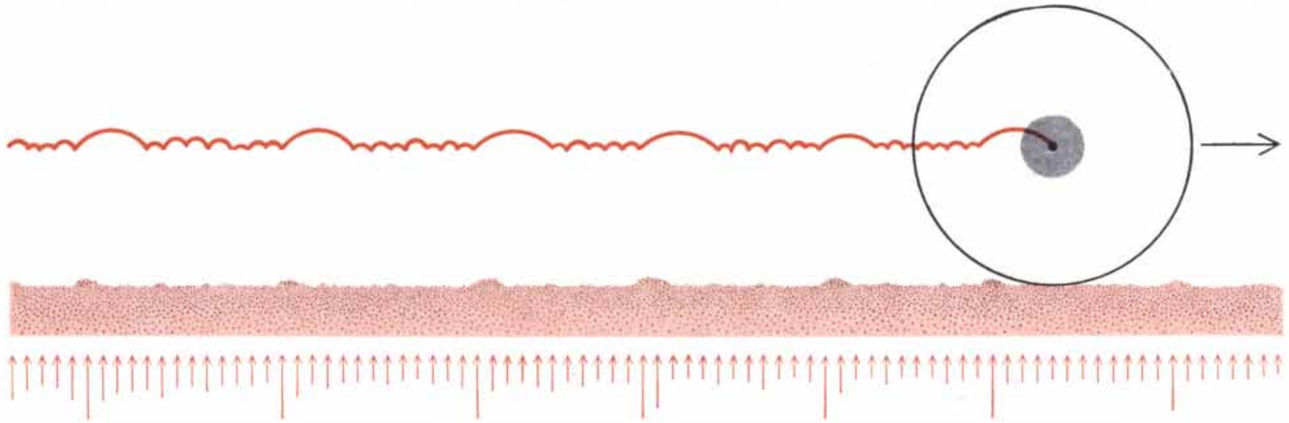
These diverse explanations are all cast in doubt by the observation that corrugations can afflict almost any surface subject to rolling or sliding motion. As municipal engineers well know, bitumen streets frequently develop washboard surfaces, but the amplitude of the waves from crest to trough is relatively small and rarely reaches the nuisance level. The corrugations are quite easy to see, particularly after a light rain, when water collects in the troughs, or at night, when car headlights throw them into relief as a series of shadows across the road. Concrete highways are more resistant, but even here one can find examples of periodicities, often following the gap between slabs.

Corrugations develop even in railroad and streetcar tracks. They also tend to follow a bump in the line, such as the junction between two rails; the "pitch" of the corrugations (the wavelength, or distance between crests) is never more than a few inches. In recognition of the peculiar sound produced when a train passes at high speed over a stretch of corrugated track, such tracks have been called "roaring rails." Corrugations can also be found on weavers' shuttles, on the races of ball and roller bearings and on ski trails, and they could probably be detected in a multitude of other places if one were to take the trouble to look. Street-railway engineers find corrugations overhead as well as on the tracks; that is, on the overhead copper conductor, where the ripples appear following a junction or kink in the line. As will be seen, the crests and troughs in these corrugations curiously represent opposite phases of the process that produces the corrugations in the track.

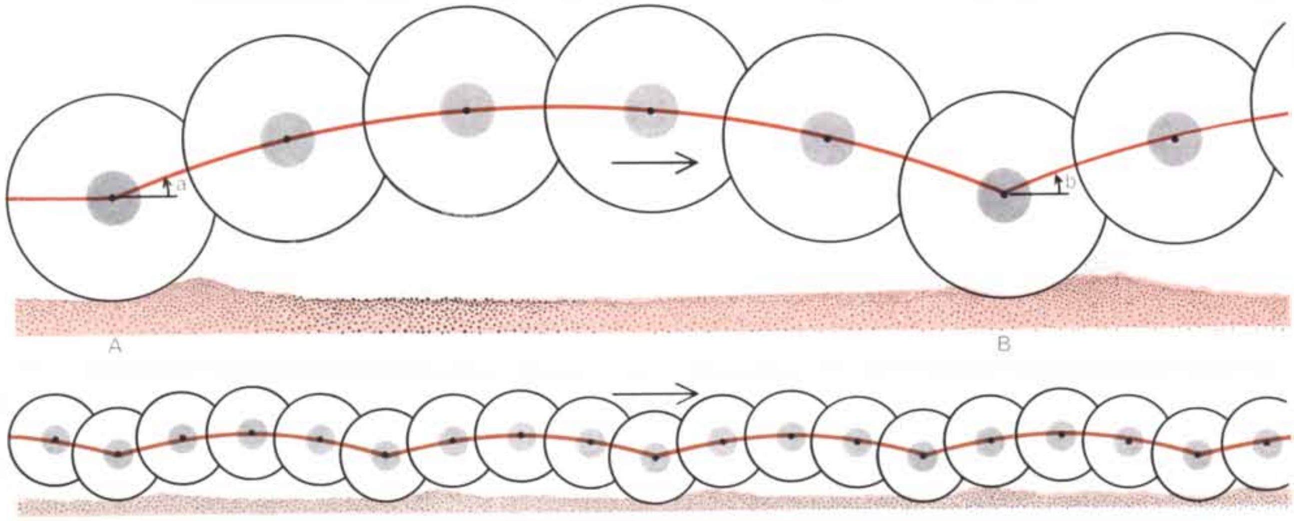
It was Frederick E. Relton, then at the Egyptian University in Cairo, who in 1938 first pointed out that corrugation is not a disease of earth roads alone and undertook to embrace the various manifestations of the process in a single generalization. Relton set speculation and research on a new course by introducing the attractive notion of "relaxation oscillation." This is to be distinguished from the simple harmonic oscillation observed in the free swinging of a pendulum or the ringing of a plucked string. Relaxation oscillation is exemplified, on the other hand, in the singing of a bowed string. The stick-and-slip friction of the bow alternately catches and releases the string; energy is stored in the string in the momentary "stick" phase of the cycle



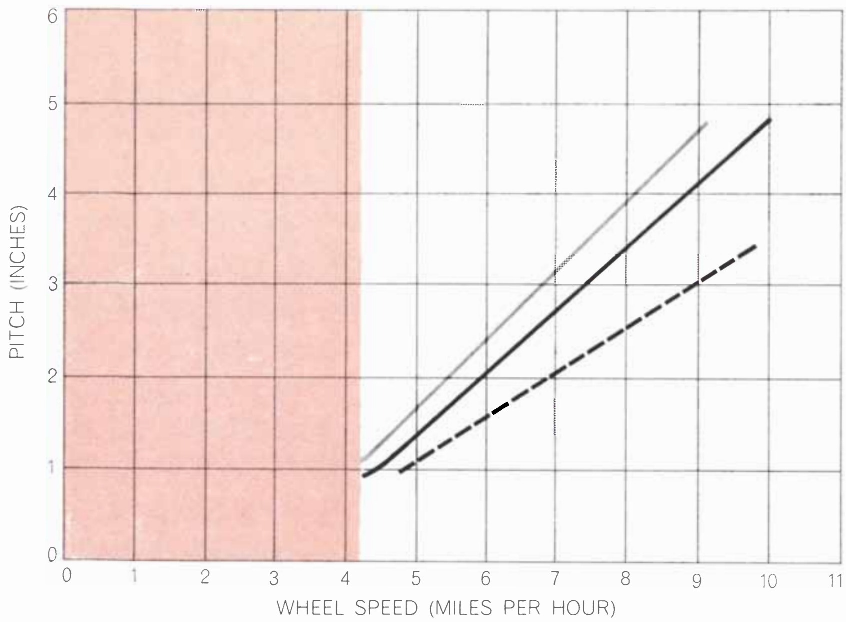
"RELAXATION OSCILLATION" theory was the first attempt to explain the periodicity of the ridges in a corrugated road. A moving wheel is said to push ahead of itself a growing heap of surface material (*1–3*). As the resistance of the heap builds up (*4*), the wheel rides over it, leaving a ridge (*5*). In this way a succession of equidistant ridges might be left along the road (*6*).



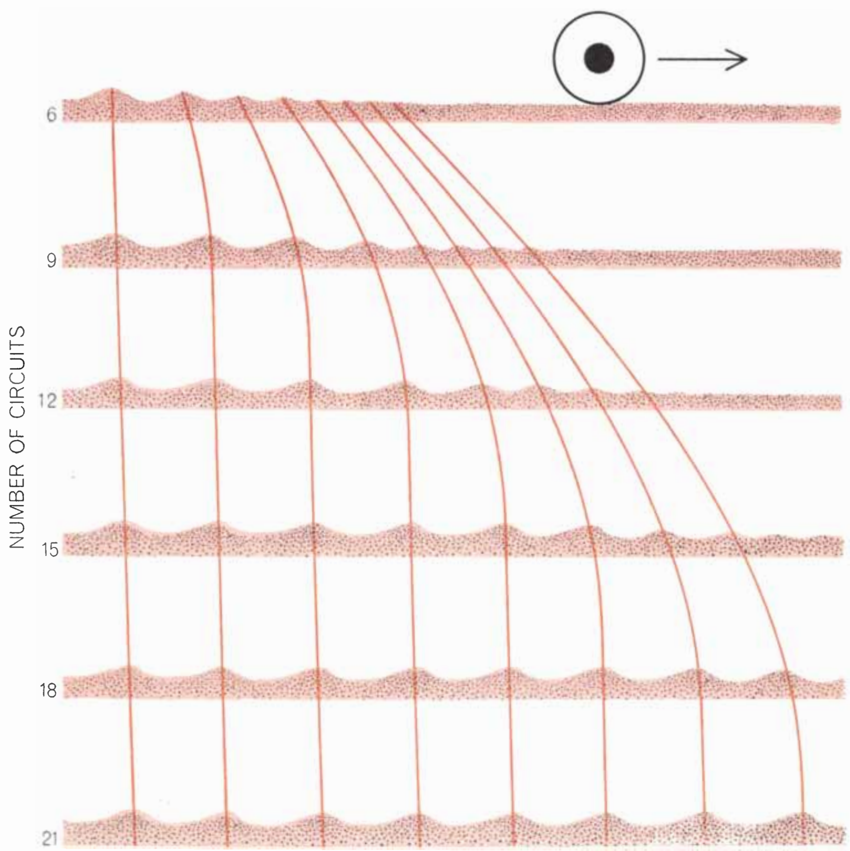
PRESENT THEORY of corrugations is based on the bouncing motion imparted to a wheel by random surface irregularities. Each impulse (*vertical arrows*) makes the wheel hop, as indicated by the colored line traced by the hub. It is the impact stress on the road at the end of a bounce, and not a piling up of loose material ahead of the wheel, that begins the corrugation process.



PROCESS BEGINS when a wheel encounters an obstacle (*A in top diagram*) and is projected upward along a certain angle (*a*). Striking the surface again at *B*, the wheel digs itself into a crater. It rides out of the crater, over the lip of surface material it has sprayed forward, at the same angle as before (*b*) and is again projected, repeating the process. Successive passes by similar vehicles develop a full set of corrugations (*bottom diagram*). The vertical scale is exaggerated in all the drawings on this page.



CORRUGATIONS are not generated until a critical speed is reached, about four miles an hour in the experiments. Thereafter the pitch, or distance between crests, increases with speed. The solid black curve is for the author's basic test situation with a hard rubber tire. Increasing the sprung weight and stiffening the spring shortened the pitch (*broken curve*); transferring the extra weight to the wheel lengthened the pitch (*gray curve*).



SET OF CORRUGATIONS develops from one major irregularity (*top left*). The crests increase rapidly in pitch and amplitude as the test wheel completes more circuits. After the pitch and amplitude become stable the crests migrate slowly in the direction of wheel travel.

and is dissipated in the "slip" phase. This system is correctly described as an oscillating one because of its repetitive nature and definite periodicity. It typifies a whole class of oscillating systems that are encountered in fields as diverse as mechanical engineering, electronics, astrophysics and physiology. The "sweep" circuit of a cathode ray oscilloscope or television picture tube is one example; a condenser charges gradually to a certain voltage and discharges, then charges again, discharges and so on. The "chattering" of a tool set improperly in the lathe, the periodic cycles of brain waves and the aeolian tones of wind blowing through crevices or over tautly strung wires—all embody the underlying idea of relaxation oscillation.

Relton pictured the system of the wheel and the road as belonging to the stick-and-slip class of these phenomena. The wheel, as he saw it, exerts a force parallel to the surface of the road. In the stick phase of the cycle it tends to remove material from the surface, even as it rolls, and to push the material ahead of it in a heap. The driven heap presents increasing resistance to the wheel and the wheel rolls over it (the slip phase of the cycle), thereby starting the process anew. The result is the series of corrugations [*see top illustration on preceding page*].

Relton's theory was attractive because it appeared to be applicable to any kind of surface and therefore unified a great many hitherto independent and disparate observations. It seemed to explain not only why corrugations appear in some surfaces but also why they do not appear in others. This would depend on the resistance of a given surface material to plastic deformation. Relton considerately spared his readers "the horrors of a mathematical demonstration" and did not attempt to state his theory in quantitative form. Nor did he carry out any experiments to verify his picture of the process.

Such was the state of the question when we undertook our studies in Melbourne. Initially we confined our observations to the roads themselves. The outstanding feature that first impressed itself on us was the regular spacing, or pitch, of the corrugations; this endows a stretch of corrugated road with an unmistakable pattern, quite distinct from the irregular damage of ruts and potholes. Generally the pitch is between 24 and 36 inches and sometimes as short as 12 inches. French engineers have reported an average of 39 inches in North

African desert roads. In Australia we found an average pitch of 29 inches, but we noted one other significant fact as well. The pitch is shorter on roads where traffic moves more slowly. This was our first clue to the importance of speed in forming corrugations.

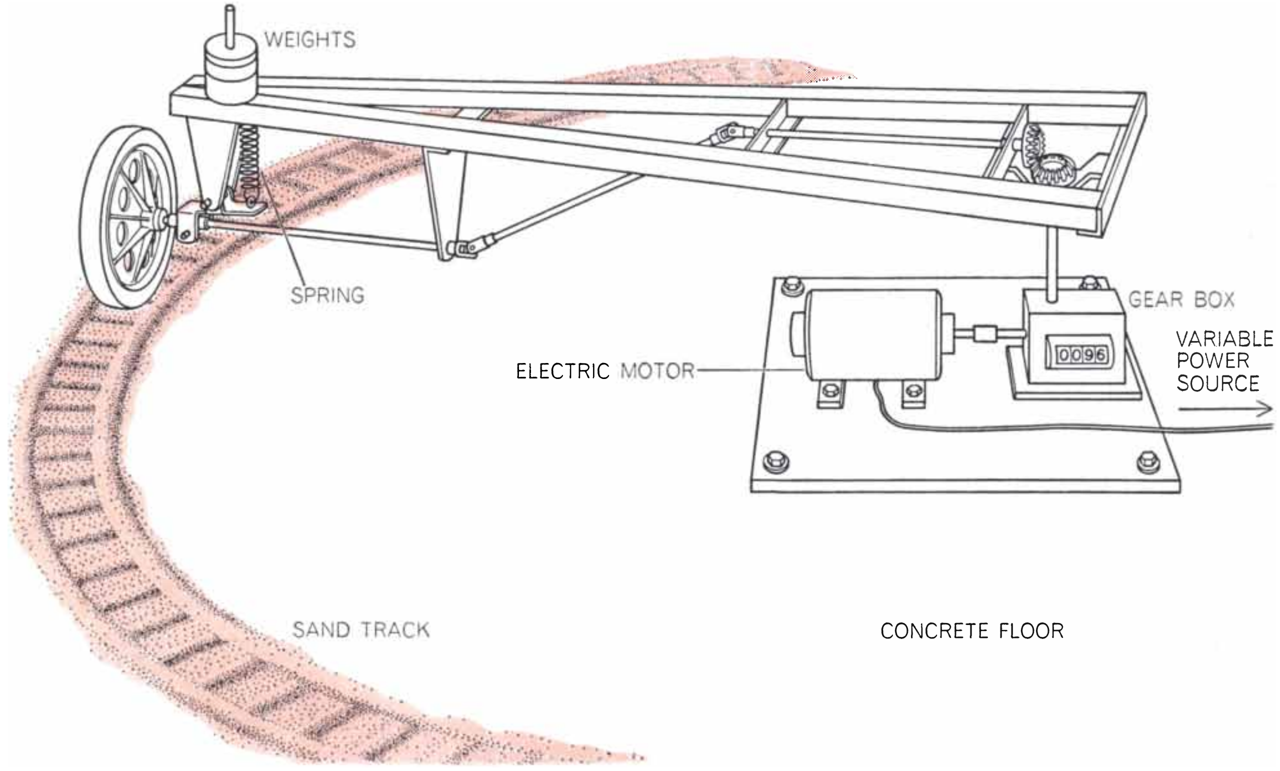
In order to become subject to corrugation, earth roads must be exposed to drying weather; the surface material has to dry out and lose its cohesion. Corrugated roads are most abundant in arid and semiarid areas. Roads develop corrugations in other regions during the dry season and dry spells. Last spring around Fairbanks, Alaska, I saw roads already becoming corrugated only a few weeks after the snow had melted off. The corrugations always develop first in the loose, friable surface material. In dry climates even a well-developed corrugation remains a soft, sandy mass that can be kicked away easily with the foot. Where rain falls more often these corrugations become consolidated into hard ridges.

