SCIENTIFIC AMERICAN

LIQUID CRYSTALS

SIXTY CENTS

August 1964

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Teeth have always succumbed to decay. Less so now because of M&T Stannous Fluoride protection.

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Sooner or later, rust or corrosion attacks metal. But much later and less severely now, with protection from M&T chromium, nickel, copper, tin and zinc plating processes.

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This is CORNING—problem solving in science and industry

Trampling hoofs dramatically prove the ruggedness of CENTURA® tableware in this scene from Corning's award-winning television commercial, "Bull in a China Shop."

Corning also has scientific tests for strength

The scientific tests proved CENTURA tableware—chemically strengthened by one of Corning's new *chemcor* processes—is so strong that a replacement is guaranteed if any piece breaks, chips, cracks, or crazes in normal use within three years.

Now the remarkable chemcor processes for strengthening glasses and glass-ceramics are helping solve problems for industry.

Chemically tempered safety plate provides the rear windows for the 1964 and 1965 Ford and Mercury convertibles. As strong as conventional auto glass, it is only one-third the weight and thickness.

Superstrong COREX® pipets are outlasting standard ware by a six-to-one margin.

Chemically strengthened eyeglass lenses provide better protection to the eyes of industrial workers. They are three times stronger than regular safety lenses and give 50 per cent better resistance to scratching.

New strengthened industrial tubing for sight sections and flowmeters has a modulus of rupture of up to 45,000 psi.

Can one of the chemcor processes help solve a problem for you?

For a technical progress report on the processes, write Corning Glass Works, 4 Houghton Park, Corning, New York—where solving problems for science and industry is our business.

CORNING
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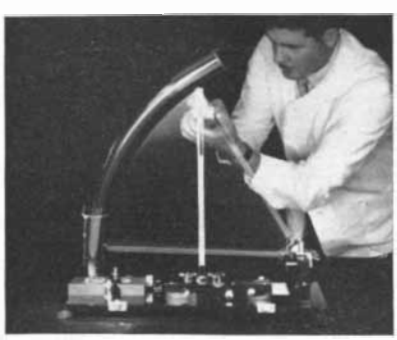

Federal specifications require safety lenses to withstand the force of a $\frac{7}{8}$-inch steel ball weighing 44 grams dropped from 50 inches. The new chemically strengthened lenses easily survive the impact of a $1\frac{1}{4}$-inch steel ball weighing 130 grams dropped from the same height. Each lens must pass this test before it is shipped to the manufacturer of the completed safety glasses.

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HOW LONG WILL OUR ABUNDANCE LAST?

Within the last hour the world's population has grown by more than 8,400 newborn souls, 292 of them American.

Our abundance will continue to outstrip our needs—if we can continue increasing our productivity. But today American agricultural employment, rural population, and the number of farms are in swift decline. Yet, each acre of those farms yields more; each farmhand controls greater horsepower. Farm machinery ranges from tractors to planes. More than 7,000 aircraft are spraying, fertilizing, and seeding. Result: U. S. crop production at a rate of only two man-days' work per acre—vs. a Far East average of 400.

Helping this production of U. S. abundance, so skillfully managed by the American farmer, Avco supplies many specialized pieces of farm machinery through its New Idea, Ezee Flow, and Barn-O-Matic Farm Equipment divisions. New Idea is offering the Uni-System—a self-propelled power unit with interchangeable machines for picking, husking and grinding corn, and for harvesting. Avco/Lycoming engines power many of the aircraft used in farming today.

Uni-System and other Avco farm machinery will help keep abundance ahead of domestic needs even as our population grows. In the year 2000 we will be feeding ourselves from one-half of the acreage required today. But of deeper significance, recognized by the people of Avco, is the promise such farm machinery holds for the better feeding of other peoples of the world, especially in areas where sufficient food may well mean peace.

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Established 1845 **SCIENTIFIC AMERICAN** August 1964 Volume 211 Number 2

ARTICLES

13 **RADIO-EMITTING FLARE STARS, by Sir Bernard Lovell**
Their radio waves are the first to be identified with a star other than the sun.

20 **INSECT ATTRACTANTS, by Martin Jacobson and Morton Beroza**
Chemists can now make synthetic lures that may reduce the need for insecticides.

28 **THE INFRA-CAMBRIAN ICE AGE, by W. B. Harland and M. J. S. Rudwick**
There is geological evidence of extensive glaciation some 600 million years ago.

46 **WINE, by Maynard A. Amerine**
Modern chemistry can account for a good wine but cannot explain great ones.

61 **THE EMBRYOLOGICAL ORIGIN OF MUSCLE, by Irwin R. Konigsberg**
Tissue-culture techniques shed light on the process by which cells differentiate.

68 **POPULATION CONTROL IN ANIMALS, by V. C. Wynne-Edwards**
Animals seem to develop social behavior that limits their rate of reproduction.

76 **LIQUID CRYSTALS, by James L. Fergason**
They behave mechanically as liquids but have optical characteristics of crystals.

86 **THE SOLUTREAN CULTURE, by Philip E. L. Smith**
A hunting culture with a unique tool kit originated in France 21,000 years ago.

DEPARTMENTS

6 LETTERS
8 50 AND 100 YEARS AGO
10 THE AUTHORS
38 SCIENCE AND THE CITIZEN
96 MATHEMATICAL GAMES
100 THE AMATEUR SCIENTIST
109 BOOKS
116 BIBLIOGRAPHY

BOARD OF EDITORS Gerard Piel (Publisher), Dennis Flanagan (Editor), Francis Bello (Associate Editor), Henry A. Goodman, James R. Newman, John Purcell, James T. Rogers, Armand Schwab, Jr., C. L. Stong, Joseph Wisnovsky
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THE COVER

The photographs on the cover illustrate some of the unusual optical properties of substances that pass through a liquid-crystal phase (see "Liquid Crystals," page 76). The micrograph at left shows the liquid-crystal cholesteryl heptyl carbonate, a naturally occurring compound that contains cholesterol. The iridescent colors of this liquid are characteristic of solid three-dimensional crystals. The three roughly actual-size squares at right each contain a mixture of two cholesteric liquid-crystal compounds: cholesteryl benzoate and cholesteryl nonanoate. The relative proportion of the two compounds differs by a tiny amount from square to square, accounting for the sharp differences in color. Liquid-crystal substances also change their color in response to minute fluctuations in temperature, chemical environment, mechanical stress and electromagnetic radiation.

THE ILLUSTRATIONS

Cover photographs by James L. Fergason and Paul Weller

Page	Source	Page	Source
14	Smithsonian Astrophysical Observatory	56	Alex Semenoick (*top*), Bunji Tagawa (*bottom*)
15–16	Allen Beechel	61–63	Irwin R. Konigsberg
17	Central Office of Information, London	64–65	Thomas Prentiss
		66	Irwin R. Konigsberg
18–19	Allen Beechel	69	V. C. Wynne-Edwards
21	United States Department of Agriculture	70	Joe Munroe–Photo Researchers, Inc. (*top*); Ylla from Rapho Guillumette (*bottom*)
22	Thomas Prentiss		
23	United States Department of Agriculture	71–73	Thomas Prentiss
24–25	Lee Boltin and Lincoln P. Brower (*top*), Thomas Prentiss (*bottom*)	74	V. C. Wynne-Edwards (*top*), Joan Starwood (*middle and bottom*)
26	Hatti Sauer	76	Paul Weller
27	United States Department of Agriculture (*top*), Thomas Prentiss (*bottom*)	78	James Egleson
		79	Alex Semenoick (*top*), James Egleson (*bottom*)
29	Joan Starwood	80–82	James Egleson
30	W. Brian Harland	85	Joan Starwood
31–36	John Langley Howard	86	Philip E. L. Smith
47	Joe Munroe–Photo Researchers, Inc.	88	Eric Mose
		89	Joan Starwood
48–49	Bunji Tagawa	90	G. Tendron, Musée de L'Homme, Paris
50	Bradley Smith–Photo Researchers, Inc. (*top*); Bunji Tagawa (*bottom*)	91	Eric Mose
		92	Philip E. L. Smith
51	William Vandivert	93	Eric Mose
52	Bradley Smith–Photo Researchers, Inc. (*top*); William Vandivert (*bottom*)	94	Joan Starwood
		96–98	Jerome Kuhl
		99	Jerome Kuhl (*top*), Joan Starwood (*bottom*)
53	Bunji Tagawa	100	Joan Starwood
54	William Vandivert	101–106	Roger Hayward

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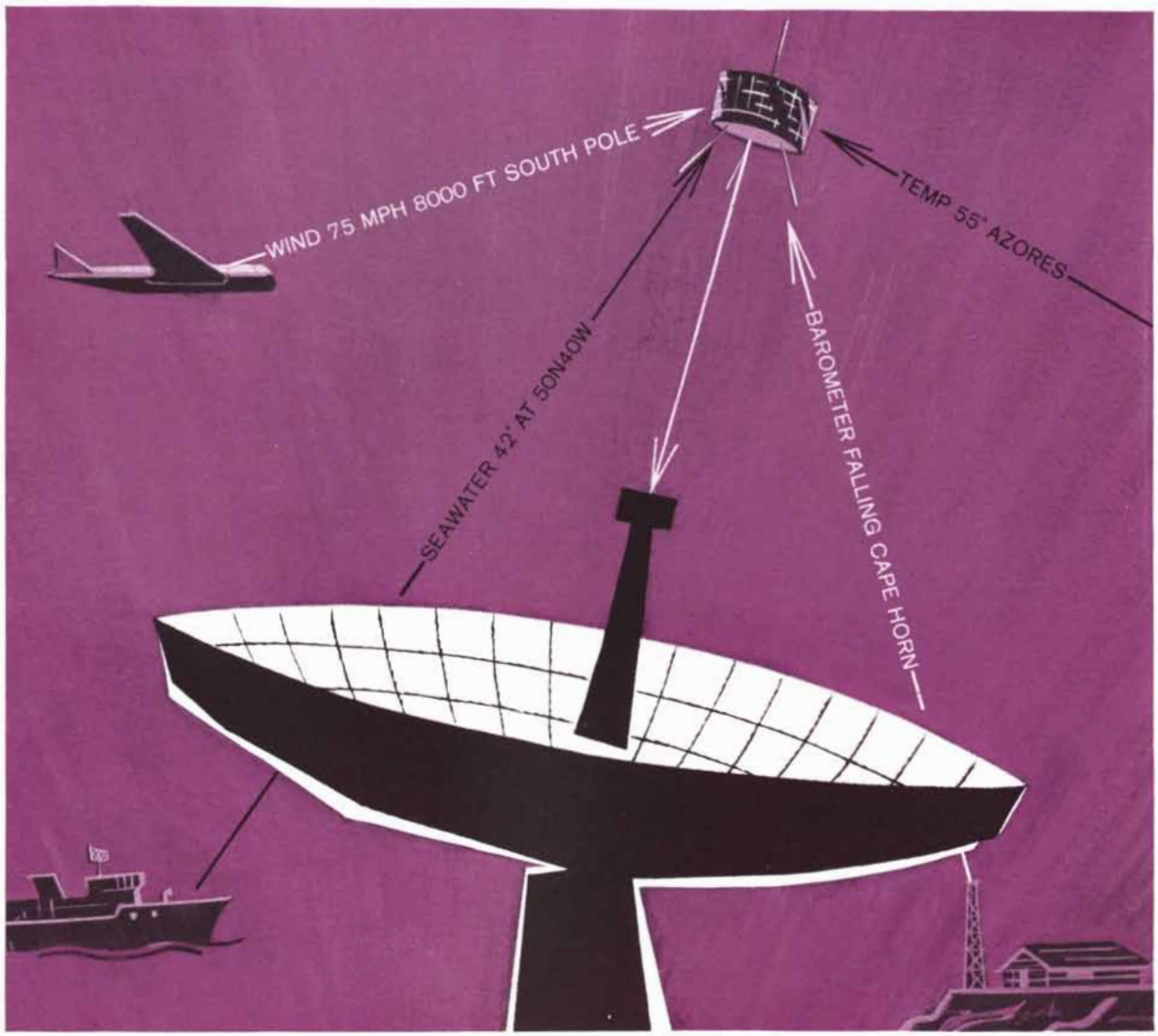
URGENT: Get sea and weather data—from everywhere at once!



Visualize, if you will, a system of sensors stationed around the world—on land, sea and in the air. Each one can sense local conditions, and store and transmit this information.

A satellite interrogates each sensor in turn. As it receives a report, the satellite determines its own position, using novel techniques. When a collection center comes into range, the satellite unloads, and waiting analysts then have a million bits of data to work with, each one keyed to its geographic point of origin!

Our Sylvania subsidiary has investigated just such a system—called DATACOL—in a study done for NASA. As projected, DATACOL would be a giant step forward in global data collection, with important commercial and military benefits. Oceanography and meteorology are prime fields where it can be used.

Working with NASA is one major way that GT&E contributes to the technical advancement of our nation. The vast capabilities of GT&E, directed by Sylvania Electronic Systems, enable us to handle every phase of almost any kind of electronic system, from initial research to on-location servicing.

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STRIP CHART RECORDERS

Shown below are three of many solid state servo strip chart recorders from Moseley, leading manufacturer of X-Y and strip chart recorders.

Model 7100A, 10", 2-pen recorder typifies precision Moseley instruments. Features include 1 megohm input impedance on all 10 ranges; 1 mv sensitivity full scale (optional), tilt-front chart carriage for quick paper change, thermocouple compensation modules, instant chart speed change, ½ second balance time, multiple calibrated spans, continuously variable remotely controlled "jump" speed, electric pen lift, recorder-controller options. Price $1800. Request catalog. F. L. Moseley Co., 433 N. Fair Oaks Ave., Pasadena, Calif. 91102.

Model 680, 5", 1-pen, compact laboratory recorder, $750.

Model 7130A, 5", 2-pen industrial recorder, available soon.

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LETTERS

Sirs:

In the article entitled "The Chemistry of the Noble Gases" [SCIENTIFIC AMERICAN, May] the authors point out that Linus Pauling in 1933 suggested the formulas KrF_6 (krypton hexafluoride), XeF_6 (xenon hexafluoride) and "certain 'perxenates'" such as H_4XeO_6 as some possible compounds of the noble elements. This section of the article is concluded with the following three sentences: "Several chemists immediately took up his suggestion and tried to produce reactions between the noble gases and fluorine or chlorine. They failed to find any evidence of the formation of compounds. The failure of these and other attempts over the years eventually convinced chemists that the noble elements were indeed immune to chemical activity."