On our Australian roads we could observe at will the development of corrugations in an initially smooth surface. The limited quantity of loose material available at the outset tends to collect into three strips running parallel to the road. As vehicles travel in both directions, the offside wheels pick up sand grains and throw them forward and toward the center, building up a broad strip down the middle. The curbside wheels similarly cast the grains toward the sides, forming the two narrower strips, one down each side of the road. It is in these strips, where there is a surplus of loose material, that corrugations first develop. Ultimately, as enough material becomes available from the wear and tear of traffic, the strips link up to give rise to ridges extending right across the road.

After watching this happen a sufficient number of times it occurred to us that we never saw the reverse process take place. In other words, starting with a road surface of a given degree of roughness, the rolling wheels of traffic did not make it smoother by wiping off the high spots and filling in the low. On the contrary, every time we watched we saw a smooth, freshly graded road transformed into a washboard. The conclusion was plain: smooth roads are unstable under the action of wheels; the stable surface is the corrugated one.

Having learned this much from inspection of the dusty Australian roads, we began to understand what we were seeing as we watched the cars and trucks speed over them. Most instructive was the rapid bouncing of the wheels and the way this raised the dust. Even on uncorrugated roads the dust comes off in little spurts—not uniformly, as one would expect. Each wheel is subjected to a random succession of small impacts, which are due to stones and pebbles of diverse sizes. The resulting semiregular oscillations raise the dust more at some points than at others.

We were now ready to observe the interaction of wheel and road surface at closer range under controlled conditions in the laboratory. Our first experimental "vehicle" consisted of a five-inch wheel mounted on a shaft, the other end of which was pivoted at the center of a circular track 24 inches in diameter. The foundation was a concrete slab with a layer of sand spread over it in the expectation that sand would corrugate quickly, if at all. We moved the wheel around the track by putting a finger behind the shaft and pushing it around the pivot to the beat of the family metronome. Greatly to my surprise this produced fairly regular little corrugations several inches apart in the sand. In the course of an hour's work we learned



EXPERIMENTS were conducted with the equipment shown here. The test track was 64 inches in diameter and the motor drove the wheel at up to 10 miles per hour. The amplitude of corrugations was measured with a micrometer screw mounted vertically in a tripod.

MODERATE CORRUGATIONS are seen in this photograph made in the Australian state of Victoria. The ridges are typical of those formed on graded dirt roads in dry weather.

DEEP CORRUGATIONS were formed in this sandy road in the dry uplands of Australia's Northern Territory. They are most pronounced in the unpacked sand between the major ruts.

enough about corrugations to form strong suspicions concerning the relaxation-oscillation theory in the form proposed by Relton.

In the first place, when the wheel was moved slowly and steadily around the track, it certainly caused plenty of deformation of the surface (in fact, it produced a deep rut), but it gave no sign of pushing a heap ahead of it, let alone riding over the heap and starting another. It was obvious that the wheel was cleaving some of the sand aside to form the longitudinal "lips" of a rut and consolidating the remainder underfoot until there was a firm enough bed so that nothing much more happened. In the second place, when we pushed the wheel around the track considerably faster, corrugations started to appear and then grew rapidly. This squared with our observations on earth roads: that speed is a major factor in building up corrugations.

With this encouragement we built a somewhat more elaborate system, equipped with a spring-mounted wheel, a variable-speed electric motor, a revolution counter and provision for changing all the important constants of the system. The stiffness of the spring, the mass of the rotating arm, the mass and size of the wheel and the stiffness of the tire were made independently adjustable so that their effects could be investigated one at a time. The diameter of the track was 64 inches, and steady speeds could be maintained from just above zero to about 10 miles per hour. Again we employed a fine sifted sand for most of the experiments, but occasionally we substituted gravel, sand with a wide range of particle sizes and even rice grains, sugar and split peas! All of these materials corrugated provided that they were dry and did not cohere.

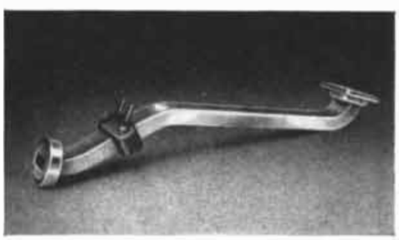
Perhaps the most valuable finding to issue from 100 experiments with this setup and a total of about 60,000 revolutions of the wheel is that corrugations can be generated readily. Corrugations could always be produced in dry sand; with hard tires and rigid wheels they developed quickly, but with soft tires they were faint and often hard to see. If the surface of the sand was dampened, the resistance to corrugations increased greatly, in accord with the general observation that road corrugations are "dry weather" effects.

One point that has long confused the literature was disposed of promptly. Whether the wheel was driven by its shaft or we unlocked the wheel and pushed the shaft by hand, corrugations

SILICOLOGY

To Protect Metals From Corrosion, Read These Test Results On A New Silicone

A new silicone metal protectant, UCAR 101, is the answer to many problems in corrosion—and in protectants, too. Its adhesion to metals is unusually tenacious. It is effective on all metals in the electromotive series from magnesium to gold. It is easily applied and forms a thin, colorless film—as thin as 1/10,000 of an inch—so that the ratio of coverage to volume is exceptionally high.



Prior to use of UCAR 101, build-up of corrosion products altered critical surface dimensions of microwave guides. Engineers can now apply the super-thin silicone and prevent corrosion without changing performance of waveguides.

Most important of all, UCAR 101 is free of pinholes and truly non-porous—superior to plated coatings in resisting penetration by corrosive moisture and oxygen. It even surpasses the oxide films formed on such metals as aluminum and stainless steel.

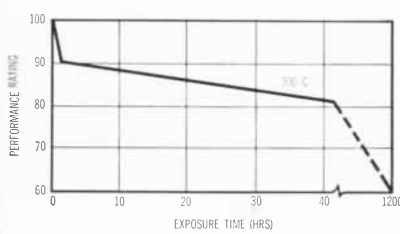
Tests of this protectant in Union Carbide laboratories have produced some interesting results. Unusual flexibility, for example, was demonstrated when a treated steel test sample was bent 180° around a 1/8″ mandrel without film damage.

Similarly, 14-gauge copper wire covered by this silicone film was stretched more than 30%, and in other tests was wrapped around itself. There was no damage to the finish.

In an impact test, UCAR 101 on steel survived a 60-in. lb. drop test. Steel samples have been cut without fracturing the film edges or causing peel-back. Treated samples have been buried in the ground for six months with no sign of failure. And in cycled alkaline solution, UCAR 101 has already outlasted other organic coatings 20 times. Its arc resistance is 80 seconds in ASTM Test D-495-48T.

UCAR 101 can be applied over such finishes as anodized aluminum and other surface passivating effects, or can replace them in many instances. Applied to decorative metal objects that require partial tarnishing for an antique effect, or to accent design details, it will arrest tarnishing at the desired stage.

It has preserved the new appearance of expensive silver-plated rectifier tubes throughout six months of exposure. Moreover, when used on machine parts, it is so thin that it will not interfere with tolerances, eliminating elaborate removal operations.



For high-temperature service, UCAR 104 performs as shown here. Rating of 100 is excellent, 50 fair, and 0 failure.

Service temperatures for UCAR 101 average 200° C., sufficient for most general purpose applications. For higher temperatures, another formulation, UCAR 104, provides a range around 300° C., as shown on the accompanying graph.

The International Copper Research Association has announced its development of an optimum metal protectant system for copper and copper products, based on 'Union Carbide' Silicones. It is the result of three years' testing of more than 100 different organic coating systems.

The INCRA report recommends that surfaces exposed to heavy traffic and extremely severe environments be given two coats of silicone finish. Total silicone film thickness would thus be 0.3 mils at most. The silicone is covered by an organic topcoat which protects the silicone from severe abrasion, while the silicone maintains the natural color and beauty of the metal.

However, two coats of silicone finish alone will suffice for moderate service conditions, according to the INCRA. The customary surface preparation by cleaning, buffing, and abrading is required.

As the leading innovator in silicones technology, Union Carbide is constantly developing such new products as this metal protectant. Information on silicones generally, or UCAR 101 in particular, is available through your Silicones Man. Contact him now.

UNION CARBIDE

SILICONES

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Silicones Division,
Union Carbide Corporation
Dept. A 84-1202, 30-20 Thomson Avenue
Long Island City 1, N. Y.

In Canada: Union Carbide Canada, Ltd. Bakelite Division, Toronto 12.

Please send me data on UCAR Metal Protectants

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SHALLOW CORRUGATIONS can develop in bitumen or even concrete surfaces. These depressions, accentuated by puddles of rain water, were photographed on a street in Montreal.

resulted. It does not matter, therefore, whether the wheel is driving or idling.

Speed proved to be the really vital factor. There is a critical speed (about four miles per hour in our experiments with the model track) that must be reached before corrugations will start, no matter how long the wheel runs. Above the critical speed the corrugation pitch increases in proportion to speed [*see top illustration on page 130*]. The actual pitch depends, of course, on the experimental conditions (the characteristics of the surface material and the vehicle), but in our experiments with sand it ranged from one to five inches. The rate at which corrugations developed also increased greatly when the wheel was rolled above the critical speed. At seven miles per hour they would become visible by the time the wheel had made five circuits of the track.

Corrugations always tended to form first at irregularities on the track. We usually followed the practice of leaving part of the concrete base bare so that at one point along the track the wheel had to run up a gentle slope onto the sand layer, about half an inch thick. At low speeds the pattern invariably began there, then propagated steadily around the rest of the track. Similarly, any obstacle deliberately introduced would start its own sequence of corrugations. At higher speeds, however, the corrugations propagated so quickly that it was difficult to see where they started. We concluded that they started at many points, as they do on an actual road. The track could never be made perfectly smooth, and any slight irregularity becomes a potential source of corrugations as the speed rises.

Without exception the corrugations would have a short pitch when they first appeared. The pitch would then grow in length as the corrugations developed in amplitude. Finally, the pitch and amplitude would reach stable values corresponding to the speed of the wheel. In the course of our experiments we also observed that the entire pattern of corrugations moves along the track in the direction of motion of the wheel. This was interesting because engineers have reported such movement, but in the opposite direction, on roads. Here

we could see each crest getting an impulse forward as the wheel struck it.

From these observations of the system as a whole and by watching the motion of the wheel from moment to moment we could now explain the origin of the corrugations. When the wheel reaches the critical speed, it begins to move in short hops, bouncing on the random irregularities of the surface. The wheel is projected into the air at a definite angle and strikes the surface again at a definite point farther along the track [*see bottom illustration on page 129*]. Where the wheel strikes after each "flight" it sprays sand forward along the track or sideways off the track. Hence it tends to form craters, which become the valleys of the corrugation pattern. Each time it digs itself in at a crater it has to ride out again. In the course of doing so it is again projected into the air. Thus the pattern tends to repeat.

In the broadest sense this picture still involves the relaxation-oscillation concept first introduced into the corrugation problem by Relton. The corrugations, however, arise in quite a different way. The key to the transformation of an initially flat surface into a washboard lies in the high stresses developed by the impact of a bouncing wheel rather than any tendency to "push a heap of material." This, of course, will apply not only to sandy surfaces but also to metal, bitumen or any other surface. The impact stress must simply be sufficient to cause permanent deformation. Whether it is sand that erodes at the point of impact or steel that flows plastically is irrelevant. Harder tires and higher speed each mean more severe impact stresses, and a less resistant surface raises the likelihood of deformation.

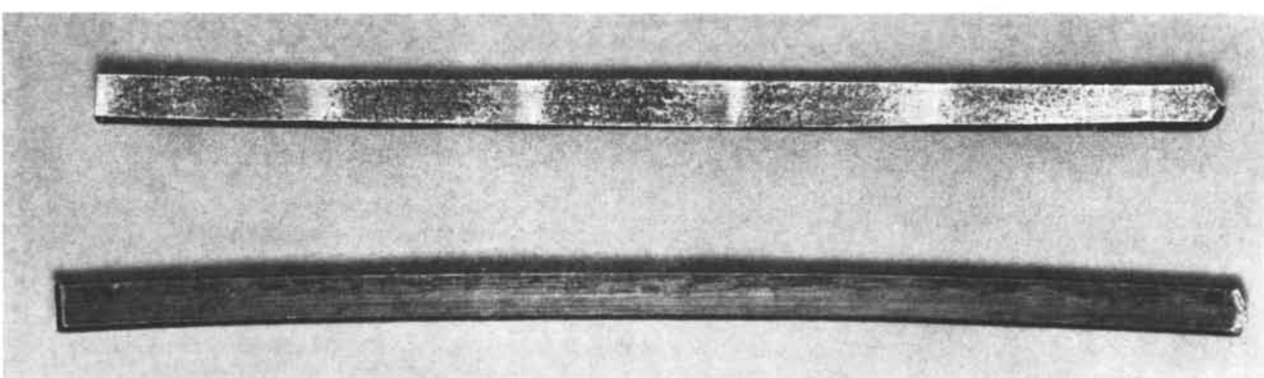
At this stage it becomes possible to state what determines the pitch of corrugations. The nature of the surface material and the mechanical properties of the vehicle are jointly responsible. For a given wheel loading and speed, the angle at which a wheel rides out of the crater formed by its impact is determined by the properties of the surface material. Experiment shows this to be characteristic for each material. With the angle thus determined, the vertical component of velocity imparted to the wheel is also determined. Where the wheel will strike the ground again depends in turn on the masses of the wheel and the vehicle. In the case of a wheel with springing, the answer also involves the stiffness of the spring, and in the case of a soft-tired wheel one must take account of the tire stiffness too. All of these factors are susceptible to mathematical treatment, and our calculations are well supported by the results of our experiments on the test track.

Actual motor vehicles are, of course, more complex. One can make a reasonable prediction, however, of the rate at which the wheel of a particular car will bounce at a given speed, and the results show good agreement with the observed pitch of corrugations on earth roads. Some critics have argued in the past that wheel bounce cannot be important on roads because of the great variety of vehicular types and speeds. The fact is that the superficial variety of vehicles conceals a considerable similarity in their "vibration properties," and the speeds of vehicles on the open road tend to bunch fairly tightly about an average value.