Further on the authors describe the production of xenon hexafluoride (XeF_6) at the Argonne and other laboratories, and they describe the production of several varieties of stable perxenates, one being the sodium salt Na_4XeO_6. Yet nowhere in the article is a direct reference made to the fact that the formulas for these compounds produced by recent investigations on noble gas chemistry are the same as those set forth by Pauling more than 30 years ago.

HERBERT A. KORDAN

University of California
Los Angeles, Calif.

Sirs:

The ancient tunnel through Mount Castro ["The Tunnel of Eupalinus," by June Goodfield; SCIENTIFIC AMERICAN, June] is evidence for such a high degree of engineering and surveying skill that it appears quite likely that Eupalinus would have been able to slope the entire tunnel from north to south had his plans called for it. A possible explanation for the horizontal tunnel with the sloping channel may be that Eupalinus anticipated meeting water seepage within the tunnel. While this would have posed no problem for the crew in the southern section of a sloping tunnel, it would have been a problem for the northern crew. There the seeping water swiftly running toward the advancing end of the tunnel soon would have inundated the working crew. In a horizontal tunnel, although the water does not necessarily drain toward the exits, it collects in wide, shallow puddles, which can drain through the same type of porous strata that enabled the water originally to reach the tunnel.

The other alternative, digging a sloping tunnel with only one crew working from south to north, was probably ruled out because speed was important. If the above assumptions are correct, then at least the channel must have been dug in a south-to-north direction only.

WOLFGANG HALLER

Washington, D.C.

Sirs:

In the review by J. Bronowski of the book *Brains, Machines, and Mathematics,* by Michael A. Arbib [SCIENTIFIC AMERICAN, June], it is said that Norbert Wiener coined the word "cybernetics."

It may be of interest to some of your readers that in 1838 André Marie Ampère, in his book *Philosophy of Sciences,* appended a table of all human knowledge. In the third part of the group of sciences he listed various categories of disciplines, of which one among the social sciences is "Cybernétique."

BERN DIBNER

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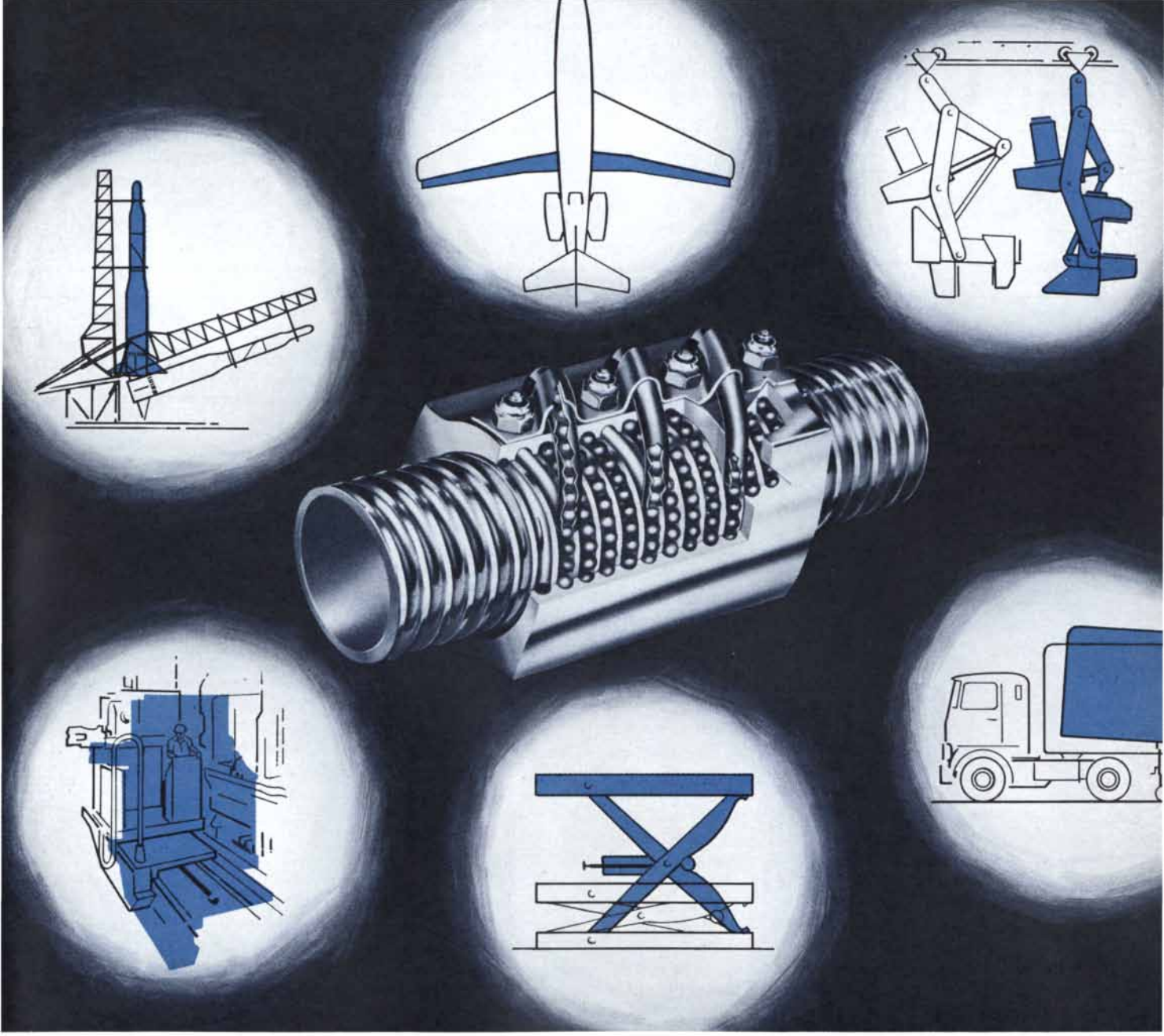

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Many advance designs now serving a wide variety of industries incorporate a ball bearing screw system of actuation for more efficient control of motion. Current applications range from missile launchers, satellites and aircraft to such down-to-earth products as automotive power steering, machine tool precision feeds and surgical tables. As the world's leading designer and producer of *ball bearing screws,* Saginaw can answer every requirement for custom assemblies, precision units or standard, off-the-shelf screws. Ball Bearing Screws have been designed and produced in sizes ranging from miniatures arming warheads on missiles to forty-foot assemblies on broaches.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

AUGUST, 1914: "The huge war now raging in Europe is the inevitable outcome of the unsymmetrical development of the mind of man. Perhaps the leading country of the world in the sciences and the arts is Germany. Certainly the leading country in the world in developing an aggressive and militarist policy is Germany. She is at once the most enlightened and the most reactionary of the greater nations of the earth. She is, above all other countries, the living embodiment of that monstrous paradox we call the advancement of science. Our progress in the control of nature for the benefit of mankind has been equaled only by the splendid intelligence with which we have perfected means of slaying one another. We learn how to abolish a disease and simultaneously invent a dreadnought. As scientific men, while half of us work for the establishment of heaven upon earth, the other half strengthens the possibilities of an increasingly ghastly hell. We approach the millennium and Armageddon along parallel roads."

"Thus far the most important lesson taught by the great European war is the supreme importance of the command of the sea. A few days ago the German fleet, most formidable in numbers and second to none in its fighting qualities, was free to steam where it would upon the high seas and the flag of its merchant marine was flown on every ocean and in every great port of the world. To-day the German battle fleet is shut up in the Baltic, its cruisers harried by the more powerfully armed ships of the allies; the ships of its truly magnificent merchant marine are either sheltering in neutral ports or being led as captures to the home ports of the enemy. So swift have been the navies of the allies to establish the supreme command of the sea that already, within two weeks of the declaration of war, Great Britain has been able to notify her merchant fleet that the customary routes of travel have been cleared of the enemy; she holds the North Sea so completely in her hand that already she has landed more than 100,000 troops upon the German right flank in Belgium."

"Among the discoveries made during recent investigations of the sun, the most interesting is undoubtedly the discovery of the sun's magnetism. The first evidence of the existence of magnetic activity on the sun was obtained through the brilliant discovery by Prof. George E. Hale of the Mount Wilson Solar Observatory that certain phenomena in the spectrum of sun-spots were due to the effects of magnetic action in the sun-spots themselves. Within the past year has come the announcement not only that there is local magnetic action in the sun-spots, but also that the whole sun is probably a gigantic spherical magnet with the poles of its magnetism agreeing approximately with the poles of its rotation. The sun's magnetic strength has been found to be about 80 times that of the earth, and the kind of magnetism, or polarity, as it is technically called, is similar to that of the earth, i.e., the north magnetic pole lies near the north pole of rotation."

"Deputy Consul-General Carl E. Loop of London reports that Dr. Archibald M. Low, a London consulting engineer, claims to have discovered a novel method for transmitting light by wire, the contrivance including a transmitter, a receiver and a connecting wire, with the transmitter a screen divided into a large number of selenium cells whose electrical resistance varies according to the light striking them. A synchronously running roller is passed over the screen and includes a number of alternating conductors and insulators, a motor driving the roller at a high speed. The invention is referred to by the inventor as a kinematographic application of common electrical principles, and while it has been tested to the equivalent of four miles, the inventor sees no reason why it should not be effective for greater distances."

"The Sperry gyroscope, in its application to the flying machine, is another example of the remarkable speed of the development of some modern epochal inventions. Two years ago Mr. Elmer A. Sperry fitted a Curtiss aeroplane with his device and experiments in stabilizing were then undertaken. Full details have now been received of the signal triumph of this wonderful product of American ingenuity in France, where, at a safety contest, the award of $10,000 offered by the French war department was won by the aeroplane fitted with the Sperry stabilizer. Lawrence D. Sperry, son of the inventor, piloted the winning machine, assisted by a mechanician. The control of the machine was perfect, young Sperry standing up during the flight with arms folded, while the mechanician climbed to the end of the lower plane and back."

Scientific American.

AUGUST, 1864: "The two rebel pirates, the *Alabama* and the *Florida*, with their tenders, have succeeded in reducing our commercial marine nearly three-quarters within three years. In 1860 the total tunnage of the United States, exclusive of whaling and steam tunnage, was 5,219,181 tuns. In 1864 it is in the neighborhood of 1,674,516 tuns; that is, we have lost in four years 3,544,665 tuns—not of course by captures alone, but by the transfer of American vessels to foreign flags."

"The prize of 50,000 francs offered by the Emperor Napoleon for the most useful application of electricity has at length been awarded to H. Ruhmkorff for his induction coil. The King of Hanover, having heard of the award, has forwarded to H. Ruhmkorff a large gold medal *pour le mérite*."

"The Paris correspondent of the London *Lancet* writes:—'Prof. Laugier, one of the surgeons of the Hotel Dieu, has recently made a most important communication to the Academy of Sciences. In an operation performed on the arm, in which the median nerve had been severed, that skillful surgeon united by a suture the two ends of the nerve. Almost immediately after signs of sensibility were observed and in a few days more the nerve had entirely recovered all its properties of sensation and motion. I need not insist on the importance of this case, which throws such a new light on the physiological pathology of the nervous system. No longer than two weeks ago, in a discussion which took place at the Society of Surgery, it was affirmed by several members that the regeneration of the nervous tubes, which alone could cause the recovery of sensibility and motility, was the work of weeks and months and could not immediately take place.' "

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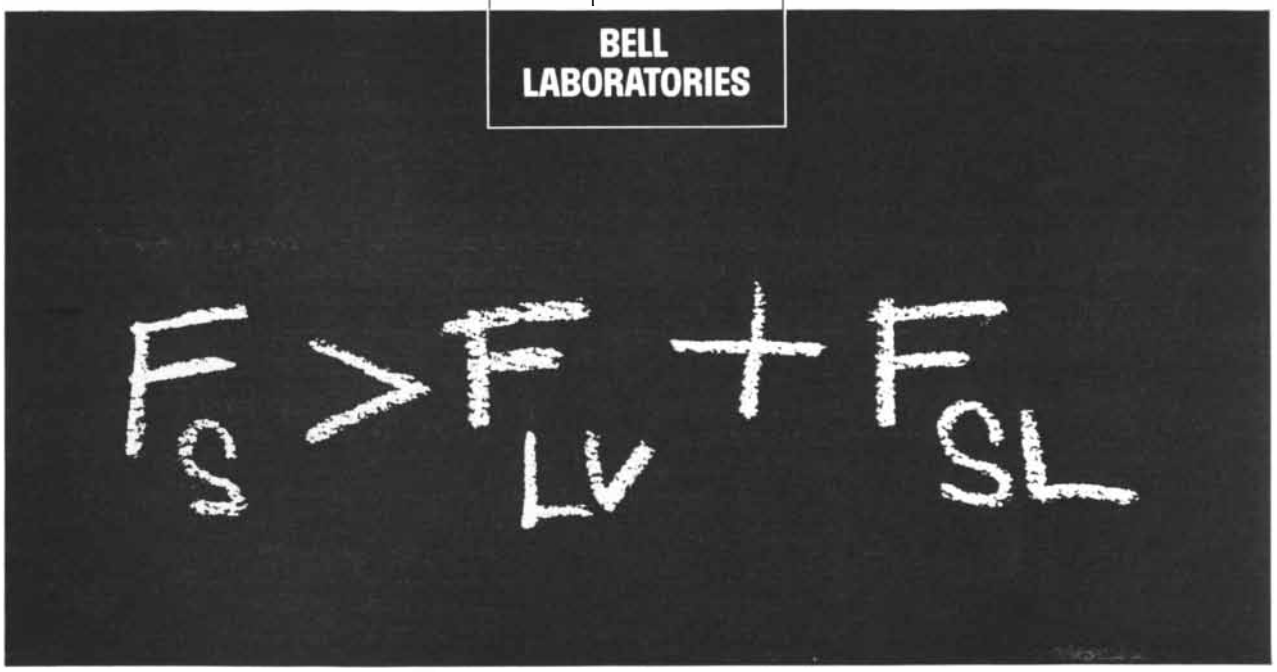
Report from

BELL LABORATORIES



Spontaneous spreading of a liquid on a solid occurs when surface tension of the solid (F_S) is greater than the sum of the surface tension of the liquid in contact with its vapor (F_{LV}) and the interfacial tension between the solid and liquid (F_{SL}).