It might still seem that the bouncing wheels even of identical vehicles should make their impacts at random points along the road. Why then should their effects be cumulative? The answer is simple: A bounce has to be triggered by something. A bump on the road that causes the wheels of one vehicle to bounce will assuredly cause the wheels of other vehicles to bounce also. The impact point following a bump will be pretty much the same for most vehicles, the angle at which their wheels ride out of the following hollow will be much the same, so their next impact point will be much the same, and so on. The argument is identical for steel rails. The quantities are different, of course, and the corrugation pitch turns out to be an order of magnitude smaller. (In the case of the overhead copper conductor of a street-railway line, the argument is still the same, but the crests represent the points of impact between the trolley, or pantograph, and the conductor, and the troughs represent the points where the bouncing of the trolley broke contact and struck an arc that melted and vaporized some of the conductor away.)

Naturally one would like to conclude such a discussion by saying how the corrugations of earth roads could be prevented. It is disappointing to have to admit that we do not know. The brute-force method would be to make a surface tough enough to resist impact stresses without permanent deformation, but engineers knew how to do this before anyone looked seriously into the question of what causes roads to corrugate. An alternative might be to use very-low-pressure tires to reduce impact stresses, but automobile designers are not enthusiastic and passengers get seasick at the mere thought. Perhaps we should build vehicles that walk instead of roll.

Nevertheless, there is satisfaction in exploring the causes of things, and one never can tell who else may turn the work to practical advantage. There was one other satisfaction in this age of high-priced science: the total cost of our equipment was $25.



COPPER CONDUCTORS that power street-railway lines can corrugate in the same way as roads, but the effect is reversed: in the corrugated segment (*top*) the smooth crests are the points of contact between trolley and conductor; the pitted areas show where the trolley bounced away from the conductor, striking an arc. An uncorrugated section is shown at the bottom for comparison.

The Science of Dynamic Crisis-Solving

The science of crisis-solving on a dynamic basis is perhaps the only thing more complex than the crises themselves. At a time when cold war politics and the destructive potential of weapons can turn a trouble spot into a global threat overnight, the decisions affecting our national purpose must stand on the strongest possible foundation. Yet these decisions must be reached resolutely and promptly.

More and more, important national decisions are preceded by intensive scientific research, quantitative where possible. The Research Analysis Corporation, for instance, applies the techniques of operations research and systems analysis to a broad diversity of major problem areas—military, political, economic, social. RAC's output is intellectual . . . the finding or recommendation or suggested solution which evolves from scientific scrutiny of alternatives and possible operational improvements, and from analyses of the potential risks and rewards of existing and hypothetical policies.

RAC is nonprofit and multidisciplinary. The professional staff comprises 32 distinct disciplines and technical specialties, and our expanding responsibilities have created singular new career opportunities for imaginative scientists and engineers. If you hold an advanced degree in mathematics, statistics, a physical science, economics, or engineering, we invite you to consider the continuing challenge of a RAC career. This is exciting, vital work, impelling you to function at the limits of your capabilities and carrying the probability of rapid personal and professional advancement. The compensation is fully commensurate with the importance of your assignments. Please send your resume to Mr. John G. Burke, Professional Staffing, Research Analysis Corporation, 6935 Arlington Road, Bethesda 14, Maryland. (Residential suburb of Washington, D. C.)
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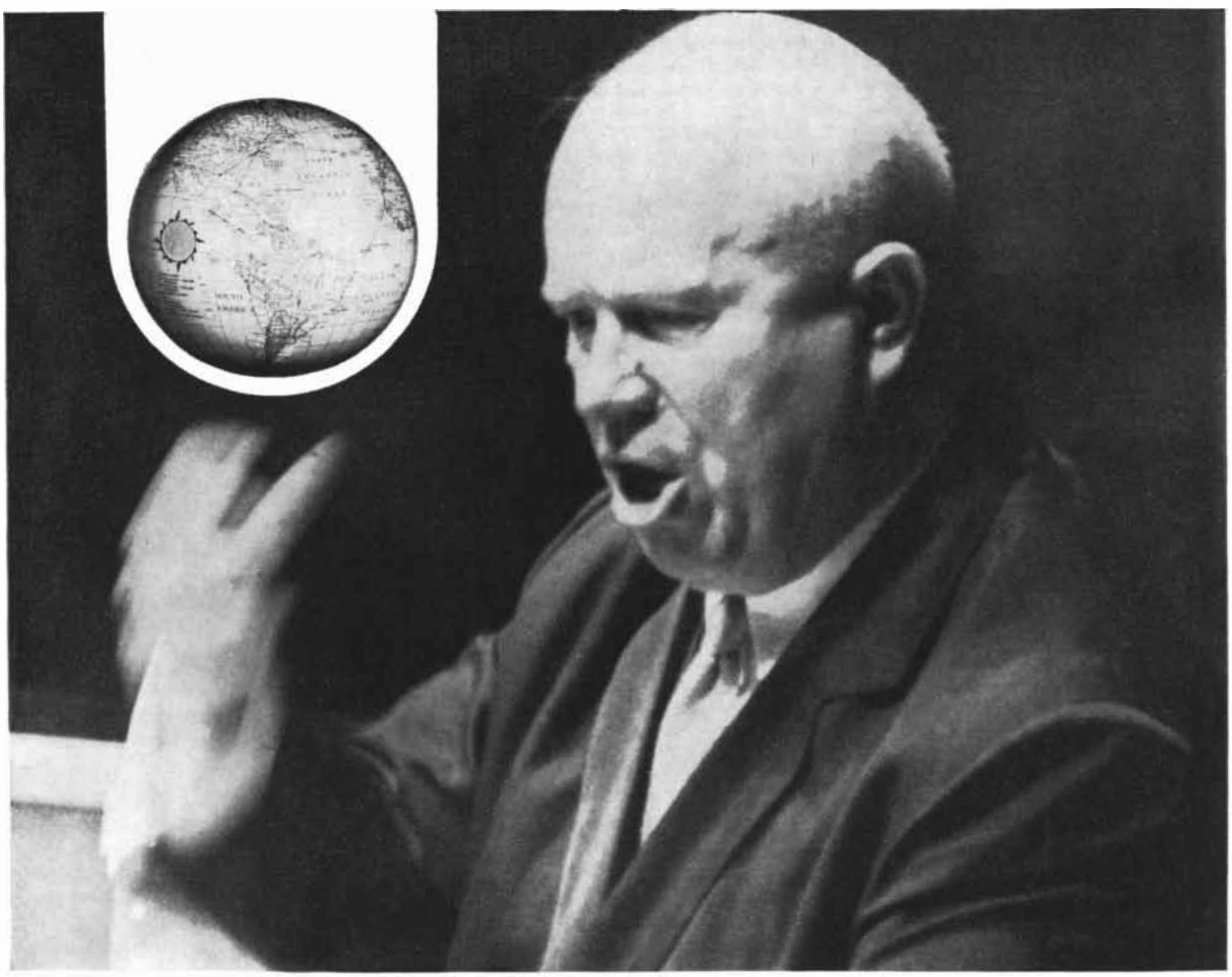


MATHEMATICAL GAMES

The author pays his annual visit to Dr. Matrix, the numerologist

by Martin Gardner

It had been two years since I last interviewed the renowned (if not corporeal) numerologist Dr. Matrix or seen his pretty Eurasian secretary, Iva Toshiyori. In January, 1961, as reported in this department, Dr. Matrix had called attention to such "pattern dates" as 6–1–61 (June 1, 1961) and had predicted that on those dates would occur events of world-wide import. To the great disappointment of his followers absolutely nothing of earth-shaking consequence took place on any of the specified dates. When I tried to reach Dr. Matrix last January, I found that he had left his Los Angeles office many months before, without leaving a forwarding address. All efforts to locate him were unsuccessful.

Then, late in 1962, on my birthday, I received a post card from him. "May the Fates be kind," it read, "to you on your 16/33 birthday." This puzzled me for some time, but when I divided 16 by 33, I found the quotient was a decimal that endlessly repeated my age. (Does the reader know how to arrive at such fractions? What, for example, is the smallest integral fraction that in decimal form endlessly repeats 27?)

The card bore no return address, but I was surprised to see that it had been postmarked in Ossining, a town on the east bank of the Hudson River about 10 miles north of Dobbs Ferry, the town where I live. I leafed eagerly through the Westchester County telephone book. No Dr. Matrix. I tried Toshiyori. Yes, there she was! A moment later I was speaking with her on the telephone.

The story she told was a sad one. After the failure of Dr. Matrix' predictions, his clientele had slowly dwindled and he found himself sliding deeper and deeper into debt. In desperation he did a foolish thing: he tried to make some $20 bills.

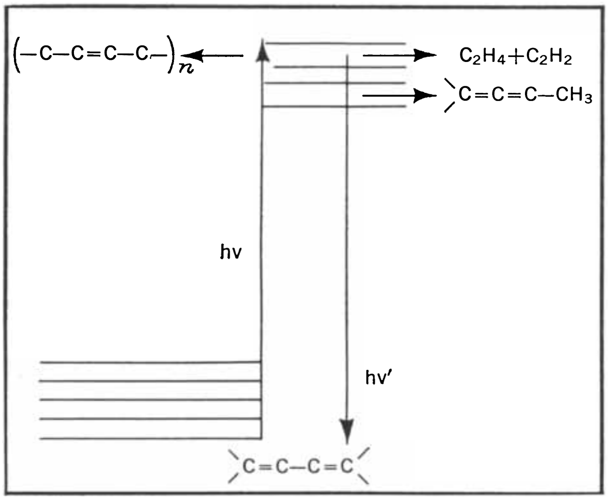
His method was a curious one. With a paper cutter he sliced each of 14 bills into two parts, cutting them neatly along the broken vertical lines on each of the schematic bills shown in gray in the illustration on page 140. The right-hand portion of each bill was then butted against the left-hand portion of the bill immediately following it. In the process each bill lost more than it gained. The result was 15 bills. They are shown in color in the illustration. Each of them was only 14/15 as long as a legitimate bill, and all but the two end bills were glued together along their cut edges, as indicated by the solid vertical lines. The loss of length was scarcely noticeable, and the carefully glued butted edges formed only a barely perceptible hairline. Unfortunately—or rather, fortunately—the U.S. Government places duplicate serial numbers at opposite corners of every bill, and most of the great numerologist's new bills therefore bore pairs of serial numbers that did not match. True, Dr. Matrix' method of making new bills was not exactly counterfeiting—he merely "rearranged" the parts of genuine bills. Nevertheless, the Treasury Department took a dim view of his work and it was not long until he found himself firmly confined within the matrix of cells at Sing Sing. Sentence: five years. Miss Toshiyori took an apartment in nearby Ossining. She was allowed to visit Dr. Matrix twice a week, and with his assistance she was managing to carry on his numerological practice by mail.

"Yes," she said on the phone, "I'm sure I can arrange for you to see him. I'll call you back in a few days and let you know when."

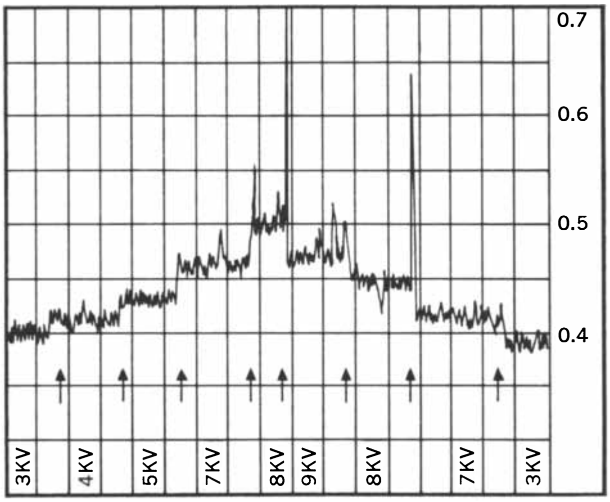
It was a sunny winter afternoon—not a cloud was in sight and the air was like wine—when I drove to Ossining and wound my way down the sloping side streets to the bank of the Tappan Zee. Behind the grim gray walls of Sing Sing the blue waters of the Hudson rippled pleasantly in the sunlight.

Miss Toshiyori was waiting in one of the visitor's rooms, as enigmatic and as beautiful as ever. She seemed unembarrassed by the context of our meeting. Through a grille beside her chair I

How can we determine the course of reactions?



The Excited State. This sketch describes possible behavior of molecules of butadiene upon absorbing light energy. Within 1,000 nanoseconds, they may undergo either polymerization, isomerization, or decomposition.



The Stark Effect. This spectrogram shows changes in optical density of methyl red at the absorption edge of the band. Similar measurements on the opposite edge of the band indicated a shift to the red rather than a band broadening.

Organic materials are a potential source of new high-speed components for data processing systems. The discovery of these components will depend on a detailed understanding of the physical properties of both known chemical systems and new systems. To help develop this understanding, IBM is investigating the mechanism of energy transfer which occurs when light is absorbed by organic molecules.

An organic molecule can react to a quantum of energy in a number of ways, as shown above. In one project, aliphatic dienes and trienes are exposed to ultraviolet light. Then the effects produced by the wave length, pressure, and temperature are determined. This study will also help to define the conditions required for photochemical synthesis of unusual compounds.

In another project, scientists are studying the physical properties of materials in the excited state. The shift of an isolated absorption band due to an applied electric field has been observed for an organic dye molecule dispersed in a solid matrix. This was the first time that this shift, known as the Stark Effect, had been observed in an organic solid. The organic dye (methyl red) was imbedded in a non-polar transparent plastic film. A high-voltage D.C. field was applied, and the resulting changes in optical density were measured with a spectrophotometer. The spectrogram is shown above. Anticipation of these results led the scientists to conclude that the dipole moment of methyl red does not change significantly between the ground and excited states. They further concluded that a quantum mechanical explanation was required to describe this phenomenon. The development of this technique provides science with an additional independent physical parameter which can be used in the study of excited states of organic molecules.

IBM scientists are also investigating the chemical changes which take place when adsorbed gas molecules are elevated into excited states. They have examined mechanisms by which a polymer film is formed on a surface exposed to ultraviolet light in the presence of butadiene. Their results indicate a mechanism of selective surface photolysis in which reaction of the adsorbed gas occurs. From research like this will come new insights into the formation of new types of thin films which may prove to be of great importance in cryogenic and microelectronic devices.

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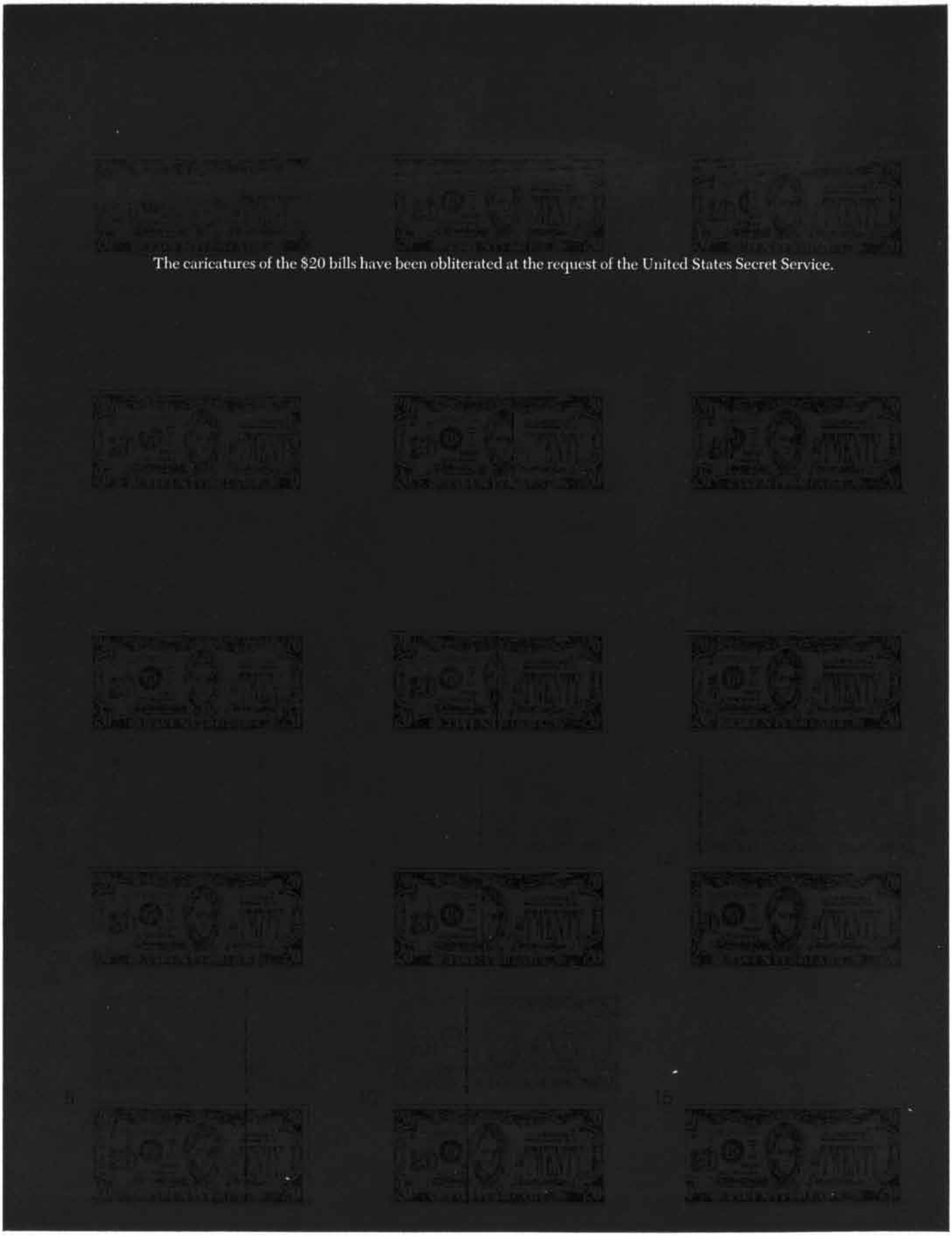


Dr. Matrix went to jail for making 15 "rearranged" bills (color) from 14 real ones (gray) by judicious cutting and pasting recognized the hawklike nose and glittering green eyes of her employer.

Dr. Matrix was in a tired, unsmiling mood but his voice was cordial. "I'm afraid 1963 is a hopelessly dull number," he said. "Its reversal, 3691, is a prime, but so is the reversal for 1964. Too bad we didn't get together last January. I could have told you that 987 plus 654 plus 321 is exactly 1962."

"What an astounding coincidence!" I exclaimed. "And it even ties in with a descending digits problem I gave last October."

Dr. Matrix shook his head. "Such things are never coincidental. They are part of that mysterious order in which both mathematics and history lie embedded. Last year was the year of the big countdown. Never before in history have so many giant rockets been fired to the accompaniment of so many backward-recited integers."

He waited until I had jotted down his remarks in my notebook. "Have you ever noticed that 12 is equal to 3 times 4, and 56 is equal to 7 times 8?"

I thought this over for a moment and gave a start when I realized that Dr. Matrix' remark contained the first eight digits in ascending order.

"My number as a prisoner is rather interesting," he went on. "It is 54748, a number of five digits. If you add together the fifth powers of each digit [$5^5 + 4^5 + 7^5 + 4^5 + 8^5$], the sum is 54748. I consider this a favorable omen."

"Are there many numbers like that?"

"Very few. One of the simplest is 153. It has three digits, so in this case we raise each digit to its third power. Sum the powers and you have 153 again. It is no accident that we are told in the last chapter of the Gospel of St. John, verse 11, that the net Simon Peter drew from the Sea of Tiberias contained 153 fish. The number has many mystical properties." (I later learned that only three other numbers are equal to the sum of the cubes of their digits. Each is a three-digit number. Can the reader discover them?)

"I seem to recall," I said, "that St. Augustine somewhere gives an elaborate numerological analysis of why those fish numbered 153."

"Yes, St. Augustine starts with 10, the number of the commandments and a symbol of the old Mosaic dispensation. To it he adds 7, the number of the gifts of the spirit and a symbol of the new dispensation. The resulting number, 17, signifies the union of old and new. He then sums the integers from 1 through 17 to obtain 153. Rather primitive numerology, in my opinion, but of course St. Augustine did not have the benefit of today's numerological techniques."

"What about the number of your cell?" I asked.

Dr. Matrix smiled. "It has two digits. Put a decimal point between them and the new number is the average of the two digits. I'm sure your readers will find it a simple matter to determine the cell number. You might also ask them to compute the dimensions of my cell floor. It's a rectangle, not a square. I measured it one day and found that the length and width were each an integral number of yards. I realized immediately that the perimeter in yards exactly equals the area in square yards."

"Excellent," I said. "I'll give both problems and keep the answers until the following month."

"We live in perilous times," Dr. Matrix continued. "Times that call for great wisdom on the part of our leaders. By the way, don't you think it odd that two of the leading philosophers of England should bear the name of Wisdom: John Oulton Wisdom and Arthur John Terence Dibben Wisdom?"

"I understand they're cousins," I said.

"I'm glad to hear that," said Dr. Matrix. "It makes it less frightening. Have you read much of Franz Kafka? We are all trapped, you know, inside an insane labyrinth, like the protagonist 'K.' in Kafka's *The Castle*. That letter 'K,' in my opinion, is one of the great prophetic symbols of modern literature. It is the 11th letter of the alphabet, a symbol of the 11th hour of the world. Who are the leaders of those two giant nations that now glower at each other around the sides of the planet?"

I must confess that little fingers tapped up and down my backbone when I realized that both "Kennedy" and "Khrushchev" begin with *K*.

"We live today," Dr. Matrix continued wearily, "in the shadow of the H-bomb. The age of fission has become the age of fusion. 'Fusion' is a word heavily charged with meaning for the numerologist."

"How it that?"

"You recall my alphabet circle?" He asked for my pencil and a sheet of paper. On the paper he jotted down the letters of the alphabet in circular form, the Z joining the A like a snake with its tail in its mouth, the ancient symbol of eternal recurrence. " 'Fusion' has six letters," he said. "We count clockwise around the circle, six letters from *F*. The count ends on *L*, the first letter of a new word. We do the same with *U* to obtain *A*, the second letter of the new word."

He continued in the same way with the remaining letters. When he finished, "fusion" had been transformed to "layout." "You see," he said, smiling crookedly, "the word 'fusion' leads inexorably, by way of 6, to an ominous hint of its power to flatten civilization."

"The world was created in six days," I said. "Didn't St. Augustine argue that God chose that number because it was the first of the so-called perfect numbers?" (A perfect number is one that is the sum of all its divisors: e.g., $6 = 1 + 2 + 3$.)

Dr. Matrix nodded. "But 6 is also the building block of 666, the mark of the beast. The world today can be destroyed in six minutes."

"You seem as much interested in letters as in integers," I said, trying to change the subject. "My readers like occasional word puzzles. Any clever word problem you can give me?"

Dr. Matrix put the tips of his fingers together, leaned back and closed his eyes. "H'm. Let's see. Oh, yes, here's an amusing anagram that will no doubt annoy many of your readers. Simply rearrange the letters of 'chesty' to form another English word. It isn't easy."

"A familiar word?"

"Yes indeed. In fact, a word most appropriate for the beginning of a new year."

When I asked Dr. Matrix about his life in prison, he made a wry face. "The name Sing Sing, as you may know, derives from the old tribe of Sint Sink Indians. We're all sin sick here. But I'm treated decently, I must admit. I work part time in the prison library. The roof of the recreation room leaks and is about to collapse, but we've managed to shore up one of its main beams. The food could be worse. Of course I never eat beans."

His remark puzzled me until I remembered the old Pythagorean prohibition about beans. "You consider yourself a member of the Pythagorean brotherhood?"

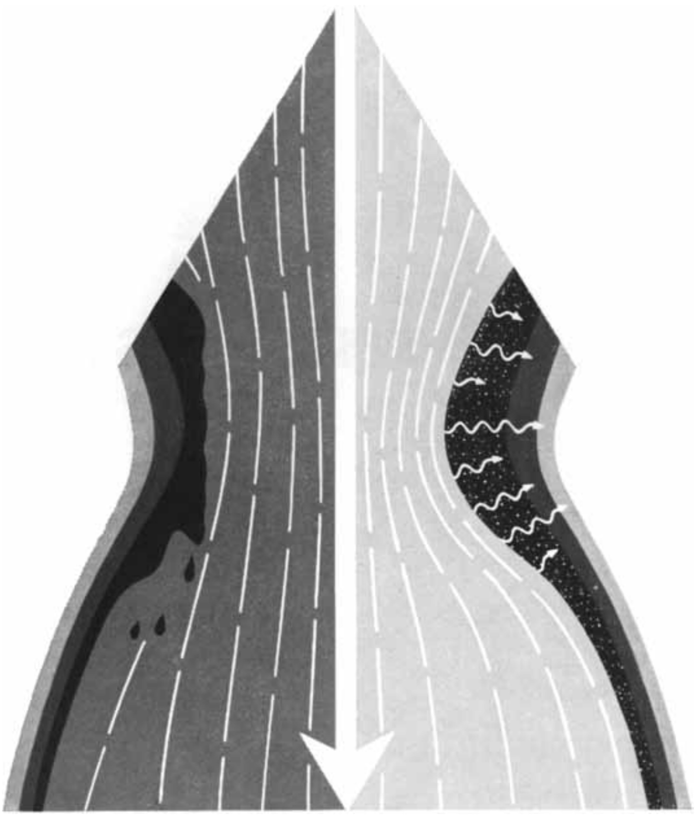
"My dear Gardner," he said, sitting more erect in his chair, "I *am* Pythagoras. I'm his 11th reincarnation."

I exchanged amused glances with Miss Toshiyori, who had been listening silently to our conversation. "I suppose," I said, "you'll be telling me next that, like Pythagoras, you have a golden thigh."

Dr. Matrix said nothing. But he tapped the lower part of his thigh with the end of my mechanical pencil. It made a sharp metallic sound!

As Miss Toshiyori and I were leaving the prison's main gate, I asked: "Does

AEROPHYSICS



New knowledge of fluid dynamics and heat transfer gradually is forcing a revision in our thinking about solid rocket-nozzle cooling problems. For example, we now know that use of the "two-metal" principle in the design of nozzles permits us to expose metals to temperatures well above their normal boiling points. In the two-metal system, one metal is allowed to boil within another. As boiling occurs, the boiling products of the first metal pass through the pores of the second, thus cooling it by convection, mass transfer, and heat absorption in the phase changes. The above drawings show how hot gases passing through a nozzle (A) erode "pure" metal such as tungsten at the throat. In (B), mass-transfer cooling protects the metal from erosion. This and other cooling techniques permit our design engineers to overcome inherent limitations of materials now available for nozzle applications.

We invite you to participate in our challenging advanced research activities. Aerojet-General® needs scientists with advanced degrees and unusually high levels of achievement in materials technology, physics, chemistry, mathematics, fluid mechanics, and heat transfer. Your letter will receive prompt confidential attention. Write Dr. P. L. Nichols, Jr., Manager, Aerojet-General Solid Rocket Research, P. O. Box 1947 –P, Sacramento, California. An equal opportunity employer.

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Dr. Matrix really believe that he's a reincarnation of Pythagoras?"

"Heavens, no," she said with a laugh. "But the old faker likes to keep up the pretense. It's all part of his act."

"You're very loyal to him."

"He's my father," she said with a sigh.

My eyebrows hopped upward. "And who was your mother?"

She slipped her arm through mine. "Japanese. They met in Tokyo." Suddenly her dark eyes brightened. "I know a quaint cocktail lounge a few miles from here, in Tarrytown. If you'll buy me a brandy Alexander, I'll tell you all about it."

At some future time, perhaps, I'll give her story. For now, I mention only one bewildering thing she said; it provides a fitting little problem with which to close this month's department.

When I asked her how old she was, she smiled and said cryptically: "The day before yesterday I was 22, but next year I'll be 25."

Can the reader deduce the date of Miss Toshiyori's birthday, as well as the date on which our conversation took place?

Readers were asked last month to find a chain of chess-king moves in Louis Aragon's surrealist poem "Suicide" that would spell a two-word exhortation appropriate for a world preparing to slash its own throat. The phrase I had in mind is "Chin up." It can, of course, be taken in two different ways. I suspect that many readers will be sending in other—perhaps better—messages. Any of particular interest will be discussed in a later issue.

With regard to the problem of placing seven 3-by-5-inch file cards on a legal-sized sheet of paper so that a maximum area is covered (the problem was given last October and answers were discussed in November and December), Donald Vanderpool of Towanda, Pa., was the first to point out that by rotating the central card a bit more than in Stephen Barr's solution (keeping the card centered on the exposed strip) a minute increase in the covered area results. The determination of the exact angle of rotation requires calculus, and it was first made by Michael Rolle of Bethesda, Md. In Barr's solution the card has been rotated five degrees 34 minutes 32 seconds from the horizontal, providing a total coverage for all seven cards of 100.059+ square inches. If the angle is increased to six degrees 12 minutes 30 seconds, a maximum coverage of 100.0684+ results, thus bettering Barr's record by about .009 square inch.

I like detective work

It started when we developed the data reduction facility for the Explorer Program. We took the magnetic tapes, reduced and recorded the data in analog fashion, and turned it over to the scientists.

One of the channels on the satellite apparently had stopped working. Our detective work said the data reduction lab was working properly and it must have been something in the satellite.

Normally you see a square wave. But it dropped to a straight line. The Geiger counter on board saw too many counts per second and it just couldn't keep up.

What happened was that this particular channel saturated because the cosmic ray intensity was so high. It was the first clue to radiation belts.

You can learn a lot here at JPL. Probably more than at any other single organization I can think of. And the engineers call the shots here. I like the freedom, the professional atmosphere, the shirt-sleeve atmosphere.

They even sent me over to Florence, Italy, last April, to present a paper I'd written.

I really like it here. The facilities, like the library, are the best. And you couldn't work with a nicer group of people.

You've just been talking to Benn Martin, Engineering Group Supervisor at Caltech's Jet Propulsion Laboratory —the facility responsible for R&D on lunar, planetary, and interplanetary explorations. He's been at JPL for 5 years. He plans to spend 50 more here. If your future doesn't look as bright, you might be right to write to JPL.

jpl

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THE AMATEUR SCIENTIST

Experiments with ptyalin demonstrate the basic principles of enzyme action

Conducted by C. L. Stong

The repertoire of any dinner-table scientist worthy of his coffee includes at least one demonstration of catalysis. A favorite one is introduced with a challenge to fellow diners to ignite a cube of sugar. All attempts fail, of course: the heat of a match simply melts the surface of the cube. After everyone gives up, the demonstrator goes into his act, melting a corner of the cube and then dipping the sticky surface into a bit of cigarette ash. When a lighted match is applied to the ash, the sugar burns with a hot, bluish flame. Everyone promptly claims a foul: the ash appears to be burning, not the sugar. This opens the way for the demonstrator to explain that in this experiment the ash can be classed with the chemical agents known as catalysts, and that it functions somewhat like a parson at a wedding: It promotes the reaction but does not participate in the consequences.

The analogy is not altogether apt. Catalysts are properly defined as substances that regulate the rate at which chemical reactions proceed. Some catalysts accelerate reactions that otherwise proceed slowly. Other catalysts slow reactions. Examples of both types exist in the thousands in the inorganic kingdom and within the cells and fluids of living organisms, where they are known as enzymes.

Enzymes differ from inorganic catalysts in that they are proteins and as such are large, fragile molecules built from amino acids linked end to end. Their positive identification at the turn of the present century by the German chemist Eduard Buchner opened a whole new field of experimentation that is as complex as it is fascinating. This may explain why amateurs tend to shun the enzymes. Most enzymes exist in only trace amounts and are all but impossible to isolate. But one need not isolate an enzyme in order to investigate the effects that stem from its presence. This is well illustrated by a series of experiments suggested by Henry Soloway of the department of pathology at Kings County Hospital in Brooklyn.