A NEW WAY OF LOOKING AT ADHESION

It is well known that any two clean solids will form a strong joint if their contacting surfaces are ideally flat and smooth. But real surfaces are rough and do not provide the proper interfacial contact necessary for forming a strong joint.

If, however, one of the materials is a liquid that *spreads* spontaneously over the second material, interfacial contact occurs extensively and rapidly. Thus the key to making strong joints is to have one material in the form of a liquid which "wets" the second material.

By the proper application of this simple theory of adhesion, research chemists at Bell Laboratories have made strong adhesive joints between what had previously seemed to be "unbondable" materials—for example, epoxy and solid untreated polyethylene. The procedure is first to cure the epoxy to its solid form, and then to bring it into contact with molten polyethylene. The molten polyethylene spreads on the epoxy and when solidified forms a strong joint.

While a complete understanding of the bonding process must await further research, detailed consideration of the spreadability concept seems to be invaluable in dictating which one of a pair of materials must be put into the liquid state to form the joint. BELL TELEPHONE LABORATORIES, World Center of Communications Research and Development.

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THE AUTHORS

SIR BERNARD LOVELL ("Radio-emitting Flare Stars") is professor of radio astronomy at the University of Manchester and director of the Nuffield Radio Astronomy Laboratories at Jodrell Bank. A graduate of the University of Bristol, he received a Ph.D. from that institution in 1936 for research on the properties of thin metallic films. From 1936 to 1939 he taught physics at Manchester, where he also studied cosmic rays with P. M. S. Blackett. During World War II he worked on airborne radar for the Telecommunications Research Establishment. When he returned to Manchester at the end of the war, he set out to investigate the possibility of detecting large cosmic ray showers using war-surplus radar equipment. This experiment was soon transferred to Jodrell Bank, about 25 miles south of Manchester, because there was too much interference at the university site. Before long research at Jodrell Bank was extended to include radio echoes from meteor trails and radio waves from outer space. Since 1958 Lovell's investigation of the flare-star problem has occupied about 10 percent of the time of the 250-foot radio telescope at Jodrell Bank. Lovell was made an officer in the Order of the British Empire in 1946 and was elected a Fellow of the Royal Society in 1955.

MARTIN JACOBSON and MORTON BEROZA ("Insect Attractants") are research chemists in the Pesticide Chemicals Research Branch of the U.S. Department of Agriculture's Entomology Research Division in Beltsville, Md. Jacobson, who is in charge of natural-product research, was graduated from the City College of the City of New York in 1940 and did graduate work at George Washington University before joining the staff of the National Institutes of Health in 1941. He began his research on the chemistry of insect-control agents for the Department of Agriculture in 1942. Beroza, who directs synthesis investigations, received a B.S. from George Washington University in 1943 and an M.A. and a Ph.D. from Georgetown University in 1946 and 1950 respectively. He joined the Department of Agriculture in 1948. Jacobson and Beroza were joint recipients of the Hillebrand Prize for 1963, awarded by the Washington Section of the American Chemical Society for elucidating the chemistry of sex attractants isolated from insects and for synthesizing new compounds useful in attracting harmful insects.

W. BRIAN HARLAND and MARTIN J. S. RUDWICK ("The Great Infra-Cambrian Ice Age") are geologists at the University of Cambridge. Harland, who is University Lecturer in Geology, received an M.A. from Cambridge in 1938. After a short time doing geophysical research in Britain he was appointed associate professor of geology at the West China Union University in Chengtu. He returned to Britain to join the Cambridge faculty in 1946. Harland has been on about 20 Arctic expeditions, devoted largely to paleomagnetic studies. Rudwick was graduated from Cambridge in 1953 and obtained a Ph.D. in paleontology there in 1957. He has traveled to Australia and New Zealand to study modern coral-reef fauna, particularly brachiopods. His interest in the evolution of brachiopods led him to the study of the origin of Cambrian fauna.

MAYNARD A. AMERINE ("Wine") is professor of enology at the University of California at Davis. Amerine was graduated from the University of California at Berkeley in 1932 and obtained a Ph.D. in plant physiology there in 1938. He joined the Davis faculty in 1936; from 1957 to 1962 he was chairman of the department of viticulture and enology at Davis. During World War II Amerine served with the Chemical Warfare Service of the U.S. Army in Algeria and India. He is a past president of the American Society of Enologists and the author of several books on wine making, including *Table Wines: The Technology of Their Production in California* (with M. A. Joslyn).

IRWIN R. KONIGSBERG ("The Embryological Origin of Muscle") does research in the Department of Embryology of the Carnegie Institution of Washington. A graduate of Brooklyn College, Konigsberg acquired a Ph.D. in biology from Johns Hopkins University in 1952. From 1952 to 1958 he did research in pediatrics in the Laboratory of Chemical Embryology of the University of Colorado School of Medicine. In 1958 he joined the gerontology branch of the National Heart Institute and in 1961 he became a member of the staff of the Carnegie Institution.

V. C. WYNNE-EDWARDS ("Population Control in Animals") is Regius Professor of Natural History at Marischal College of the University of Aberdeen. A graduate of Rugby School and the University of Oxford, he did research at the Marine Biological Laboratory in Plymouth from 1927 to 1929. After obtaining an M.A. from Oxford he taught zoology for a year at the University of Bristol before joining the faculty of McGill University in 1930. While in Canada he participated in the MacMillan Baffin Island expedition in 1937 and organized the Canadian Fisheries Research Board expeditions to the Mackenzie River in 1944 and to the Yukon Territory in 1945; he was also a member of the Baird expedition to Central Baffin Island in 1950. He was appointed to his present post in 1946.

JAMES L. FERGASON ("Liquid Crystals") is a senior physicist in the applied physics department of the Westinghouse Research and Development Laboratories in Pittsburgh. He received a B.S. in physics from the University of Missouri in 1956 and joined the staff at Westinghouse in 1957. He is currently working on a biological model for the senses of smell and vision that is based on liquid crystals.

PHILIP E. L. SMITH ("The Solutrean Culture") is assistant professor of anthropology at the University of Toronto. A native of Newfoundland, Smith was graduated in 1948 from Acadia University in Nova Scotia, where he studied medieval and modern history and economics. He did graduate work in anthropology at the University of Bordeaux and at Harvard University, where he received a Ph.D. in 1962; this article is based on his doctoral dissertation on the Solutrean culture in prehistoric France. Although his original archaeological interest was in New World prehistory, particularly in the Mayan civilization of Central America, Smith later turned to Old World prehistory as a result of an expedition to the Shanidar Cave in Iraq. He has done fieldwork in Mexico, the U.S., the Middle East, the Nile valley, Japan and France. In 1962 he was appointed director of an expedition sponsored by the National Museum of Canada to work in association with the UNESCO project to salvage the antiquities at the site of the Aswan Dam Reservoir in Egypt.

MARCUS G. RASKIN, who in this issue reviews *Strategy and Conscience,* by Anatol Rapoport, is codirector of the Institute for Policy Studies in Washington, D.C.

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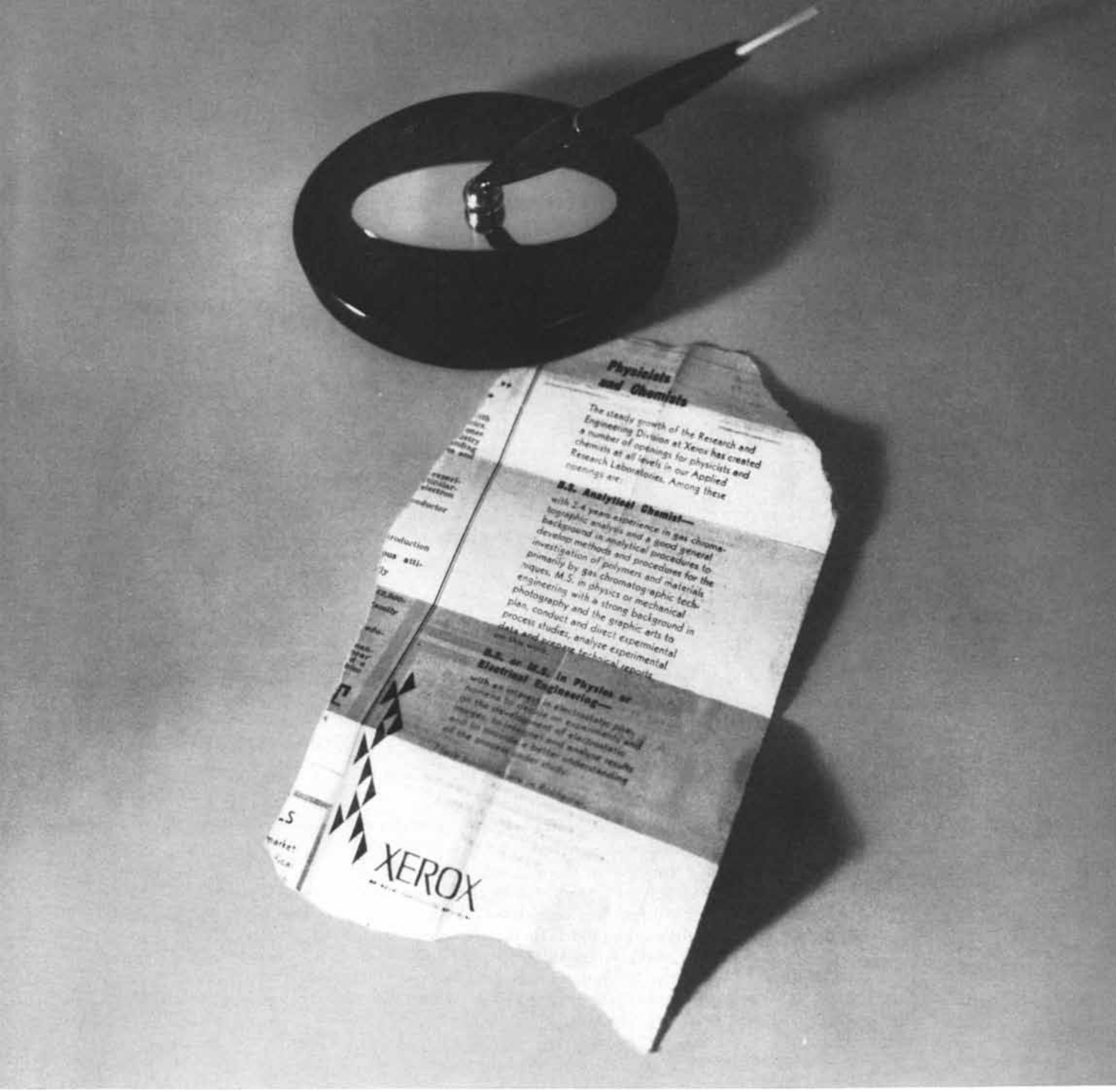

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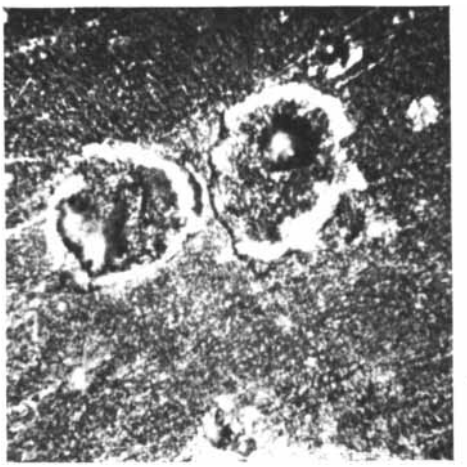

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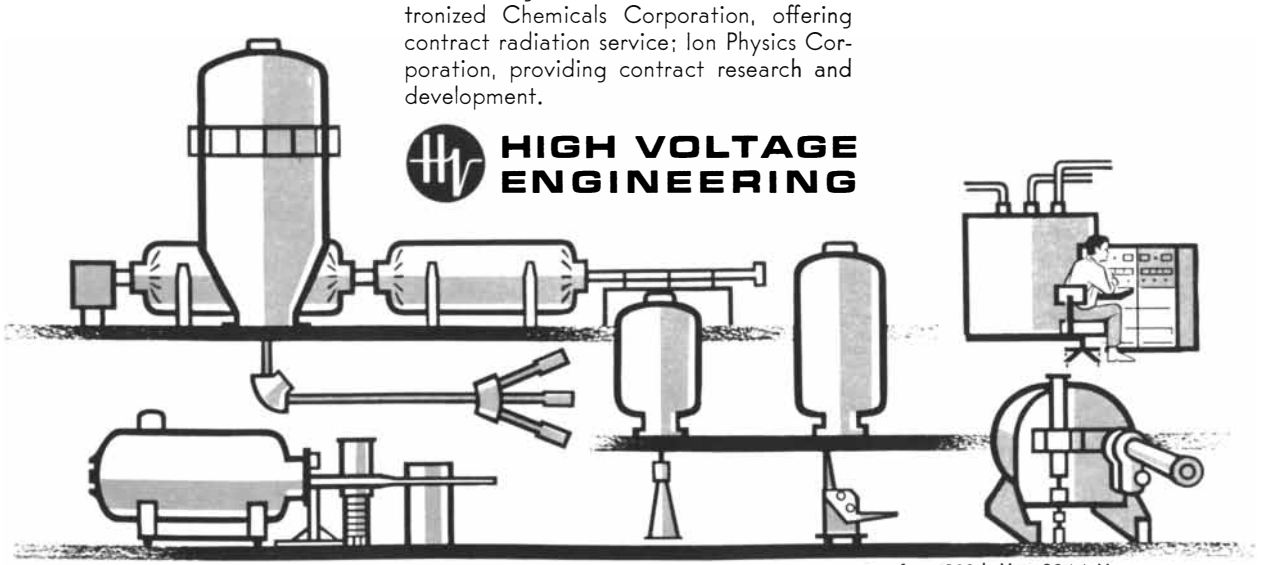

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Radio-emitting Flare Stars

Certain stars periodically erupt in a brilliant flare. The radio waves that are emitted by these flares are the first to have been definitely shown to come from individual stars other than the sun

by Sir Bernard Lovell

One of the earliest hypotheses of radio astronomy was that at least some of the radio waves falling on the earth from space were emitted by individual stars. In the three decades since the beginnings of radio astronomy the "radio star" hypothesis has been proposed twice on the basis of good evidence and rejected twice as a result of still better evidence. In recent months, however, it has been demonstrated that certain stars in our galaxy definitely do emit radio waves.

Until this demonstration was achieved the only common type of star among the 100,000 million stars in the galaxy that was known to emit radio waves was the sun. The sun's radio waves are detectable simply because it is so close. If other stars generated radio waves as the sun does, the problem of detecting their emissions would be formidable. In its quiescent state the sun has an equivalent black-body temperature of about a million degrees Kelvin (degrees centigrade above absolute zero) on wavelengths in the centimeter range and a lower temperature on longer wavelengths. (A black body is an ideal emitter of radiation, and "equivalent black-body temperature" is a measure of radio brightness.) When the sun produces a large flare, however, its black-body temperature can reach values of the order of 10 million million degrees. Flares this hot on the nearer stars would probably be just at the limits of detection by the largest radio telescopes. Such maximum-energy flares have erupted from the sun only a few times in the past 20 years, and each one has lasted for no more than a few minutes. Therefore if the sun is typical, the task of identifying any other stars as radio emitters could not be pursued with great hope of success. Nevertheless, a few years ago it occurred to me that certain features of a particular type of faint variable star might indicate conditions favorable to the frequent production of powerful radio emissions. Accordingly in 1958 I initiated a long investigation of these stars with the 250-foot radio telescope at Jodrell Bank in Britain. After some years of uncertainty these studies have now begun to yield gratifying results, which I shall describe after a brief review of the background of the radio-star problem.

As regular readers of *Scientific American* are aware, Karl G. Jansky of the Bell Telephone Laboratories founded radio astronomy in 1932 when he discovered the existence of extraterrestrial radio waves. His proof that the source of the radio disturbance was not only extraterrestrial but also extrasolar was simple and elegant: the strength of the radio waves varied with a period of 23 hours 56 minutes, which is a sidereal day. The subsequent task of discovering the precise source of the radio emissions turned out to be long and arduous, and in spite of the dynamic advances of the subject during the past 15 years we cannot even today give an unequivocal description of the origin of the whole phenomenon.

Grote Reber, using his historic pre-World War II radio telescope in Wheaton, Ill., produced a rough map of the intensity of the radio emission from different parts of the sky. The similarity between the distribution of the radio intensity and the known stellar structure of our galaxy suggested that the ordinary stars might be generating energy in the radio region of the spectrum as well as in the region of visible light. Reber soon dismissed this simple idea because he was unable to find evidence that any of the ordinary stars produced radio waves. He suggested instead that the radio energy must be coming from ionized hydrogen in interstellar space, whereupon the idea of radio stars was dropped.

At the end of World War II a number of groups turned their attention to the problem of the radio emissions from space. The rapid technical developments in radio telescopes and receiving equipment produced an increasing amount of detail, which soon led to a revival of the radio-star concept, at least in partial form. There were three main reasons. First, wartime radio equipment had revealed the sun to be a strong emitter of radio energy, particularly when it was disturbed by sunspots and flares. Second, the observation that the radio emissions from the

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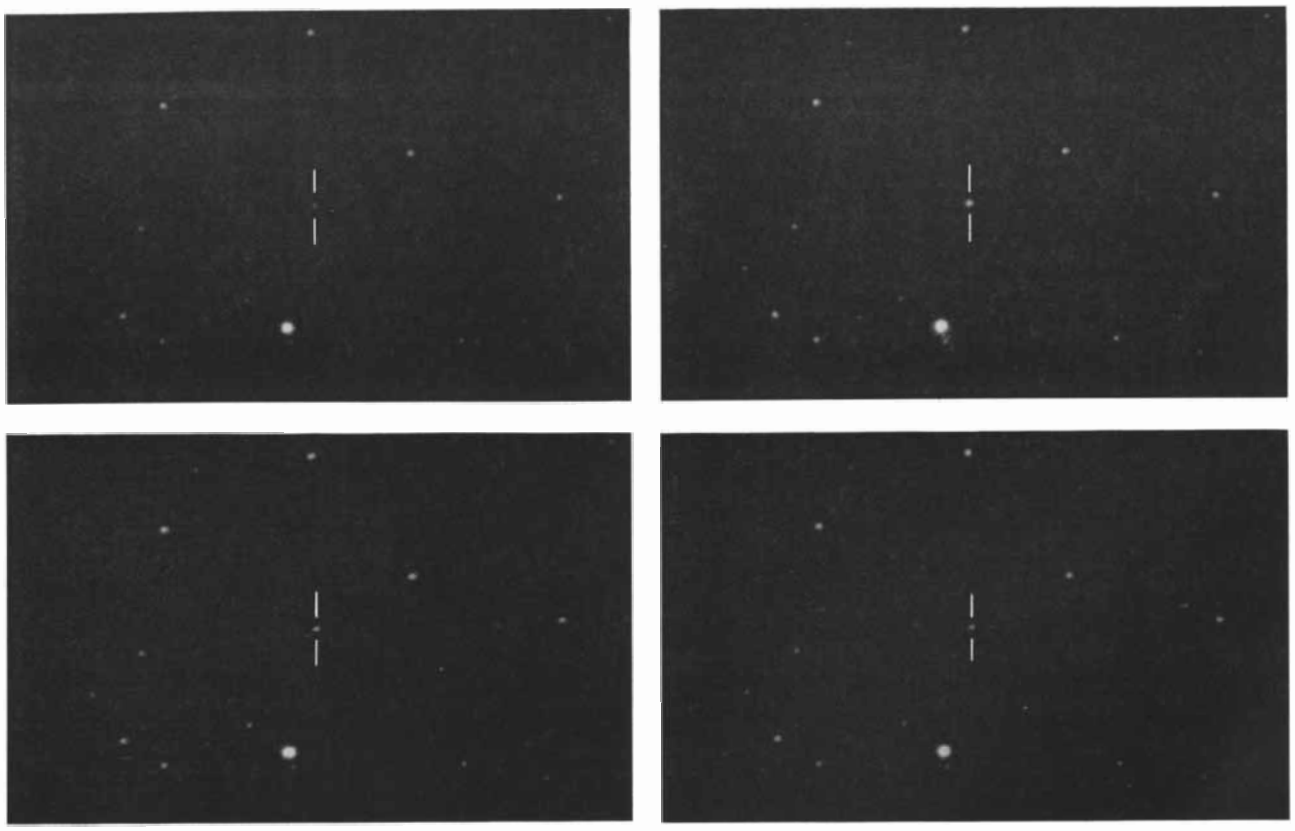

FLARE STAR, Ross 882 (*between white lines*), blazes up in one of its periodic flare events (*top right*). The photographs were made at two-minute intervals by the 20-inch Baker-Nunn satellite-tracking camera at the Iranian station of the Smithsonian Astrophysical Observatory. It is possible that the peak brightness occurred between the first and second photographs. Even in the first and last two photographs the star is somewhat brighter than normal. Photographic and radio changes of this event are shown on page 18.

direction of Cygnus fluctuated in intensity led to the idea that at least some of the radio waves must be originating in starlike objects. Finally, new techniques employing two or more antennas could pinpoint radio sources with some degree of accuracy. These showed that localized sources of radio emission do indeed exist. In 1949 the German astrophysicist A. Unsöld and in 1951 the Dutch astronomers Gart Westerhout and Jan H. Oort developed comprehensive theories of the radio emission from our own galaxy that called for a contribution from stars.

Once again these radio-star theories did not survive for long. The majority of the discrete sources were found to be far outside our galaxy, although a small number turned out to be remnants of supernovas within it. In this period the Soviet astrophysicist I. S. Shklovsky developed the theory that radio emissions in our galaxy have two major components: a thermal component due to ionized hydrogen (as suggested by Reber) and a nonthermal component generated by the synchrotron process, involving the motion of electrons traveling at nearly the speed of light in the magnetic field of the galaxy. These general ideas are invoked today to explain the radio emission observable over a wide range of wavelengths from our galaxy. As a result of the Shklovsky theory the radio-star concept was dropped for a second time.

An account of the first true radio stars should begin in October, 1948, when William J. Luyten of the University of Minnesota discovered a star 8.6 light-years away, which makes it one of the nearest stars. Now designated UV Ceti, the star is a faint red dwarf only about 50 millionths as luminous as the sun and 8 percent the diameter of the sun. On December 7, 1948, Luyten observed a short-lived increase in brightness of two magnitudes (six times), which drew attention to some measurements that Alfred H. Joy and Milton L. Humason had made at Luyten's suggestion a few months earlier with the 100-inch telescope on Mount Wilson. They had observed the sudden appearance of bright lines of helium in the spectrum of the star and a strengthening of the continuous spectrum in the ultraviolet region. In retrospect it seemed clear that effects reported in 1940 and 1945 by Adriaan van Maanen of the Mount Wilson Observatory on the stars WX Ursae Majoris and Ross 882 represented similar events. After Luyten's discovery visual and photoelectric observations of the flares were undertaken by a number of other astronomers, particularly P. E. Roques of the Griffith Observatory in Los Angeles, the French astronomer M. Petit and the Yugoslav astronomer V. Oskanjan.

In 1950 the International Astronomical Union officially recognized such bodies as a new class of variable stars, now commonly known as the UV Ceti class or as flare stars. All are red dwarfs, which are the most common single type of star in the galaxy. The flare phenomenon is a sudden, irregular, short-lived increase in brightness. On one occasion Oskanjan observed a six-magnitude (250 times) increase in the brightness of UV Ceti. Increases of more than one or two magnitudes, however, are quite rare. Normally the spectra of the stars show emission lines of hydrogen and ionized calcium, but during the flare the hydrogen lines and the ultraviolet continuum grow stronger and lines of neu-

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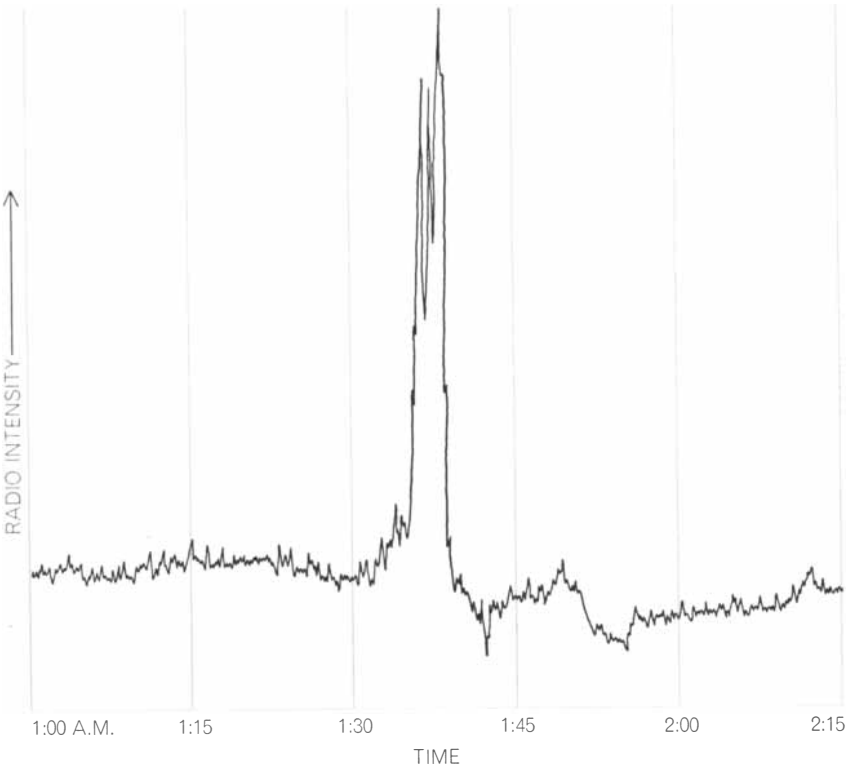
tral and ionized helium and singly ionized iron appear.

At the I.A.U. symposium on nonstable stars in Dublin in 1955 some astrophysicists suggested that the flares, like those on the sun, occur in only a small part of the star's atmosphere, whereas others held that the entire atmosphere is involved. Because the output of energy in the visible portion of the spectrum was so much greater than in solar flares, I was led to hope that greater energies might also be manifest in the radio part of the spectrum. By 1958 optical observations had shown that flares of one or two magnitudes appear at the rate of about one every 35 hours, the small flares lasting a few minutes and the larger ones half an hour. With flares occurring so regularly I thought it would be a reasonable gamble to devote a small amount of the time of the 250-foot Jodrell Bank radio telescope to the study of flare stars.

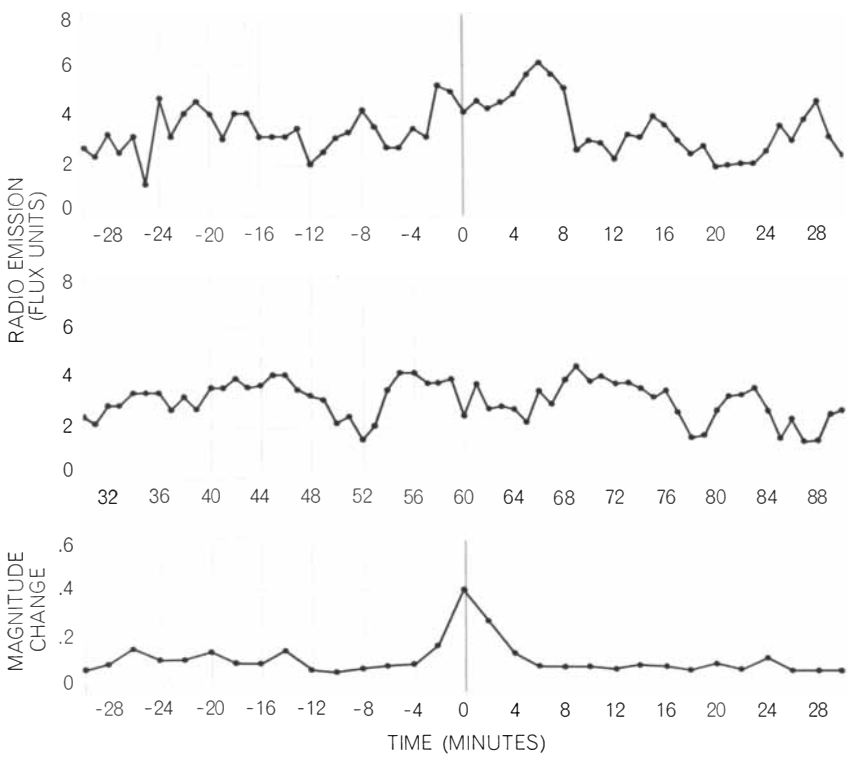
For the attempt to detect radio emissions the telescope receiving equipment was set at a frequency of 240 megacycles, continuously recording on a paper chart. The big parabolic reflector was placed in automatic sidereal motion to track UV Ceti across the sky. On the very first night—September 28–29, 1958—we apparently succeeded in recording for the first time a radio emission from a star other than the sun! The record was clean for the first four hours, but shortly after 1:30 A.M. a burst of radio waves caused the pen to jump [*see top illustration on this page*]. The main effect ended in 15 minutes and the minor disturbances ceased after 30 minutes. For the rest of the night's run the record remained virtually smooth.