"To detect the presence of an enzyme," Soloway writes, "one takes advantage of the fact that an enzyme mediates a specific biochemical reaction. In other words, to demonstrate the presence of an enzyme that converts substance A into substance B, a known quantity of solution A is mixed with the solution suspected of containing the enzyme. After an appropriate interval the mixture is tested for the presence of substance B. If B is detected, the presence of the suspected enzyme is confirmed. An equal quantity of substance A, unmixed with the suspected enzyme, is kept in a separate container under the same conditions for an equal interval as a control.

"In principle the procedure is simple and fairly obvious, but putting it into practice is another matter. Enzymes are temperamental molecules. They function only in rigidly controlled environments. Maintaining such conditions in the laboratory often requires costly facilities. Temperature changes of even a few degrees exert a profound effect on them, as do slight variations in the acidity or alkalinity of the solution. Many refuse to function in the absence of trace amounts of substances called activators, and their action can be completely arrested by traces of heavy metals dissolved from laboratory glassware. Such difficulties may explain in part why the study of enzymes has failed to lure an enthusiastic following of amateurs.

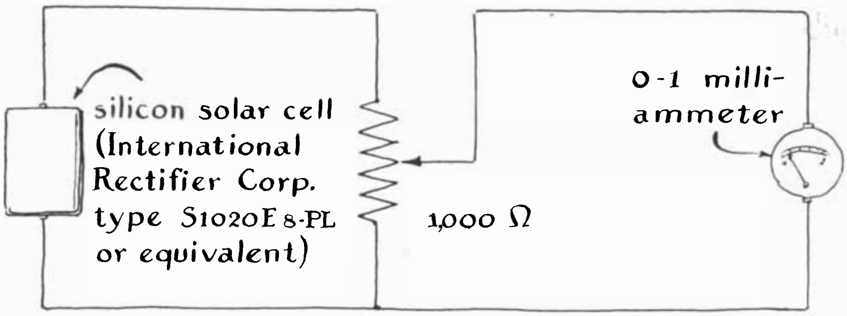
"Fortunately, a few rugged enzymes have been identified that are readily available. One in particular is well suited to amateur experimentation and can be used to demonstrate most of the basic principles of enzyme reaction. It is called ptyalin and is secreted by the salivary glands. It has the function of splitting starch into sugar.

"The starch molecule is a large one, with branching chains of glucose units. Ptyalin splits off the glucose units two at a time, thereby destroying the integrity of the starch and forming numerous fragments composed of two glucose units each. To observe this action the experimenter must prepare a solution of the enzyme and one of starch, and also a system capable of detecting the amount of starch consumed or the number of two-unit glucose fragments produced.

"Ptyalin is collected in saliva and cornstarch can be bought from a grocer. Iodine changes the normally milky color of starch solutions to a bluish-black, the depth of the shade increasing with the concentration of starch in solution. It therefore functions well as a detector or indicator of enzyme action.

"To collect saliva place a glass funnel lined with coarse filter paper over a glass beaker. Salivation can be encouraged by chewing a piece of paraffin of the kind used for sealing jelly. The amount of ptyalin present in saliva varies from person to person, so it is desirable to collect a pooled sample from a number of individuals. Approximately 80 milliliters should be collected and stored in a refrigerator at 40 degrees Fahrenheit. All the experiments to be described must utilize this stock solution. The concentration of ptyalin may vary substantially in different collections and the variation might introduce confusing results if tests made on one solution were grouped with those made on another.

"The starch solution is prepared by pouring one liter of boiling water over two level tablespoons of powdered cornstarch. (Distilled water should be used throughout these experiments.) After thorough mixing with a spoon or a glass stirring rod the solution is filtered through coarse filter paper (a paper napkin will do) to remove undissolved lumps of starch. The amount of starch contained in one milliliter of this stock solution is adopted as one unit of starch activity for the purposes of the experiments, and all measurements are expressed as a percentage of this unit. Since the results of the experiments are all relative, the numbers expressing quantities are empirical; the investigator



Schematic circuit diagram of photometer

can alter them to units of any size. But by the same token measurements made with one set of solutions cannot be lumped with those of another set.

"The indicator solution is prepared by diluting 10 milliliters of 2 per cent tincture of iodine in 600 milliliters of water. The activity of the enzyme is determined by measuring the amount of light transmitted by a test tube containing the stained starch. A photometer measures the light intensity. The solution to be measured is placed between a standard source of light and a silicon solar cell. The cell converts the light to an electric current, which actuates a milliammeter. The circuit includes a potentiometer with which to adjust the milliammeter to full scale during calibration [*see illustration above*]. The cell, test tube and potentiometer are assembled in a lightproof box of corrugated cardboard (or some other opaque sheet material). A lightproof partition in the box supports the test tube as shown in the accompanying drawing [*page 150*]. A slit in the two sheets of cardboard that form the partition allows light from the source to reach the solar cell. A sheet of translucent tissue paper of the type used for making tracings is placed between the test tube and the cell to diffuse the beam and so distribute the light uniformly over the active face of the cell. A 35-millimeter projector will serve as a light source, or an incandescent bulb can be built into a lightproof compartment of the box. The test tube should fit snugly against the slit facing the source so that all the light reaching the cell will pass through the test tube.

"To calibrate the photometer one prepares a series of starch standards, measuring the light transmitted by each standard and plotting the measurements. The resulting graph shows the relative variations of the meter readings with respect to the percentage of starch in solutions of unknown concentration.

"To make up the standard starch solutions for calibrating the instrument place in glass containers 20, 15, 10, five and two milliliters of the starch solution. (All glassware, including the pipettes used for transferring solutions, must be scrupulously clean.) Then add enough water to bring each of the last four containers up to 20 milliliters of starch solution. Fill a sixth container with 20 milliliters of distilled water. Mark the container with the undiluted solution '100 per cent starch' and the remaining five 75, 50, 25, 10 and 0 per cent respectively. Next, place exactly one milliliter of each of the six standard starch solutions in each of six test tubes of equal size, add 10 milliliters of iodine indicator solution and one milliliter of water. (The milliliter of water represents the volume in which ptyalin will be contained during subsequent experiments.) Shake all test tubes gently to distribute the color evenly. Then insert the most transparent tube (the one containing no starch) in the photometer, turn on the light source and adjust the potentiometer so that the pointer of the milliammeter swings to the top of the scale. Prepare a table of two columns, one for the meter readings and the other for the percentages of starch in solution. Enter the maximum value of the meter scale in the first column and '0' in the starch column and then, without changing the potentiometer setting or the light intensity, proceed to measure and tabulate the light transmission of the remaining five solutions. Plot the results as shown in the accompanying illustration [*top of page 152*]. The resulting calibration curve will be valid only for the materials in this particular experiment.

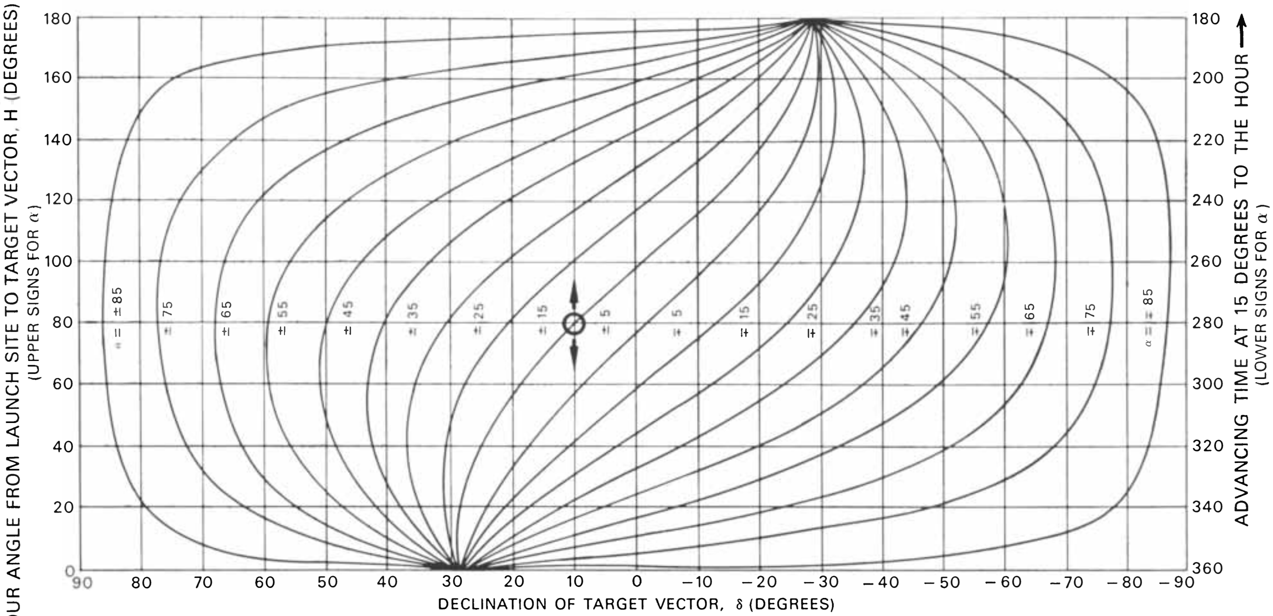
"With these preparations completed the first portion of the experiment can be undertaken. This part of the experiment will determine how the amount of starch broken down into glucose increases with time. First, clean all glassware thoroughly. Then place exactly one milliliter of standard starch solution in each of six test tubes of equal size. Using another clean pipette, transfer one milliliter of filtered saliva to each of these tubes. After 15 seconds add 10 milliliters of indicator solution to the first tube, swirl the contents to distribute the color, measure the light transmission promptly and tabulate the measurement. After 30 seconds repeat the procedure, using the second test tube of solution, and then repeat it with the remaining samples after one, two, four and seven minutes respectively. The over-all reliability of the experiment will be no greater than the accuracy with which the measurements are timed. Unless the experimenter is experienced in making measurements of this type it is advisable to run through the procedure a few times, perhaps using tubes of colored water.

"The tabulated readings are converted to percentages of starch digested by reference to the calibration graph and are then plotted against time. (Because the schedule of measurement involves constantly increasing intervals that range from seconds to minutes, the time coordinate of the graph should be divided into logarithmic intervals.) The concentration of ptyalin used in this portion of the experiment is so high that substantially all the starch is digested within approximately 30 seconds. The rate of digestion can be lowered by diluting the enzyme, thereby giving the experimenter more time to manipulate the apparatus and an opportunity to observe the effect of concentration on enzyme action.

"This effect can be observed in considerable detail if one performs the experiment on serial dilutions of the enzyme. The procedure requires a grid of 36 test tubes arranged in a pattern of six rows and six columns. Place one milliliter of water in each of the 36 test tubes. One milliliter of filtered saliva is then placed in each of the six test tubes that make up the first column (the first tube of each row). Swirl each tube gently to mix the solution. All tubes in the first column now hold two milliliters of solution. The remaining 30 tubes hold only one milliliter. Using a clean pipette, transfer one milliliter of solution from the first tube in the first row to the second tube in the first row. Swirl the second tube gently to mix the contents. Then transfer one milliliter of solution from the second tube to the third. Swirl. Repeat the procedure until the sixth tube of the first row contains two milliliters of solution. Remove and discard one milliliter of solution from the sixth tube. All tubes in the first row now contain one milliliter of solution. Repeat the procedure for each of the remaining five rows. All test tubes in the first column will then contain a 1:1 dilution of saliva-water solution. All tubes in each of the remaining five columns will contain dilutions in the ratios

LUNAR LAUNCH · JULY 17, 1968

How would you aim a vehicle to the moon?

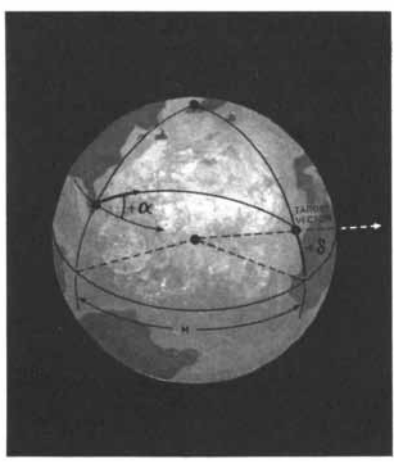


LAUNCH AZIMUTHS FOR TARGET DECLINATION VERSUS HOUR ANGLE FROM LAUNCH SITE TO TARGET

ENGINEERS AND SCIENTISTS

How do you launch into a geocentric planar trajectory from Cape Canaveral to a specified target vector? This family of curves demonstrates the interrelationships of the target vector declination, equatorial hour angle and launch azimuth. They can be used to estimate the launch requirements of lunar probes. For example, suppose a lunar vehicle launch is scheduled for July 17, 1968. At this time the declination of the moon will be $+10°$ (NASA Technical Note D-911). Assuming an hour angle of $80°$, the launch azimuth can be found to be $+5°$. The azimuth change for a ± 1 hr. launch window ($\pm 15°$ in H) will be $\alpha = -2°$ to $+12°$ as can be determined by moving along the $\delta = 10°$ line.

Plotting complex launches to the moon and planets is among scores of space-oriented activities in progress at Astronautics. We're also deeply involved with the development and design of boosters and vehicles for space exploration and travel. We're developing, too, the incredibly precise electronic systems necessary to guide, track and communicate with these probes.



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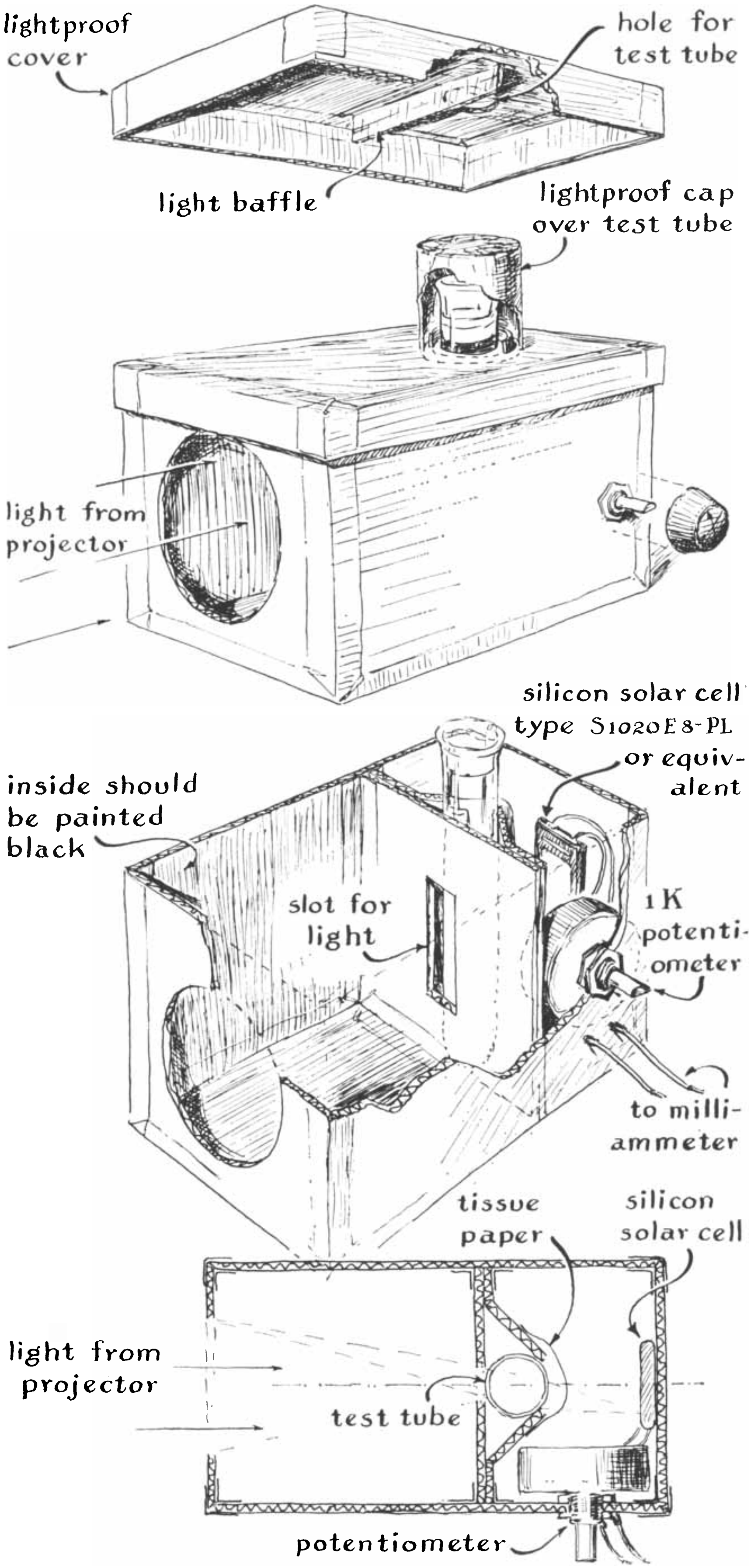


Construction details of photometer

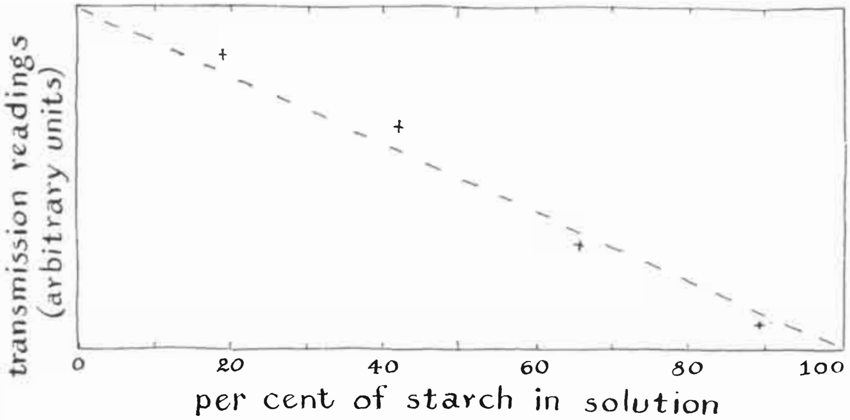
of 1:2, 1:4, 1:8, 1:16 and 1:32 respectively.