Although in retrospect I believe this is the first recorded example of radio emission from a flare star, the proof at that time was not certain. Perhaps we had merely detected a radio disturbance of terrestrial origin. In an attempt to exclude this possibility we set up two aerials in the radio telescope and two recording channels. The aerial at the focus of the parabolic reflector followed the star, as in the first series; the other aerial pointed a few feet off the axis of the reflector so that its beam swept out a nearby comparison area of the sky. Any radio emissions of terrestrial origin should therefore have been recorded simultaneously in both channels.

In this way we studied five different flare stars at intervals until April, 1960, observing them for a total of 474 hours. After the exclusion of some doubtful cases there were 13 events similar to the first one, all compatible with bursts



RADIO EMISSION was recorded on September 29, 1958, as the 250-foot telescope at Jodrell Bank in Britain tracked the prototype flare star, UV Ceti, across the sky. The record probably represents the first radio emission to be detected from a star other than the sun.



RECORDS OF 23 MINOR FLARES were made by superimposing the individual records. The radio record starts at the top and continues in the middle, extending to 90 minutes after the peak of the photographic flare. The continuation is a "control," which shows that no spurious effects were introduced in superimposing the radio results. The photographic record (*bottom*) covers a period that includes 30 minutes before and after the peak of the photographic flare. It shows changes in photographic magnitude. The flux units on the vertical radio scale are 10^{-26} watt per square meter of receiver area per cycle per second.

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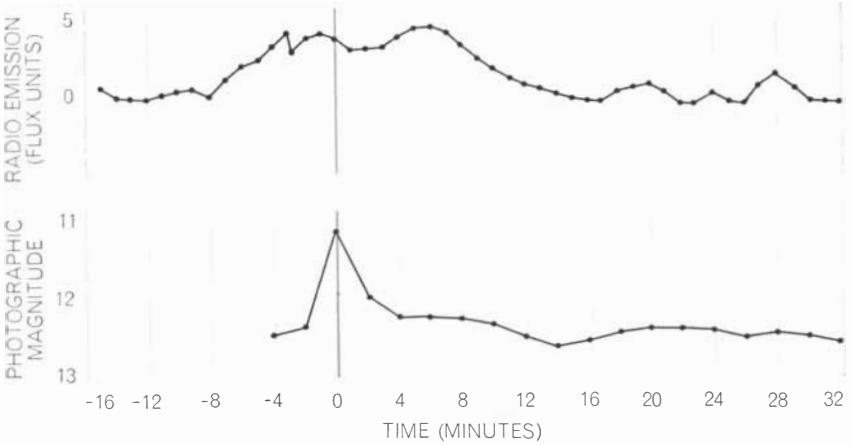
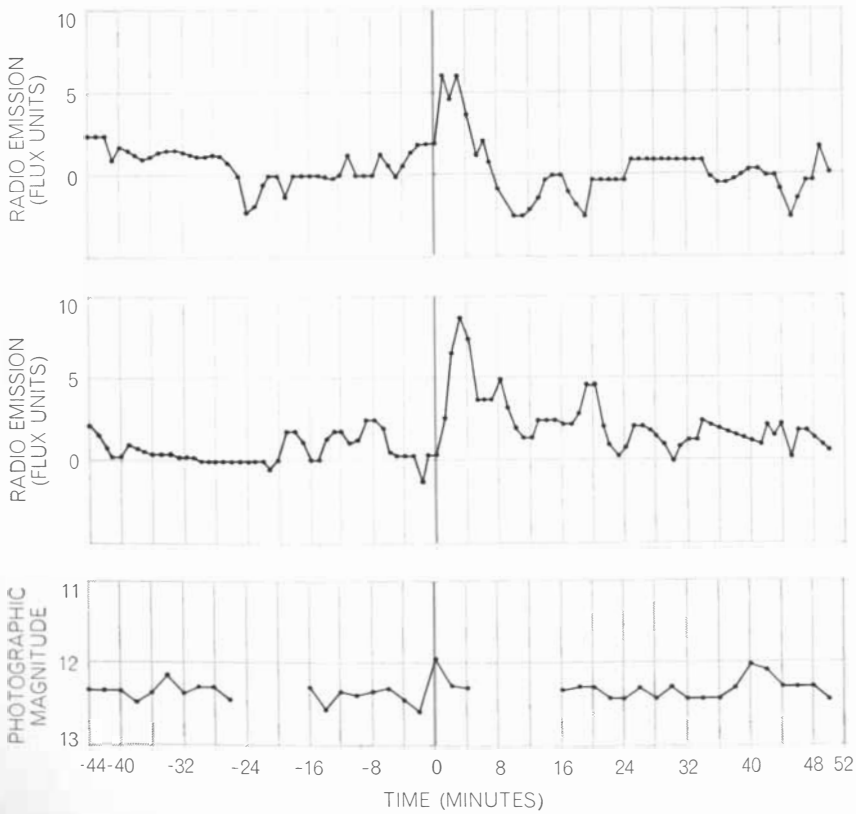
of radio emission from the flare star. These appeared only on the star channel, not on the comparison channel. The belief that they did indeed represent real effects from the star drew support from the fact that the rate of "radio flares" on UV Ceti was one in 35 hours, the same as the rate reported by Roques for visual flares.

At this stage it seemed unlikely that further radio observations alone would yield a more decisive answer to the problem of whether or not we really were detecting radio emissions from stars. I was unwilling to publish the results until the relation of the radio emission to visible flares could be established absolutely. Therefore in the summer of 1960 I asked Fred L. Whipple, director of the Smithsonian Astrophysical Observatory in Cambridge, Mass., if he could assist by photographing the star simultaneously with the radio observations. He immediately arranged for the 20-inch Baker-Nunn cameras of the Smithsonian's satellite-tracking network to be used when they were not tracking satellites. In September, 1960, we began a cooperative program of simultaneous photographic and radio observation that is still continuing. The technique has been to schedule a period of about 14 days when the moon is not up and to work every night between certain hours on an agreed star mutually visible to one or more of the satellite cameras and the radio telescope.



UV CETI FLARE of October 19, 1963, produced records like those of the 23 earlier minor flares. This radio record, like several others, shows change in output in relation to a steady celestial radio source that is used for calibrating the receiver before each night's work.



FLARE OF OCTOBER 25, 1963, on UV Ceti appears to have been a rare event. It produced significant emission on 408 (*top*) and 240 megacycles (*middle*). The optical peak occurred first; the radio output was much greater than usual for the change in optical magnitude. During the blank periods in the photographic record the camera was tracking satellites.

The five Baker-Nunn cameras are at longitudes spread about Jodrell Bank: Shiraz in Iran, Olifansfontein in South Africa, San Fernando in Spain, Curaçao in the Netherlands Antilles and Villa Dolores in Argentina. The most recent series of observations—in February of this year—were the 20th in the combined program, in which the flare stars UV Ceti, Ross 882, Ross 154, AD Leo, V371 Orionis and EV Lacerta have been observed for a total of 2,245 hours. The task of analyzing the photographic results has been undertaken by Leonard H. Solomon of the Smithsonian staff. The work is so time-consuming that thus far only a third of the record has been completely analyzed.

In the first year of the joint program—September, 1960, to October, 1961—six series of combined observations were made. Although no really bright optical flares occurred during this period, there were 23 minor flares, as indicated by fractional increases in the photographic magnitude of the star. Since the optical flares were decisively correlated with radio emissions, the results were published in April, 1963. In this phase of the program the radio telescope followed the flare stars for 727 hours and the cameras made photographs for 216 hours, resulting in an overlap of good radio and photographic coverage of 166 hours. Because of the lack of any really bright flares, the relation of the radio records to the flares was investigated by superimposing the records of all the events, aligned on the time of the peak of the photographic flare [*see bottom illustration on preceding page*].

The superimposed records indicated that there is a significant increase in the radio emission extending from two minutes before to eight minutes after the peak of the photographic flare. In order to make quite certain that this apparent

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rise was not introduced in the process of analysis, we analyzed a further hour of each record as if a radio flare had occurred exactly one hour after the optical flare. There was no sign of any increase of radio intensity in this "control" analysis. Hence there is only one chance in several hundred million that the increased strength of the radio signal at the time of the photographic flare was not associated with the flare. Comparison of the mean increase in radio emission with the mean peak change in the photographic magnitude of the flares over an 11-minute interval gives the relation between radio output and flare magnitude as 4.7 flux units per magnitude change in flare intensity. (The flux unit is 10^{-26} watt per square meter of receiving surface per cycle per second.)

As the analysis of the subsequent series was proceeding, a quick look at the photographs made during the 18th series of observations on UV Ceti (in October, 1963) indicated that an optical flare of magnitude 1.1 had occurred on October 19 and one of magnitude .6 on October 25. Encouraged by the success of the earlier experiments, we had by this time equipped the radio telescope to observe not only at 240 megacycles but also at 408 megacycles (respectively equivalent to wavelengths of 1.25 meters and .735 meter). Offset aerials on each frequency provided comparison channels. The relative intensity of radiation at various frequencies—in other words, the spectrum of the radiation—tells much about whether it originates in a thermal process or in a nonthermal one; since this question is of great interest we immediately undertook to analyze the two events [*see illustrations on opposite page*].

The time relation of the aligned radio and photographic records of the October 19 event has an obvious similarity to that of the 23 superimposed observations made earlier, with the radio emission rising to a maximum before the peak of the optical flare. Moreover, the increase of 4.5 radio flux units for this magnitude 1.1 photographic flare corresponds closely with the increase in radio flux per magnitude found in the earlier analysis. At 408 megacycles little, if any, change was recorded. Whatever increase there may have been was less than 2 flux units. Hence in the October 19 event the intensity of radiation dropped significantly with increasing frequency. Plotted on a graph, the spectrum of 240 and 408 megacycles is a curve with a slope that is characterized as being steeper than $f^{-1.5}$ [*see bottom illustration on next page*].

THE 250-FOOT TELESCOPE at Jodrell Bank is the largest fully steerable antenna in the world. It was used to make many of the important new observations discussed in this article.

The flare of October 25 shows an entirely different state of affairs. Not only is there significant emission on both radio frequencies; there is also a pronounced time lag between the maximums of the optical and the radio flares and between the maximums on the two radio frequencies. Moreover, the radio output of 13.3 flux units per magnitude is significantly greater than in any previous events studied. The decrease in intensity with increasing frequency is less than half that observed in the October 19 event; in graphic terms the spectrum has a slope of $f^{-.6}$.

The evidence so far on both the time relations and the spectra suggests that we are dealing with two separate phenomena. The 23 superimposed events of the earlier work and the event of October 19 are of one type. They are apparently analogous to Type I solar bursts: large bursts of radio noise in which energy is emitted over a broad range of frequencies and reaches its maximum at about the time the optical flare is brightest. The October 25 flare is a much rarer event on a flare star, resembling solar bursts in which the peak intensity of the radio emissions starts at high frequencies and drifts to lower frequencies. We cannot yet say whether the October 25 flare is analogous to the Type II solar burst, which is characterized by a relatively slow frequency drift, or with the Type III burst, in which the frequency drifts rapidly. The reason is that it is difficult to compare solar radio events with those on flare stars, which have a low temperature, a low density and a high surface gravity.

On February 8, 1964, the Smithsonian

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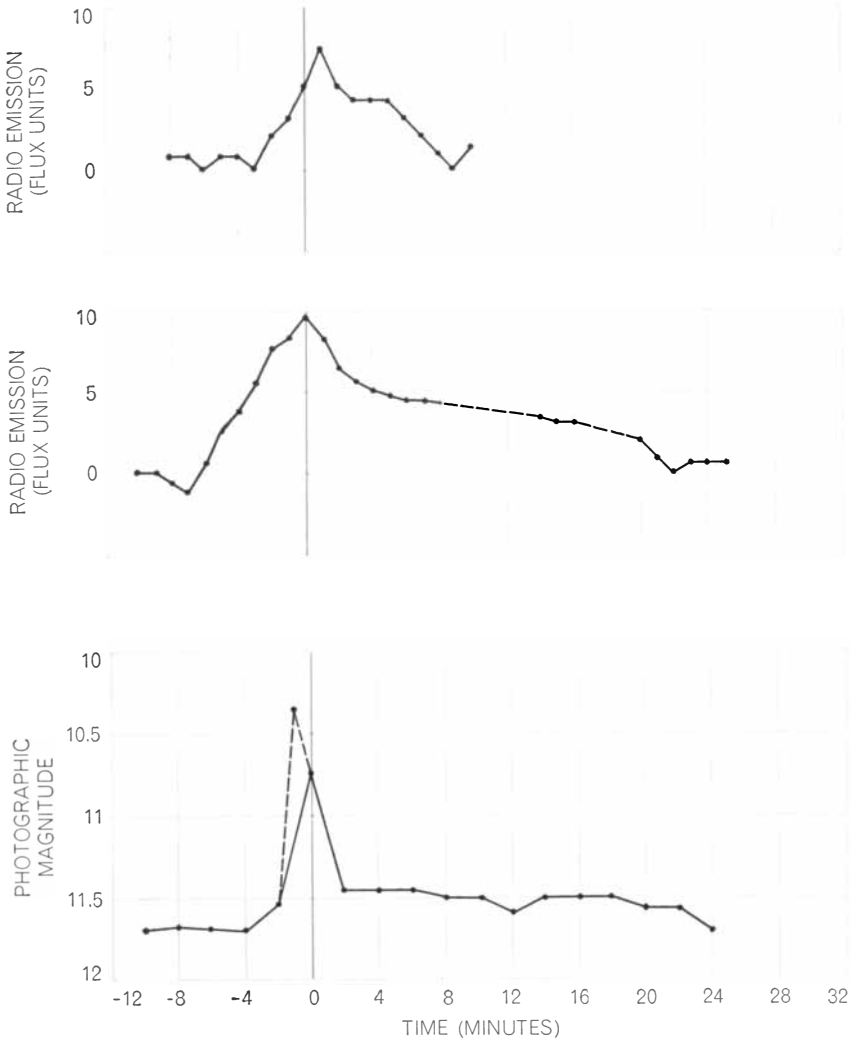
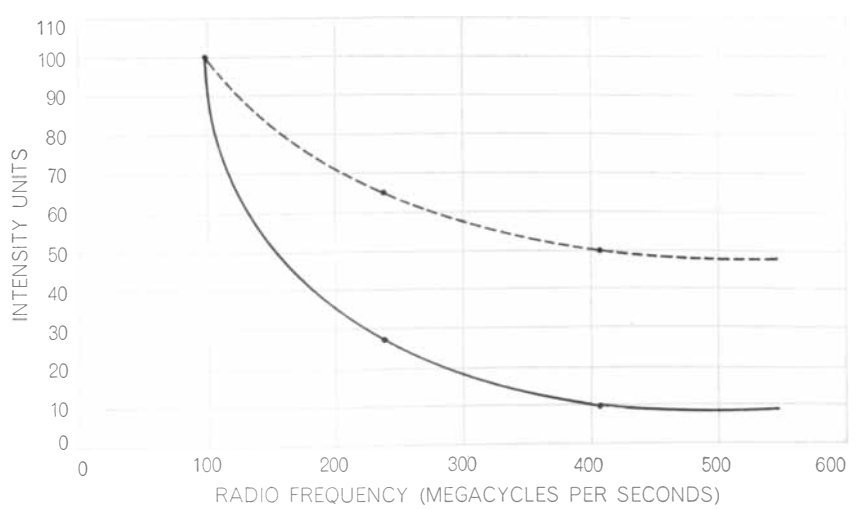


ROSS 882 FLARE of February 8, 1964, was observed on 408 megacycles (*top*), 240 megacycles (*middle*) and photographically. There is less difference in the intensities of the radio records on the two frequencies than there was in the October 19 UV Ceti event. Peak of optical flare may have occurred between two of the photographs, as indicated by broken line.



RADIO SPECTRUMS of $f^{-1.5}$ (*solid line*) and $f^{-.5}$ (*broken line*) for 240 and 408 megacycles per second are said to have a negative slope because they are higher on the left. If they were higher on the right than on the left, the curves of the spectrums would have a positive slope.

camera in Iran recorded a large flare on Ross 882 and good radio records were obtained simultaneously at Jodrell Bank on 240 and 408 megacycles. This event seems to be typical of flares we have provisionally designated Type I. The frequency spectrum, however, has a slope of $f^{-.5}$ compared with a slope of $f^{-1.5}$ for the Type I flare of October 19. It is not yet possible to draw conclusions from this sparse data on the frequency spectrum of the February 8 flare other than that nonthermal mechanisms must be operating. If the mechanism were thermal, the spectrum would slope in the opposite direction and would be steeper; that is, the radiation would be considerably stronger at 408 megacycles than it is at 240 megacycles, rather than somewhat weaker.

In addition to the joint program with the Smithsonian Astrophysical Observatory, I have carried out some combined photoelectric and radio observations with Soviet astronomers, particularly with V. A. Ambartsumian at Burakan in Armenia and P. F. Chugainov at the Crimean Astrophysical Observatory. Correlations have been secured in both instances, but so far most of the data has come from the Crimean observations. These will be published in the near future.

A combined record of three flares on UV Ceti is typical of the results [*see illustration on opposite page*]. The total change in photographic magnitude of the three flares was 2.1, which gives a radio output per magnitude change of 4 flux units, in good agreement with the previous results. Both this value of intensity and the time relation of the radio output to the flare is similar to the majority of the previous flares, which are Type I events.

The photoelectric records were obtained with the 64-centimeter (25-inch) meniscus telescope in the Crimea, using a photomultiplier tube with either a yellow or a blue filter. Because this system records continuously and because it is extremely sensitive, it is beginning to fill in many of the details of the flare phenomenon, such as the fluctuations in light output during the flare maximum. Of particular interest in the combined work is the observation that, although the main flare phase may last only a few minutes, the star remains brighter than normal for up to 20 minutes. Hence the difference in duration of the optical and radio flares indicated in the photographic recordings may be more apparent than real.

Photoelectric-radio correlations have

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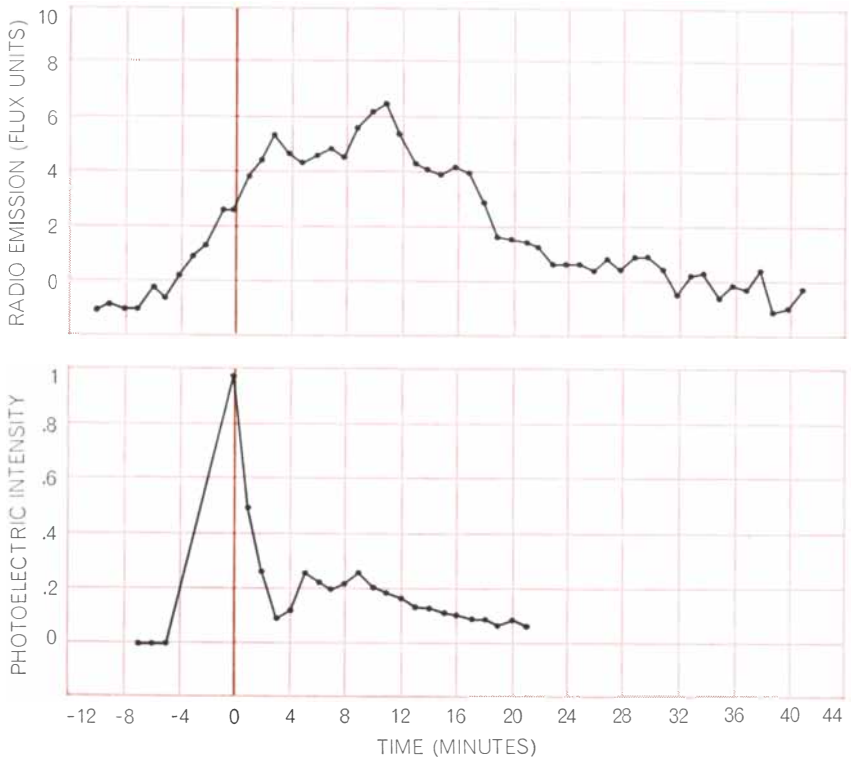
been obtained for EV Lacerta as well as for UV Ceti. These indicate that at least in the case of these two stars, if account is taken of the difference in their magnitudes, the ratio of the radio flux to the visual flux is practically the same.

Combined radio and photographic observations similar to ours have recently been made in Australia, using the 210-foot radio telescope at Parkes and three optical telescopes. O. B. Slee, Solomon and G. E. Patston have published the results of an observation of the radio emission on the star V371 Orionis correlated with a flare of magnitude .6. The flare exhibited most of the same general features as the flares already described, although there is a considerable discrepancy in the radio output per magnitude change. The observers estimated it to be 12 flux units on 410 megacycles and 45 flux units on 240 megacycles. The latter value is 10 times higher than the Jodrell Bank intensities. It may be that there is considerable variation in the ratio of radio to light flux among certain types of stars, although the ratio for UV Ceti and EV Lacerta is constant. Further measurements on V371 Orionis will clearly be of great interest.



PHOTOELECTRIC RECORD (*bottom*), made in the Crimea, of three flares on UV Ceti and the accompanying radio record (*top*) are in good agreement with previous studies of typical flares. The photoelectric system records continuously and is extremely sensitive.

Since it has now been established beyond doubt that radio emissions can come from stars, the question again arises whether or not stars are responsible for any significant part of the galactic radio emission, particularly since it is probable that a high proportion of the stars in our galaxy are red dwarfs of the same spectral type as the flare stars. With Whipple and Solomon, I have published calculations on this point. They indicate that in certain directions in the galaxy the flare-star contribution to the nonthermal radio emission may be a few percent. Thus the complete abandonment of the radio-star hypothesis may have been somewhat premature, but it is not likely that the new knowledge will lead to any significant change in the idea that the synchrotron mechanism provides the main component of the nonthermal galactic radio emission.

A major consequence of the discovery will be the new insight it will provide into processes in the atmospheres of stars. Even the preliminary results reported here indicate that the flare-star events are much more violent than solar flares. For example, if UV Ceti were as close to us as the sun, then during a visual flare of magnitude .5 the radio signal received on earth would be 8.3×10^{-15} watt per square meter per cycle per second. Since the diameter of UV Ceti is only 8 percent of the diameter of the sun, its equivalent blackbody temperature would be greater than 1,000 million million degrees Kelvin—100 times hotter than the largest disturbances recorded from the sun. Another way of regarding the matter is to consider whether or not the apparatus used in our experiments would be able to record the radio emission from solar flares if the sun were at the distance of UV Ceti. It would be barely possible, but only for the largest solar disturbances. Thus even the rather minor flares on UV Ceti stars observed so far seem to be of an exceedingly violent nature when compared with solar flares.

This point is emphasized by provisional calculations of the total energy output by flare stars in the optical and radio parts of the spectrum during flares compared with the strongest solar flares. In the continuous optical spectrum, even for the small star flares of magnitude 1, the output is 10 to 100 times greater than that of the strongest solar flares ever recorded. In the radio spectrum the output is greater than that of solar flares by a factor of 10,000 to a million. Furthermore, much more efficient processes for the conversion of energy to radio emissions seem to be at work in the flare stars, the ratio of radio to optical energy being 1 to 100 for the stars compared with 1 to 100,000 for the sun.

An unexpected bonus from this work is the opportunity it provides for testing one of the most fundamental facts of physics: the constancy of the velocity of electromagnetic radiation over a wide range of wavelengths. Light from UV Ceti, the nearest flare star studied, takes 4,600,000 minutes to reach the earth. When an optical flare appears, the radio waves, which are some two million times longer, arrive no more than two minutes after the light waves. Even allowing for several minutes of uncertainty in the correlation of the times of the optical and the radio events, we can confidently conclude that the velocity of light and of radio waves is the same to within one part in a million. Calculations based on observations of three other flare stars give the same results.

The future for this flare-star work is full of hope. The development of solar radio astronomy has had a profound effect on our knowledge of the sun's atmosphere and has deepened our understanding of the sun. We are now at the beginning of a similar phase for the stars, but since the phenomena are so much more difficult to observe, it is unlikely that progress will be as rapid.

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INSECT ATTRACTANTS

Having analyzed several natural attractants, chemists can now make synthetic ones in quantity. Their use as lures has already reduced the need for massive applications of pesticides in insect control

by Martin Jacobson and Morton Beroza

Man's efforts to control harmful insects are increasingly encumbered by an awkward dilemma. There is rising protest that pesticides are destroying harmless wildlife and endangering the health of man himself. Hardly a week now passes without a new alarm about the killing of fish or birds or the contamination of food and water. Yet any significant retreat from the use of insecticides would bring even more alarming consequences. According to the World Health Organization insect pests are responsible for half of all human deaths and deformities due to disease. Insects consume or destroy about a third of everything that man grows or stores. The agricultural revolution in the U.S. that enables a small proportion of the population to raise more than enough food for the whole nation has been made possible largely by the extensive use of modern pesticides. Without them the U.S. could not maintain its present standard of living.

Unfortunately pesticides frequently generate increasing immunity among their intended victims. To this food-raisers are responding with heavier applications and pleas for more potent new chemicals. At the same time health authorities are becoming more sensitive to the dangers of toxic residues and more alert to the detection of these residues in food and water, even in concentrations as small as parts per trillion. Thus the designers of the weapons for the control of insects—that is, economic entomologists and chemists—find themselves in an embarrassing cross fire: on the one side from the farmers demanding more potent insecticides and on the other from the health agencies demanding less toxic residue.

Irreconcilable though these demands may seem, it now appears that there is a good chance that both of them can be satisfied by new methods of attack. One method that has already made a promising start involves the use of odorous chemicals to lure insects into lethal traps.

Many insects find their food, their partners for mating and favorable sites in which to deposit their eggs by means of automatic responses to various scent cues. Male moths, for example, can smell potential sexual partners at a considerable distance. Not surprisingly, each species tends to have its own distinctive odor, which facilitates the meeting of partners capable of mating with each other.

This behavior makes the odor-baited lure a most promising means of getting rid of malignant species of insects. Instead of spraying the whole countryside with insecticide, one could attract the unwanted insects to traps where they would make contact with an appropriate insecticide, with a sterilizing chemical or with some other exterminating device. Females could be induced to lay their eggs not on nourishing plants but in places where the emerging larvae would starve for lack of food. The odorous lures and the lethal chemicals could be applied only at the most effective time and place. Any new infestation of insects could be detected early and eliminated before it had a chance to spread. In sum, the battle against harmful insects would be much less costly and more efficient, and the problem of the contamination of the environment by toxic materials would be vastly reduced.

The principal difficulties in such a program are the problem of identifying the specific odorous substances to which various insect pests respond and, in the case of the natural sex lures, the task of obtaining large enough amounts of these substances to carry out the program. Until about a decade ago the prospects for the effective employment of attractants on any large scale did not look bright. In recent years, however, the method has scored an impressive success in the U.S. by helping to eradicate the Mediterranean fruit fly from a million infested acres in Florida. On the strength of this demonstration and a wealth of information acquired by intensive research, it can be said that the outlook for eradicating insect pests by means of attractants is now much more encouraging.

The investigation of insect attractants goes back to discoveries made in the 19th century by Jean Henri Fabre, the French naturalist to whose endless curiosity we owe many other insights into the lives and habits of insects. Fabre had been looking for years for a certain moth whose larvae fed on oak leaves, and one day he finally found a cocoon of the insect on a leaf. From this there soon emerged a female moth. Fabre placed his prize in a cloth cage near an open window in his house. Within 15 hours no fewer than 60 males of this previously elusive species came out of the woods and collected around the cage containing the virgin female.