"The series of reactions and measurements is started by adding one milliliter of standard starch solution to the first test tube in the first column. Ten milliliters of indicator solution is added after an interval of 15 seconds, the activity is promptly measured and then tabulated, as in the initial experiment. Next, one unit of standard starch solution is added to the second tube of the first column (the first tube of the second row) and after an interval of 30 seconds is similarly measured and tabulated. Thereafter the identical procedure is repeated on all remaining specimens in the first column, the enzyme having been allowed to act prior to measurement for intervals of one, two, four and seven minutes respectively. The remaining five columns are then reacted, measured and tabulated on the same schedule.

"The tabulated data for each column is now converted to percentages of starch by reference to the calibration curve and plotted against time as shown in the accompanying illustration, a graph of the effect of concentration on enzyme action [*bottom of page 152*]. With these data at hand still other factors can be investigated that tend to modify the rate of starch conversion, such as temperature and acidity.

"The rate at which many chemical reactions proceed increases with temperature over a broad range of temperatures. Is this true of reactions that involve enzymes? Ptyalin might be expected to work most effectively at a temperature near 98 degrees F., the approximate temperature of the human mouth. To test the hypothesis, select from the graph just completed a concentration of ptyalin that produces, say, 80 per cent starch digestion in four minutes and prepare approximately 60 milliliters of ptyalin solution at this concentration as a stock specimen. Then improvise a constant-temperature water bath by adding hot or cold water as required to a large beaker initially filled to about a third of its capacity with lukewarm water. Adjust the bath to 94 degrees F. Make up a series of starch dilutions from 100 per cent to 0 per cent as in the first calibration run. Place these dilutions in the water bath and, after they have reached 94 degrees, make a new calibration curve for starch at this temperature. Now place nine test tubes in the bath, each containing one milliliter of stock specimen, together with a single test tube containing 10 milliliters of standard starch solution.

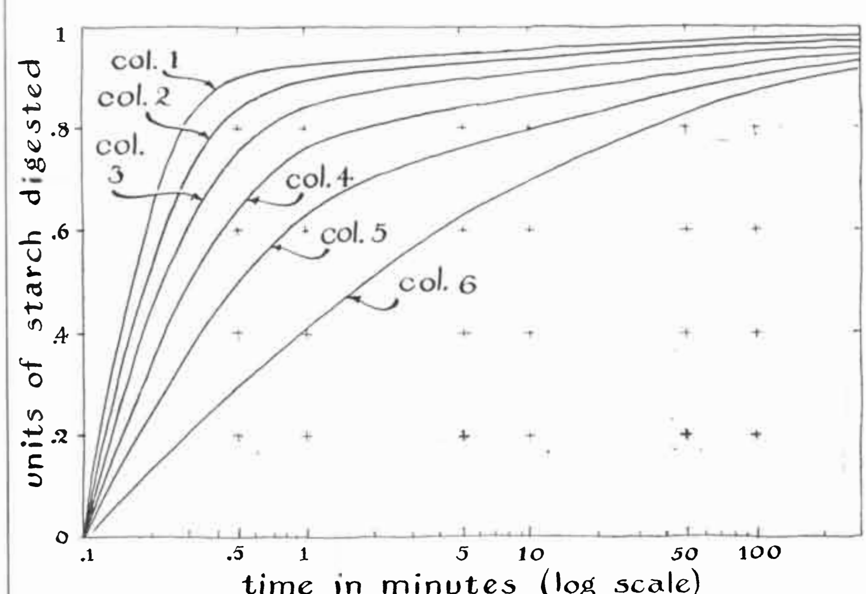
"Keep an eye on the temperature of



Calibration graph for standard starch solution

the bath and stir in enough hot water from time to time as required to maintain the specified temperature. When all test solutions have reached the temperature of the bath, transfer one milliliter of standard starch solution to each of the stock specimen solutions and, using the new calibration curve, carry out the procedure for measuring and plotting the rate of digestion. Thereafter increase the temperature of the bath in increments of two degrees to 110 degrees, repeating the complete procedure, including calibration, at each increment of temperature increase. If performed carefully, the experiment will demonstrate that the action of the enzyme increases to a maximum at a temperature somewhat above 98 degrees and thereafter declines to zero at 110 degrees. It is easy to demonstrate that the effect of high temperature on an enzyme is not reversible. A specimen of ptyalin first heated to 110 degrees shows no activity when subsequently tested at lower temperatures.

"Enzymes are similarly touchy with respect to the acidity or alkalinity of their environment. Normal saliva is slightly acid. On the *p*H scale universally used for expressing acidity and alkalinity, normal saliva has a value of *p*H 6.7. (A *p*H of 7 is neutral. Acid solutions have *p*H values lower than 7 and alkaline solutions values higher than 7. Each unit of the scale represents a tenfold change in hydrogen-ion concentration, a *p*H of 4 being 10 times more acid than *p*H 5 and 100 times more acid than a *p*H of 6. Similarly, a *p*H of 10 is 100 times more alkaline than a *p*H of 8.) One might suppose that the reaction mediated by ptyalin would proceed most effectively in an environment of *p*H 6.7. The hypothesis can be tested by maintaining standard starch and ptyalin solutions at a constant concentration and temperature while varying the *p*H



Graph of ptyalin activity against starch concentration

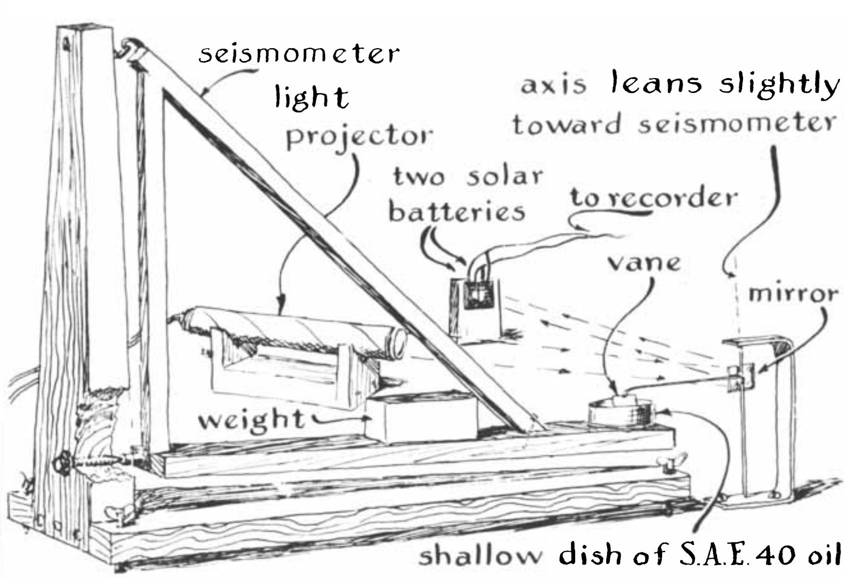
in small increments. The pH is altered by adding dilute sodium hydroxide (.1 molar) or dilute sulfuric acid (.1 normal) in small amounts to the specimen solutions and measuring the pH with Nitrazine paper, or by any comparable technique. Nitrazine paper, such as Squibb No. 5262, can be bought at drugstores.

"Adjust 80 milliliters of standard starch solution to pH 4 by adding dilute sulfuric acid drop by drop, and prepare a new calibration curve. Then, using dilute sulfuric acid, adjust one milliliter of ptyalin solution to pH 4, add the adjusted standard starch solution, after an interval of four minutes add 10 milliliters of indicator solution and carry out the procedure for plotting the digestion rate. Repeat this routine, including a new calibration run each time, in increments of two pH units from pH 4 to pH 10. If carefully performed, the experiment will demonstrate that ptyalin functions most effectively in a slightly acid environment.

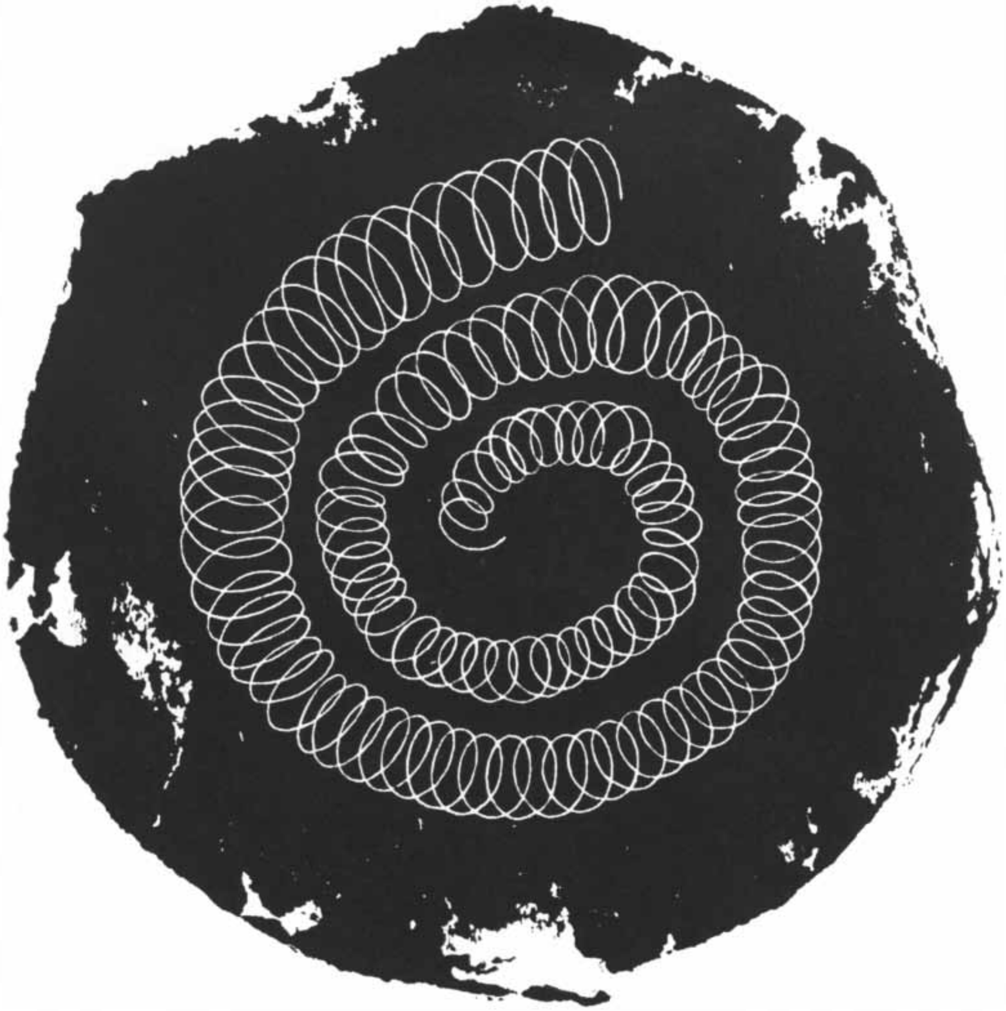
"Many other factors are known to alter the rate of enzyme activity. The activity of ptyalin is increased by the presence of chloride ion in relatively low concentrations and by exposure to red and green light of moderate intensity. Its activity is destroyed, on the other hand, by the salts of heavy metals such as silver nitrate and mercuric chloride. These and still other environmental factors can be investigated by this same photometric procedure."

Seismographs of the type that employ pendulums swinging in the horizontal plane, such as those described in this department by A. E. Banks of Santa Barbara, Calif. [see "The Amateur Scientist," SCIENTIFIC AMERICAN, July, 1957], are subject to long-term drift. Gradual changes in the tilt of local terrain and in the dimensions of the instrument cause the center of the pendulum's swing to creep slowly toward one side of the instrument or the other and distort the record. The effect is of little consequence in the case of seismographs of the Galitzin type, which have a pendulum bob in the form of a coil of copper wire that swings in a magnetic field and translates earth movements as low-frequency electric currents. The voltage is proportional only to the velocity of the pendulum's swing and hence is unaffected by drift. But seismographs that employ a mechanical linkage, such as the Banks instrument, are another matter. In this arrangement a pivoted mirror is driven by the bob through a short lever arm of magnetized piano wire that is attracted to, and therefore held in contact with, an iron peg in the end of the bob. Any displacement of the bob, including drift, is communicated directly to the mirror system and appears as a bias in the recording. A nice solution of the problem has been suggested by J. P. Parker of the American Enka Corporation.

"Replace the magnetized piano wire with a coupling of viscous oil," he writes. "This can be accomplished by putting a shallow dish of oil on the seismometer arm and letting the oil drive a vane attached to the mirror lever [*see illustration below*]. A small restoring force must be applied to make the mirror seek the center of its angular excursion; this is achieved easily by fitting the mirror assembly with a weak centering spring."



Seismograph equipped with antidrift device



Said Svante Arrhenius: *"The change of the logarithm of a chemical reaction rate constant with respect to temperature, is inversely proportional to the square of the absolute temperature."*

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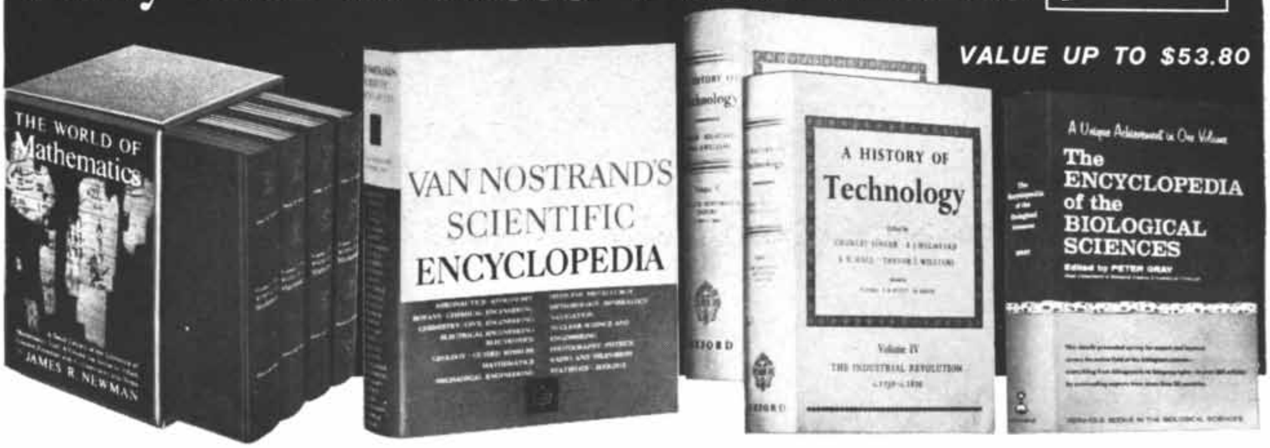

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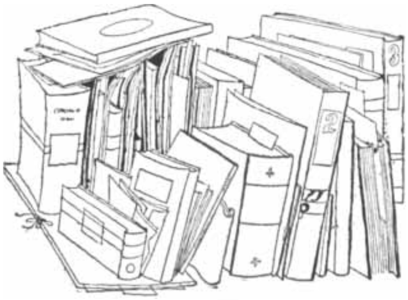

BOOKS

Two recent studies of modern society

by Kenneth E. Boulding

OF TIME, WORK, AND LEISURE, by Sebastian de Grazia. The Twentieth Century Fund ($6).

COMMUNICATION AND SOCIAL ORDER, by Hugh Dalziel Duncan. The Bedminster Press ($10).

The hard scientist who is an active member of the human race will feel an urge to spend part of his leisure, if any, in exploring the literature of social problems and social systems. He usually finds the going hard and the signposts unreliable. He is apt to emerge from the jungle with the feeling that the professionals in this field are mainly engaged in dressing up little knowledge with big words and spurious quantifications. We are all amateurs in social systems anyway, as we all have to live in them, and we cannot help acquiring a good deal of folk knowledge about them. It is tempting for the nonsocial scientist to conclude that amateur status is all that is necessary in this field, and that if we need to solve social problems, a few Pugwash conferences of distinguished physicists will do the trick. I am frankly interested in undermining this view and in persuading the scientific community that social systems must be studied professionally, extensively and scientifically. I approached these two volumes, therefore, with the question: Will they aid or hinder the major objective, or should they be placed on the Index of books unfit for scientists to read?

The De Grazia book, in spite of some virtues, I think I would regretfully put on the above Index. The book is the product of a Twentieth Century Fund study, but whereas previous studies by this estimable institution have tended in the direction of a solid and encyclopedic dullness, this one makes a stab at being sprightly. There has evidently been a research assistant who has compiled some tables to give the whole business a factual air; one would guess, however, that the author knew the answers before the tables were compiled. The conclusions exhibit a somewhat tenuous connection with the evidence.

The study began, as August Heckscher, director of the Fund, explains in the foreword, as an expansion of earlier studies on patterns of consumption as related to leisure, and then, he goes on, "it became apparent that leisure could not be treated apart from work and that both had to be viewed against the changing concepts of time in our civilization. Accordingly, the work developed its present scope—in effect, tending to become a critique of advanced industrialism as it exists in the United States today." The problem, then, is one of enormous importance: What has the rise of scientific knowledge and the technology based on it done to the over-all quality of human life? It is a subject worthy of intense, prolonged and serious study. This study impresses me as casual rather than intense, and prolix rather than prolonged. I am probably being unfair to De Grazia because he raises the hackles of so many of my pet prejudices. He likes the ancient Greeks, whom I confess I regard as an insufferably superstitious and quarrelsome bunch of slavers with an undeservedly good press. He gives way to what he unashamedly calls "musings" (page 395), and he approaches the whole problem with the presumption that the leisure technology is supposed to have bestowed on mankind is a fraud, and that whatever technology may save us is gobbled up in commuting, job shifting and recuperation from the strain. It is true, of course, that crude statistics on the reduction of the number of hours worked per day, week or year exaggerate the gain in what the author calls, somewhat patronizingly, "free time." The author's romantic bias, however, leads him into some dubious statistical arguments, and into an unduly roseate view of the hard, brutal and short life of the preindustrial craftsman; it leads him, furthermore, to miss the significance of the widened field of choice and the enormously expanded intake of information that constitute the main fruits of technology in the quality of ordinary life.

For De Grazia leisure is the Greek "good life," which the unfriendly might take to be the contemplation of the infinite while being waited on hand and foot. I feel a bit ashamed of myself for sounding so cross, as the author is obviously a charming fellow and the perfect dinner companion. I am cross, however, because the subject is much too important to be pre-empted by philosophizing. De Grazia has missed the whole point of the fantastic revolution in the state of man that is going on in the world and that is greatly increasing both his stock of knowledge and his use of information, as well as his ability to satisfy his desires, good and bad. I suspect the real difficulty is that De Grazia is a civilized man, emotionally committed to the era of civilization (3000 B.C. to A.D. 2000) that is now passing away. De Grazia, like Hannah Arendt, whose book *The Human Condition* De Grazia's somewhat resembles, belongs to a tradition of civilized thought that is not really capable of dealing with the problems of the postcivilized society toward which we are so rapidly moving.

The second of these two books belongs to a very different tradition. For one thing, it is peculiarly North American; I am sure it could not have been written in any other continent. It is part of an intellectual constellation that goes back to Thorstein Veblen, George Mead, William James, John Dewey and particularly Kenneth Burke, to whom Duncan clearly owes a great deal. It is related, somewhat more remotely, to what might be called the Toronto school of social theorists, originating with Harold A. Innes and continuing through the work of Edmund S. Carpenter to Marshall McLuhan's astonishing and provocative *Gutenberg Galaxy*. These writers are all preoccupied with the problem of what it is that constitutes the peculiar and distinguishing characteristics of social systems and they all emerge with much the same conclusion: What distinguishes social systems from mechanical or biological systems is the fact of symbolic communication, that is, language. This is not to say that social science is reduced to linguistics, any more than it can be reduced to economics. Each of these disciplines represents a legitimate abstraction from the social system. But if the social system is to be treated as a whole, an abstraction that excludes the element of symbolic communication is excluding precisely that element which gives social systems their unique character. The key to the dynamics of social systems in this view, therefore, is rhetoric: the process by which one person changes the inner structure and ultimate behavior of other persons by means of symbolic communication. Attempts to produce purely mechanical models of social systems, as in the case of classical or even Keynesian economics or, more dubiously, the sociology of Talcott Parsons and his followers, have only a limited validity. There is some tendency even among social scientists to regard art, literature and oratory as being superficial epiphenomena flashing gaily on the surface of the solid mechanical system below. In the study of social systems this view can be dangerously misleading. Duncan's central idea, which he modestly admits has been presented by many other writers, is that the dynamics of society cannot be understood without an understanding of the process of communication, by which the great artist changes the taste of millions, the dramatist arouses images that deflect the course of history and the orator stirs men to glory or to madness. I may perhaps be reading something into Duncan's book that is not in the mind of the author, but this at least is the message that comes across to me.

The book in itself would be a useful introduction to the whole field of thought out of which it comes, a body of thought whose intrinsic importance is matched only by its lack of recognition. For this reason alone the book is to be highly recommended for serious students of the social system. It begins with a historical review: Freud, Georg Simmel, Bronislaw Malinowski, James, Dewey, Mead and Burke. This part of the book is perhaps rather labored and overfootnoted, as if the author were working a little too hard to establish his reference group. The busy reader may want to begin with Part Five, enticingly headed: "Social Mystification in Communication between Classes." Here, when the author comes to discuss Hitler's *Mein Kampf* as "rhetoric as an instrument of domination through unreason," the footnotes fall away and an infectious intellectual passion carries the author in a style that is both emotionally moving and intellectually exciting. The major theme of the whole work is the use of communication in establishing hierarchy, by which Duncan means essentially the structure of roles in society and the establishment of these roles by the communications that surround them and that pass between them. He extends the concept of hierarchy to include not only the superior-inferior relation but also the relation among equals. Duncan's discussion of the nature of social equality indeed impresses me as being the most profound body of insight into this subject I have ever read. Duncan points up the great dilemma of social organization: conversation can take place only between equals; organization involves unequal relations of higher and lower ranks that destroy conversation; and without conversation communication is inevitably corrupted. We try to escape this dilemma through wit, jokes, jesters, art, overlapping hierarchies, established or disestablished religion, office Christmas parties and the like—and with only modest success.

An important virtue of Duncan's approach is that he brings explicitly into his argument elements of symbolic systems that more mechanically minded social scientists reject as too literary, vague, sentimental or theological to include: topics such as guilt, victimage and redemption as elements in social dynamics; the role of comedy, even of obscenity, in what he calls "the rhetoric of reason in society"; the possibility of replacing a tragic victim by a comic victim; the curious relation between asceticism and criminality, and a number of other topics of this kind—all examples of an unusual richness of ideas and material. To an economist Duncan's observations on the symbolic uses of money in a plutocratic society, often reminiscent of Veblen, are both strange and illuminating, like hearing a familiar accent in a foreign land.

In spite of, or perhaps because of, its profundity and wisdom, this book should be classified as philosophy rather than science. It is philosophy rather than philosophizing, which sets it at a higher level of information organization than the De Grazia book. A science of symbolic systems, however, would have to be at a still higher level of organization. The treatment of money is a good illustration of the point. There already exists an abstract science of the monetary system using what are essentially mechanical theoretical models; it deals with such things as the quantity of money, its velocity of circulation, the various forms and species of liquid and other assets, the rates at which they are created and destroyed, and the reciprocal impacts of this system on interest rates, prices and incomes. At a mechanical level of abstraction this theory is fairly successful, and it tells us a good deal about the social system. It does not include and does not need to include the symbolic uses of money that Duncan writes about so entertainingly. All these things can be subsumed in the simple mechanical parameters. At this level of analysis the fact that we do not have an abstract theory of symbolic systems is perhaps not serious, because we can operate the monetary system fairly successfully without it. As we move into other areas of social life—politics, war and peace, religion and so on—we find that the mechanical models by and large fail us. By what theoretical model, for instance, would we have predicted the rise of Nazism or Islam, Christian Science or Bahai? Even at the level of the theory of war and peace, even though we have mechanical models of a sort, the symbolic elements are so woven into the system that we cannot abstract from them without grave danger of a lack of realism. When it comes to formulating actual theoretical models of symbolic systems, however, that might be capable of quantitative treatment, we find ourselves at a loss. Symbolic systems are so rich in variables that up to now, at any rate, it has been extremely difficult to abstract what is essential in them. Philosophy talks about these systems in all their richness; a science of symbolic systems would have to abstract their naked essence. This we have not yet done. Nevertheless, where there is a philosophy a science may be possible. The greatest danger of the scientist—and the social scientist is peculiarly exposed to this—is that he confines himself to the study of the things for which his existing methods are suitable. This means that he often does not ask himself questions that are intrinsically important, because he does not have any immediate means of answering them. It is the business of philosophy to ask important questions that do not have immediate answers. It is the great virtue of

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Duncan's work that he has enriched the agenda of the study of social systems and therefore has contributed to opening a way toward a much deeper social science than we now possess.

Short Reviews

MINUTES OF THE VIENNA PSYCHOANALYTIC SOCIETY, VOLUME I: 1906–1908, edited by Herman Nunberg and Ernst Federn. International Universities Press, Inc. ($10). In 1902 Freud began in his own apartment a series of meetings that became known after a time as the Wednesday Evening Meetings. To these he invited a heterogeneous group of intellectuals—physicians, physiotherapists, music critics, teachers, publishers and others—to discuss mental or behavioral disorders and their interpretation through the new techniques of psychoanalysis. This loose circle met regularly, took its work very seriously under the strong and provocative leadership of Freud himself and after a time was transformed into the Vienna Psychoanalytic Society. Among the members of the group were such well-known figures as Alfred Adler (who was to become chairman of the Vienna Society in 1910 and who was later to turn from Freud), Paul Federn (a professor of internal medicine who remained loyal to Freud throughout his life), Max Kahane (one of the four original members), Otto Rank (until his defection Freud's favorite pupil) and Wilhelm Stekel (another original member, who separated from Freud a little after Adler did). Although the meetings were instituted in 1902, minutes were not kept until 1906. They continued until 1915; Rank, the official salaried secretary of the society, was entrusted with the task of recording them. This volume, the first of three, covers the period from 1906 to 1908. It is of interest as both a chronicle of the coming of age, spread and development of psychoanalysis and a developing portrait of the workings of Freud's mind. One is struck alike by the scientific naïveté of the discussions and by the sincerity, dedication and imagination displayed by the master and the disciples. One is no less impressed—perhaps one may be allowed to say amused—by the fact that many of the views put forward today by orthodox Freudians differ little from those expressed in Freud's apartment more than half a century ago. The jargon vocabulary has become much more elaborate, but the contradictions, the vagueness, the oceanic conceptual muddle remain. Freud may have got over many of his early ideas, but his latter-day disciples evidently have not.

THE PAPERS OF BENJAMIN FRANKLIN, VOLUME IV, edited by Leonard W. Labaree and others. Yale University Press ($10). Benjamin Franklin, the 15th child in a family of 17, was, as an American contemporary once wrote to him, a "True Genius" who would not "content [himself] without entering more or less into almost everything." Like Jefferson, Franklin did so much in his life, enjoyed every phase of it, from female society to static electricity, so hugely that one marvels he ever found time to put words to paper. Yet somehow he found the time to do so in books, essays, letters, tracts, pamphlets, poems and other writings, which give expression to his incredible vitality, his unquenchable curiosity and enthusiasm, his penetrating intelligence, his shrewdness, his sense of humor and above all his sheer joy of life. The fourth volume of this scholarly and absorbing collection of his papers covers the period from July 1, 1750, through June 30, 1753. It contains, among other things, basic papers on electricity, including the experiments that proved the identity of lightning and electricity and the account of his famous (and hair-raisingly dangerous) experiment with kite and key; excerpts from *Poor Richard;* observations on astronomy and astrology; reports of conversations about natural history, Niagara Falls, frost damage, Franklin stoves, hickory tea; information on how to prevent candles from dripping; an essay on the rapid increase of mankind; conjectures about and observations on weather; memoranda on currency; astringent anticlerical opinions ("Now a days we have scarce a little Parson that does not think it the Duty of every Man within his Reach to sit under his petty Ministrations, and that whoever omits them offends God"); correspondence on books and printing, magic squares and magic circles, water spouts, electric shock treatment, hospital administration, fire insurance; an essay on "Making oneself a disagreeable companion," and so on and on. There is no better book to curl up with to dispel the vapors and to draw refreshment from a great and lively spirit. Each succeeding volume of the Yale *Franklin* earns the praise Henry Steele Commager aptly applied to the first: "A work of art."

THE FIRST NINE MONTHS OF LIFE, by Geraldine Lux Flanagan. Simon and Schuster, Inc. ($3.95). A well-conceived

MATHEMATICAL TABLES AND FORMULAS, Robert D. Carmichael and Edwin R. Smith

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IDEAS ON HUMAN EVOLUTION, edited by William Howells. Harvard University Press ($10). Twenty-eight selected essays written within the past 12 years that consider current varieties of thinking about evolution based on new finds and new applications of biological theory. Of central concern are the crucial problems surrounding the emergence of *Homo sapiens*. Among the contributors are George Gaylord Simpson, Theodosius Dobzhansky, Fredrik Barth, S. L. Washburn, Ernst Mayr, J. T. Robinson, W. E. Le Gros Clark, J. Bronowski, Kenneth Oakley, Henri-V. Vallois and Franz Weidenreich. Many illustrations.