Fabre began a series of experiments to try to discover what had attracted the males. When he placed the female in a tightly closed transparent container, where the moth could be seen but not smelled, no males appeared. On the other hand, an open container recently occupied by the female was strongly attractive to the males, although the female was no longer there. They made their way to the container in spite of the presence in the room of strong odors

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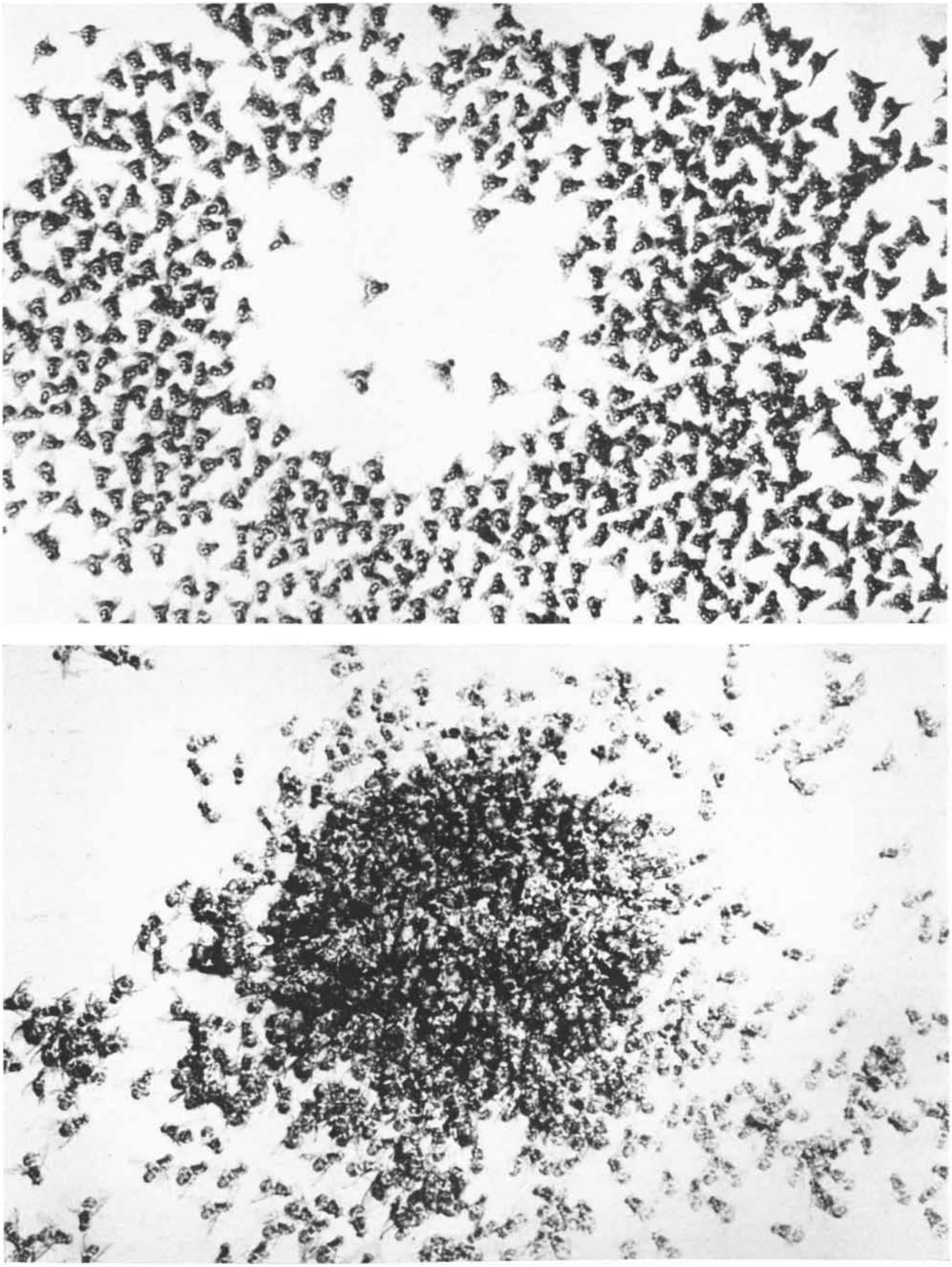

SYNTHETIC ATTRACTANTS vary in their action. One compound that normally attracts Mediterranean fruit flies will repel them instead if the concentration is too high (*center area of top photograph*). The lure that attracts oriental fruit flies is effective in both high and low concentrations (*bottom photograph*). Used with an insecticide, it has entirely rid one Pacific island of fruit flies.

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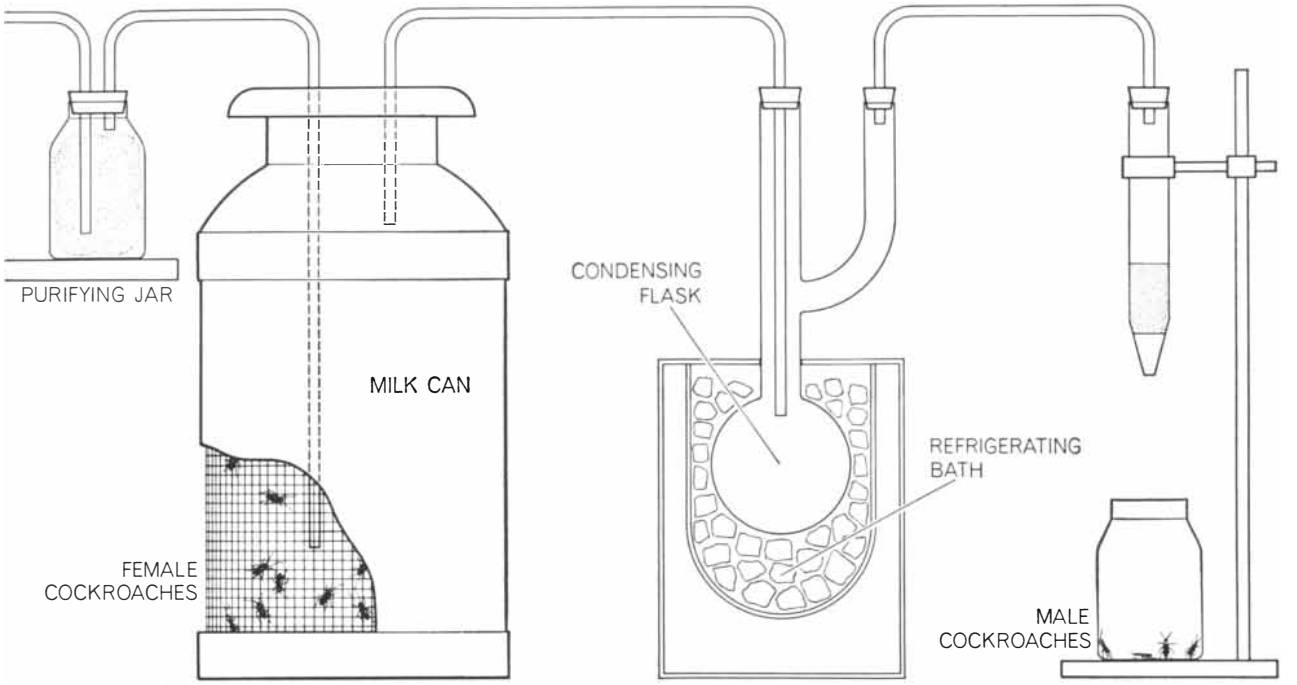

NATURAL ATTRACTANT, a sexually stimulating pheromone that is produced by virgin female cockroaches, was concentrated by passing air through a container filled with females and then liquefying the attractant vapor in a dry-ice trap. Males (*right*) served as monitors. The experimenters needed nine months' time and 10,000 females to isolate 12.2 milligrams of pure attractant.

from naphthalene, hydrogen sulfide or tobacco smoke. Fabre extended the same tests to the emperor moth and got the same results. A female emperor moth placed in a gauze bag on a table in his study lured about 40 males in a single evening. For eight successive nights, as Fabre wrote, "males seemed to take possession of the house." They hovered around the female's resting place even when it was hidden from sight in a drawer.

The experiments certainly indicated strongly that the females of both species attracted the males by odor (although the human nose could not detect it). Yet Fabre could not bring himself to believe that odor could draw moths from hundreds of yards or even miles away. He thought it quite unlikely that odorous vapor from the source could reach to such distances in any detectable amount. Fabre's guess was that some sort of vibration produced by the female moth generated waves that traveled through the air and were received by the male moth's antennae. He determined, in fact, that males deprived of their antennae seldom found the female.

Fabre was correct in identifying the antennae as the receptor organs but wrong in his conclusion that the message was not carried by odor. It was eventually proved beyond doubt that male moths are indeed guided to females by their sense of smell, that their odor-sensitive organs are located in their antennae and that they can detect the female scent in fantastically small amounts. The sex attractants of insects are probably the most potent physiological substances known; in some cases reception of just a few hundred molecules or less by the sensitive cells of the antennae is enough to stimulate the male [see "Pheromones," by Edward O. Wilson; SCIENTIFIC AMERICAN, May, 1963].

That scent plays an important part in sexual attraction throughout the animal kingdom has, of course, long been suspected. The details of its operation in individual species, however, still constitute one of nature's best-kept secrets. Not only is the attracting substance itself extremely difficult to identify; its effects usually elude discovery because they vary with different mating habits. This point is well illustrated by the moth of the European corn borer. Even when the population of corn borers is very sparse in a field, all the adult females in the moth stage somehow manage to mate. Yet experiments with a caged female failed to show any sign of a lure to males—until observations were made at night. In a darkened laboratory room (where the female was observed by means of an infrared light) males were attracted to the cage, so that the attraction must have been the emission of a scent. The answer was elementary: corn borer moths usually mate at night. Experiments have now established the fact that some species of moths mate only between 11:00 P.M. and 4:00 A.M. (presumably releasing their scents only during those hours), whereas others always mate between 2:00 A.M. and 6:00 A.M. Indeed, the moths are nocturnal. For example, although the male gypsy moth locates its partner during daylight hours, mating takes place in twilight or darkness.

Moths and butterflies—the insect order Lepidoptera—have been the main subjects in the investigation of sex attractants. The most remarkable finding is the great distances at which their lures are effective. Experiments with marked male gypsy moths have shown that they are attracted to a female up to half a mile away. Males of the saturniid and lasiocampid families (which include silkworms, tent caterpillars and eggars) have been reported to be lured to females from distances as great as two and a half miles. The extraordinary potency of insect sex lures was also demonstrated by an experiment in which a single caged female pine sawfly—a member of the order Hymenoptera—attracted more than 11,000 males!

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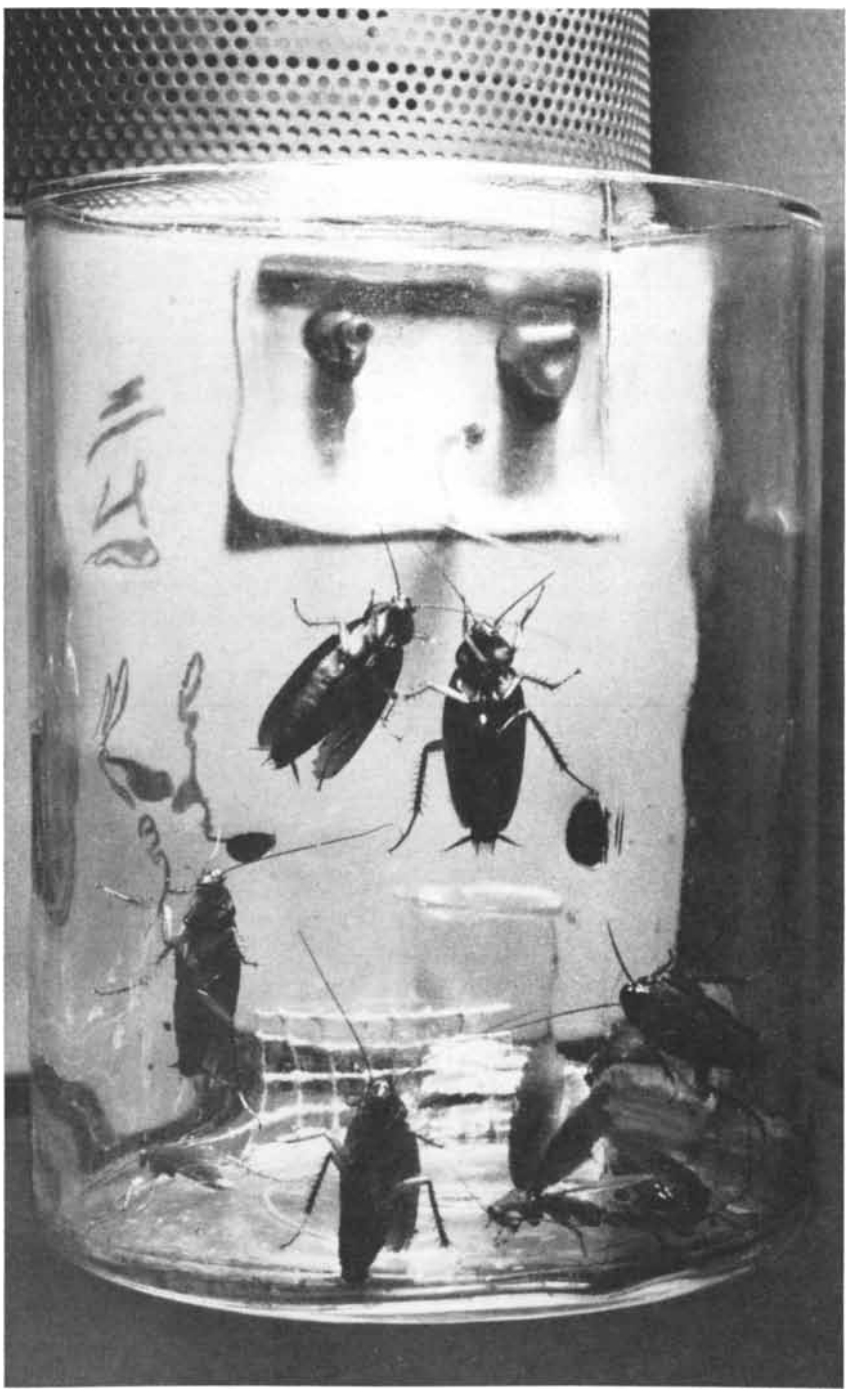
Another notable feature of the sex lures is their sharp specificity. In most cases the female's scent attracts only males of the same species. There are, to be sure, a few exceptions, which only emphasize the rule. For example, the scent of the female tobacco moth has been found to excite male Indian meal moths and Mediterranean flour moths to make attempts at mating although anatomical differences make mating between them and the tobacco moth female impossible.