SUBANTARCTIC CAMPBELL ISLAND, by Alfred M. Bailey and J. H. Sorensen. Denver Museum of Natural History ($7). A report—based on 1958 field work by the Denver Museum of Natural History expedition and on the experience of Sorensen and other naturalists—on the geology, vegetation, mammals and birds that have been observed on this small island lying south of New Zealand at the 52nd degree of latitude. Campbell is surrounded by notoriously storm-lashed waters and its normal weather consists of overcast skies and gale winds; snow occurs rarely but the number of days of rain in a year is 322, the average annual total of sunshine is 685 hours and the mean annual temperature is 44 degrees Fahrenheit. There is a year-round weather station, and attempts (unsuccessful) have been made to raise sheep on the island. Campbell is the main breeding ground of the southern race of the Royal albatross, the largest of flying birds; it is also the home of fur seals, sea lions and elephant seals. In addition to the life-history notes and the historical material contained in the report there are numerous photographs of the birds and mammals. A delightful book, which few readers would normally have access to and which every bird lover should have brought to his notice.

WORLD RAILWAYS 1961–1962, edited and compiled by Henry Sampson. Simmons-Boardman Publishing Corporation ($20). The seventh edition of a standard world-wide survey of railroad operation and equipment. Overcapitalized, in many respects inefficient, their operations often uneconomical, railroads are still struggling to survive, striving to compete as passenger and freight carriers with buses, trucks, barges and airplanes. If they are to hold out at all, efficiency will have to be much improved, one of the big hopes for the future lying in the automation of train controls and signals, of motive power, of business and accounting methods. The present volume makes it clear that some steps to improve the systems have been taken but that automation is a long-term project still in its infancy.

THE BIOLOGY OF ART, by Desmond Morris. Alfred A. Knopf, Inc. ($6.50). During the past half-century a number of chimpanzees, gorillas, orangutans and capuchin monkeys have produced approximately 1,000 paintings and drawings. They have not been helped or guided in this work and have not been rewarded for doing it. They have of course been provided with the necessary equipment, but beyond that they have been left to their own devices. The author of this book, a curator of mammals at the London zoo, has given more attention to this subject than anyone else. His story is concerned mainly with the 300-odd paintings and drawings of a young male chimpanzee named Congo. Congo is a passionate artist who works in short, intense spurts, turning out half a dozen or more drawings in half an hour. When he is practicing his art, he is so engrossed that he will not tolerate any interruption, even for food. He uses both hands; he holds his brush sometimes like a dagger, sometimes between forefinger and thumb like a pencil; he sits on a chair with an expression of intense concentration on his face; he uses color riotously but with taste; he is quite capable of drawing fine lines; his patterns are characteristic, at best having balance and harmony and at worst resembling the scribbles of very young children. What all this means is not too clear, but no one can look at Congo's drawings without the feeling that here is the work of a talented young cousin.

A History of Formal Logic, by I. M. Bocheński. University of Notre Dame Press ($20). This is a considerable achievement: a complete history of formal logic, from the beginnings in antiquity through its extensive development in modern times, including the pursuit of the form in India. Father Bocheński's book was first published in Germany in 1956 and was at once recognized as a landmark. Now it appears in an able translation—which could not have been easy—by Father Ivo Thomas, who has made certain revisions and adjustments to meet the requirements of English readers, added some material, omitted some lengthy citations of Aristotle and updated the bibliography. The summaries and interpretations are excellent and make possible a grasp of the subject as a whole and the tracing of the growth of its main systems. One of the valuable features of the book is the many annotated excerpts from writings on logic, material that is often hard to come by and not available in translation. An immense bibliography containing several thousand items, and meticulous indexes of names, symbols and subjects, add to the worth of this book as a reference.

An Introduction to the Physics of Vibrations and Waves, by Norman Feather. Edinburgh University Press. Aldine Publishing Co. ($6). A successor to Feather's *Introduction to the Physics of Mass, Length and Time*, noted in these columns two years ago. By reason of its clarity and the fact that the author even when discussing the pure theory of the subject never loses sight of the underlying physical phenomena, this is a much better than average introduction to mechanical vibrations, elastic waves, sound, light and the classical concepts of electricity and magnetism. An excellent chapter is devoted to modern subatomic physics and the wave-particle dualism characteristic of the contemporary approach.

Permanent Magnets and Magnetism, edited by D. Hadfield. John Wiley & Sons, Inc. ($16.50). A symposium that presents information on all aspects of permanent magnetism. The articles—which are addressed to engineers in the user industries, to those concerned with the technical and practical sides of magnet design and manufacture and to professional physicists as well as to graduate students—cover the history of magnetism, fundamental theory, classification of permanent magnet materials, magnet design and manufacture, permanent magnet applications, magnetic stability, the development of the permanent magnet industry, current research (much of which has been hitherto unpublished), future trends. Many illustrations.

Physics and Astronomy of the Moon, edited by Zdeněk Kopal. Academic Press ($16.50). An international group of scientists has contributed to this volume authoritative articles on such topics as the motion of the moon in space, libration of the moon, dynamics of the earth-moon system, photometry of the moon, the polarization of moonlight, lunar eclipses, topography of the moon, interpretation of lunar craters, physical observations of the lunar surfaces, temperatures on the lunar surface, radio-echo studies of the moon, the origin and history of the moon. Many illustrations.

Horizons in Biochemistry: Albert Szent-Györgyi Dedicatory Volume, edited by Michael Kasha and Bernard Pullman. Academic Press ($16). An international group of 28 scientists contributes essays that cover new concepts, new research findings and philosophical viewpoints concerning the future of modern biochemistry and molecular biology. The breadth of subject matter is most appropriate in this dedicatory volume because Szent-Györgyi himself has never ceased to push forward the horizons of biochemistry in the search for new mechanisms and new concepts to explain the central problems of biology.

Ancient Israel: Its Life and Institutions, by Roland de Vaux, McGraw-Hill Book Co., Inc. ($10.95). Father de Vaux, a leading biblical scholar and director of the École Biblique in Jerusalem, who has also had extensive experience as a field archaeologist, has assembled in this scholarly compendium every jot of information available about the life and institutions of ancient Israel. The topics include nomadism and its survival, family institutions, civil institutions (for example slavery, the concept of the state, the royal households, finance and public works, law and justice, economic life, divisions of time, weights and measures), military institutions (the armies of Israel, fortified cities, armaments, war), religious institutions (from the sanctuaries and temples to the rituals and feasts). The book is much too densely packed—the

facts descend on one like hailstones—for straight-through reading, but if you are looking for a reference source, De Vaux's work is without a peer in its field.

HUMAN PROBLEMS OF SUPERSONIC AND HYPERSONIC FLIGHT, edited by A. Buchanan Barbour and Sir Harold E. Whittingham. Pergamon Books. The Macmillan Co. ($20). Proceedings of the Fifth European Congress of Aviation Medicine, held in London in 1960. Man has a hard enough job keeping his kind alive on earth and he has now complicated the task, as one can see from the contributions to this book, by soaring upward and contemplating even more audacious voyages in the solar system. Oddly enough, however, it seems likely that he will get to the moon safe and well before he learns how to meet the challenges of his own environment and the dangers of living with others of his own kind.

ATLAS OF MESOPOTAMIA, by Martin A. Beek. Thomas Nelson & Sons ($15). An illustrated survey by the professor of Old Testament Exegesis at the University of Amsterdam of the history and civilization of Mesopotamia from the Stone Age to the fall of Babylon. Twenty-two colored maps and 296 gravure plates, some of which are superb, are supported by a concise text that touches on land and climate, archaeological excavations, the decipherment of cuneiform, the civilization of the Sumerians, the age of Hammurabi, the period of the Kassites, the rise of the Assyrians, the encounter of Israel and the Assyrians, Nebuchadnezzar, the religion of the Babylonians and related topics. Informative and readable.

FIVE INDIAN TRIBES OF THE UPPER MISSOURI, by Edwin Thompson Denig; edited by John C. Ewers. University of Oklahoma Press ($4). Observations of the manners and customs of the Sioux, Arikaras, Assiniboines, Crees and Crows, written by a fur trader on the Upper Missouri (1833–1858) who was married to an Assiniboine woman and assisted Audubon and the Culbertsons in collecting Missouri River fauna and provided Henry Schoolcraft with an Assiniboine vocabulary as well as a detailed "Report on the Indian Tribes of the Upper Missouri," which was not published until 1930, 76 years after it was written. Nothing is known of Denig's education, but the quality of his writing and his acute understanding of the history and ethnology of the region in which he spent 25 years mark him as a man of unusual gifts.

ON THE EXTERNAL CHARACTERS OF MINERALS, by A. G. Werner. University of Illinois Press ($4.50). An English translation by Albert V. Carozzi, professor of geology at the University of Illinois, of a classic of science written when Werner was 25 years old and published in 1774. The book represents a major advance in mineralogy in setting forth a systematic classification of minerals based on such external features as color, cohesion of the particles, shape, luster, transparency, hardness, flexibility, weight, and even smell, taste, sound, "adhesion to the tongue." His crystallographic concepts are rather poor because he considered crystallography to be applied mathematics rather than a branch of mineralogy, but the book as far as it goes can be regarded as the first modern text on descriptive mineralogy. The translator has worked from Werner's personal annotated copy of the original edition, now in the University of Illinois library, which contains much revised material not to be found in the first and only printed edition.

Notes

THE SCIENTIFIC OUTLOOK, by Bertrand Russell. W. W. Norton & Company, Inc. ($1.65). A soft-cover reissue of one of Russell's most attractive general books, which considers the effect of science on human life. It was first published in 1931, but like so many of Russell's writings it has gained rather than lost in point over the years.

ANATOMY OF AUTOMATION, by George H. and Paul S. Amber. Prentice-Hall, Inc. ($10.60). A plainly written student's handbook on the fundamentals of automation: where and how it fits into production sequences and industrial practices.

SCIENCE AND INFORMATION THEORY, by Léon Brillouin. Academic Press ($9). The second edition of this excellent book, one of the best advanced surveys of information theory, contains a number of revisions and adds two new chapters incorporating recent ideas and developments.

THE OVARY, edited by Sir Solly Zuckerman. Academic Press ($44). A two-volume account of the principal aspects of ovarian development, structure and function. Special emphasis is laid on the vertebrate ovary and mammals,

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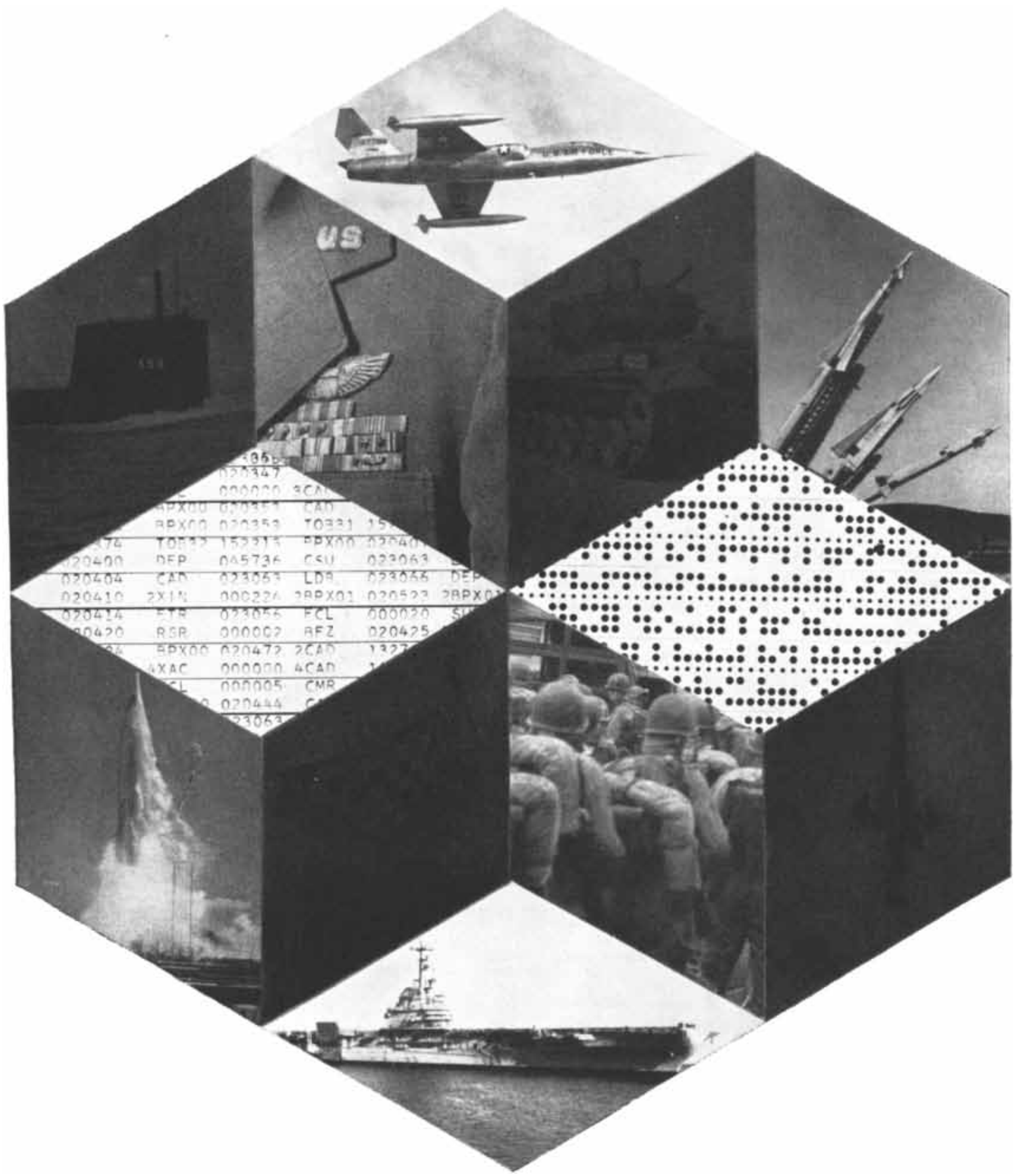

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but the invertebrate ovary is also briefly discussed.

Time's Arrow and Evolution, by Harold F. Blum. Harper Torchbooks, Harper & Row, Publishers ($1.65). A soft-cover edition of a thoughtful essay on the relation between the second law of thermodynamics and evolution.

Greek into Arabic, by Richard Walzer. Harvard University Press ($11). A collection of essays by an Oxford scholar, which deal mainly with his work in tracing lost Greek texts in Arabic versions and investigating the importance of Greek ideas in fashioning Islamic philosophy.

Neutron Diffraction, by G. E. Bacon. Oxford University Press, Inc. ($8.80). The second edition of a monograph on the technique of using neutron beams from nuclear reactors for studying the atomic architecture of solids and liquids.

A History of Physics, by Florian Cajori. Dover Publications, Inc. ($2). A soft-cover reissue of a well-regarded history of the elementary branches of physics, from the Greeks through 1925.

The Aim and Structure of Physical Theory, by Pierre Duhem. Atheneum Publishers ($1.65). A paperback of a classic on the philosophy of modern science that first appeared half a century ago but that is still, as the philosopher Ernest Nagel has remarked, "highly pertinent to current problems and a living source of current ideas."

The Encyclopedia of Electronics, edited by Charles Susskind. Reinhold Publishing Corporation ($22.50). A 1,000-page reference that contains more than 500 articles on all phases of electronics from accelerators to Vladimir Zworykin. The literacy level is higher than that usually encountered in books of this kind, many of the articles being clearly and simply written, with historical perspective.

Applied Dynamic Programming, by Richard E. Bellman and Stuart E. Dreyfus. Princeton University Press ($8.50). A detailed account of the application of the theory of dynamic programing to the solution of problems arising in connection with satellites and space travel, the determination of trajectories, feedback control and servomechanism theory, inventory and scheduling processes, allocation of resources and so on.

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