A typical virgin female of a lure-producing species of moth secretes the odorous substance from a pair of glands located between the last two segments of its abdomen. It releases the attractant by protruding these glands in what is termed the calling position. The attracted male, on arrival, begins to circle the female with its abdomen bent in the female's direction and its wings vibrating rapidly in what is called a whirring dance. In many species the male moth in turn excites the female with an aphrodisiac scent of its own, produced in glands under its wings and scattered around the female by its wing vibrations. The male scents of many species of insects can be detected by the human sense of smell and have been variously likened to pineapple, chocolate, lemon oil, musk, flower fragrances and other odors. One of these substances, a clear fluid with a cinnamon-like odor secreted by a tropical water bug, has long been used as a spice by inhabitants of southeast Asia. In 1957 the German biochemist Adolf Butenandt and his associate Nguyen Dang Tam isolated the odorous substance in pure form and identified it as *trans*-2-hexenyl acetate. They then succeeded in synthesizing the compound, and the synthetic product is now sold as a spice in Asia.

The story of the conversion of sex attractants into a weapon against insects begins with the gypsy moth. This insect, a European species similar to the silkworm moth, was brought to the U.S. in 1869 in a misguided effort to found a silk-growing industry. Leopold Trouvelot, a French artist, naturalist and astronomer, thought that by crossing the gypsy moth with the silkworm moth he might breed a hardy new race of silkworms that would thrive in New England. His attempt did not succeed, and unfortunately in the course of his experiments some of the gypsy moth eggs or caterpillars escaped and the insect proceeded to multiply at a prodigious rate. Eventually it infested all New England. The hairy, mottled caterpillar of the gypsy moth feeds voraciously on tree leaves and has done millions of dollars' worth of damage.

The use of a sex lure to trap the gypsy moth was begun many years ago. The female cannot fly and is therefore completely dependent on its scent to attract males. It was discovered that an extract from the abdomens of virgin females, prepared by using benzene as a solvent, could serve as an attractant for baiting traps. The U.S. Department of Agriculture also tested many laboratory chemicals, by the same kind of screening methods that have been used to search for medical drugs, in the hope of finding an attractant that would be available in substantial quantity. More than 2,000 chemicals were screened, and surprisingly several turned out to be at-



MALE ROACHES are sexually excited by an infinitesimal amount of attractant. Thus they serve to detect any leakage from the collection apparatus (*see illustration on opposite page*).

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tractive to the male gypsy moth. All of these were alcohols with a straight-chain backbone of 16 carbon atoms.

Meanwhile the Department of Agriculture pursued intensive efforts to isolate the pure attractant from the female moth. The crude extract was not too reliable as a lure and was obtainable only in small amounts. The laboratory substitutes were only weakly attractive—less than a millionth as potent as the natural lure. For any large-scale trapping campaign against the gypsy moth it would be necessary to isolate and identify the natural compound and then try to synthesize it in quantity.

After 30 years of painstaking chemical work the gypsy moth sex attractant was at last identified in 1960 by three of us in the Department of Agriculture: the authors of this article and W. A. Jones. It took the abdomens of 500,000 female gypsy moths to yield 20 milligrams—less than a thousandth of an ounce—of the pure attracting substance. We identified it as the dextrorotatory form of a compound that in chemical terms is described as 10-acetoxy-*cis*-7-hexadecen-1-ol [*see illustration on page 26*]. In laboratory tests it was found that a male gypsy moth would curve its abdomen and make copulatory motions when exposed to as little as a trillionth of a microgram of this substance! And a trap in the field baited with only one ten-millionth of a microgram would lure males to it.

In the same year Butenandt and a team of chemists at the Max Planck Institute for Biochemistry in Munich isolated the sex attractant of the female silkworm moth. They too had had to extract the abdomens of 500,000 virgin females to obtain a tiny amount (12 milligrams) of the pure substance. Their "bombykol" (from *Bombyx*, the generic name of the commercial silkworm) is as potent as the gypsy moth's attractant and also remarkably like it in chemical structure: the description of bombykol is *trans*-10, *cis*-12-hexadecadien-1-ol. Very likely the sex attractants of other species of moths will be found to be chemically similar to these; yet with rare exceptions each attracts only its own species.

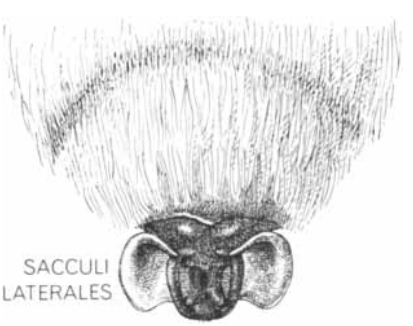
Fifteen years ago it would have been virtually impossible to isolate and identify minute amounts of sex attractant. That it is now possible is owing to the evolution of electronic instruments and their application in chemical technology. The new tools (such as infrared and ultraviolet spectrometry, mass spectrometry, gas chromatography and nuclear magnetic resonance) enable chemists to work with substances available only in milligram or even microgram amounts.

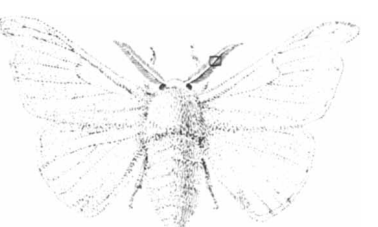
Once we had discovered the molecular structure of the gypsy moth attractant we soon succeeded in synthesizing it. We could not resist the temptation then to try to improve on nature and produce a still more effective lure for the male gypsy moth. Our first thought was that if we reduced the size of the molecule, say by shortening the chain from 16 carbon atoms to 14, the compound might be made more volatile and perhaps more attractive. This alteration did not work: the altered product failed to attract the males. Trying various other modifications, we found that a product in which the carbon chain was *lengthened* by two carbons was just as attractive to male moths as the natural lure [*see illustration on page 26*]. This 18-carbon analogue (which, as it happens, is closely related to an ingredient of castor oil) is much easier to synthesize than the natural substance, and it has been adopted by the Department of Agriculture as the agent for trapping the gypsy moth. It has been named gyplure.

For several summers now male gypsy moths have been flying enthusiastically into traps baited with gyplure. About 50,000 such traps are set out each year throughout New England and adjacent areas to check on the whereabouts of the insect. As the moth moves into new areas, control measures are applied promptly to prevent its spread. So far the campaign against the gypsy moth has been a holding action: a vigorous effort to confine the insect to a limited area, where it is so prevalent that a monumental attack would be necessary to eradicate it. Thanks to the use of the sex attractant, the moth has been prevented from spreading outside the northeastern U.S.

In the areas where the gypsy moth is strongly entrenched gyplure is now being tried as a subtle means of birth control. Granules containing the attractant are sprinkled in the woods to confuse the male moths in their odor-controlled search for mates. The tactic, called Operation Confusion, has not worked well in its trials so far because of unforeseen difficulties, but better results are expected in a new trial this summer in which gyplure-scented traps are being used [*see bottom illustration on page 27*].

The idea that food or food substances might be used as bait to trap insects is an old one and has long been investigated in a number of different ways. Experimenters have found that various insects are attracted to stale beer, rum, fermenting sugar solutions, cereal products, bacterial cultures, sliced cucumbers, crushed bananas, beef liver in water and fish meal. Plant extracts also have been extensively tested. The food lure has two aspects: it may draw adult insects simply as something





FEMALE SILKWORM MOTH (*extreme left*) **emits a sexual pheromone from a pair of sacs that extrude from the abdomen** (*detail second from left*). **The male** (*center*) **receives the stimulus, which may consist of no more than a few hundred molecules of the attractant, by means of its antennae** (*shown in detail at increasing magnifications*). **Sensory studies by the German physiologist**

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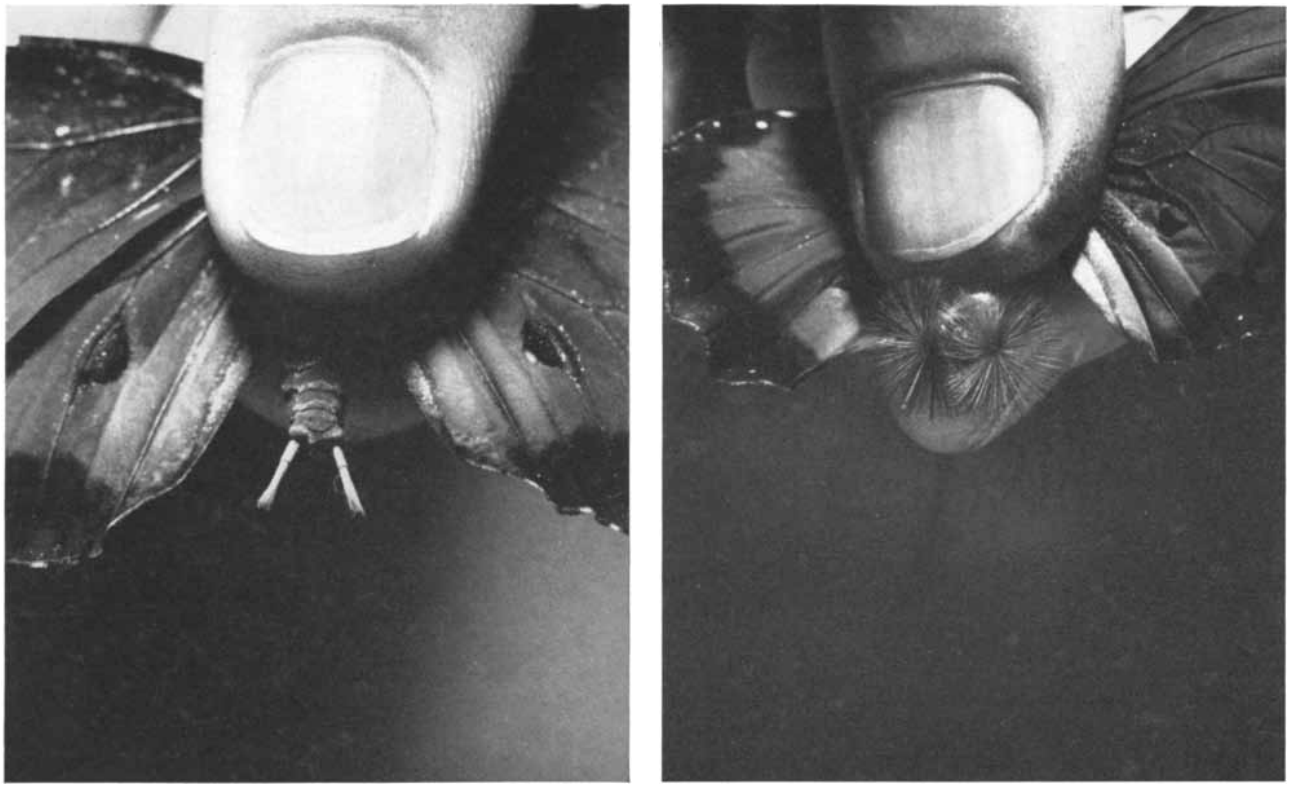


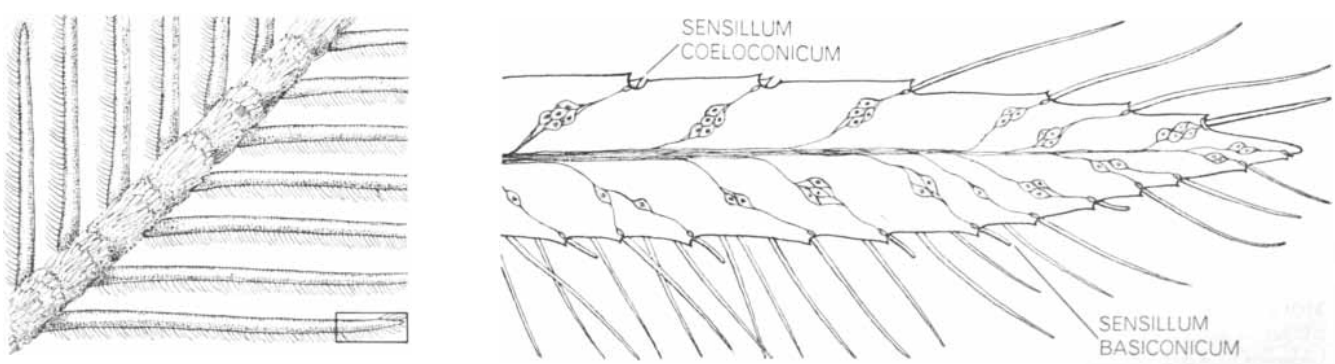
SOME MALE INSECTS can produce sex attractants. When courting, a male queen butterfly approaches the female and extrudes a pair of "scent pencils" (*left*) that bush out (*right*) and disperse a pheromone. The attractant renders the female sexually receptive.

on which they can feed themselves, or it may attract egg-laying females because it will provide food for the young when they hatch.

For baiting traps to catch specific insects, food per se or chemicals derived from foodstuffs have proved disappointing. Their drawing power is short-lived, unpredictable and likely to attract insects indiscriminately rather than the particular species one seeks to trap. Derivatives that have been identified are ammonia, certain amines, fatty acids and sulfides. Ammonium carbonate, for example, has been found to be attractive to female houseflies, which suggests that for the housefly the odor of the chemical indicates a favorable place for depositing its eggs. Some fermentation wastes are attractive to the Mexican fruit fly.

For many years the Entomology Research Division in the Department of Agriculture has been conducting a systematic program of screening plant substances as possible insect lures. Our laboratory uses a standard procedure in this search. First a specific part of a plant (the flower, seeds, stem or root) is minced and dried, and the material is then put through a series of extractions with certain solvents, in this order: petroleum ether, ether, chloroform, ethanol and finally water. Each extracted fraction is tested for its attractiveness to insects. When an extract proves to be attractive, it is purified and tested in successive steps until the active substance is finally isolated.

In recent years we have searched for pure chemical compounds that will act as strong lures for specific insects. One



Dietrich Schneider and his associates have demonstrated that either or both of two antenna organs may act as the chemoreceptors. First are the pitlike *sensillae coeloconicae* (*upper surface of cross section at extreme right*); second are the short rodlike *sensillae basiconicae* (*lower surface*). Relatives of the silkworm moth can be lured from more than two miles away by such sexual pheromones.

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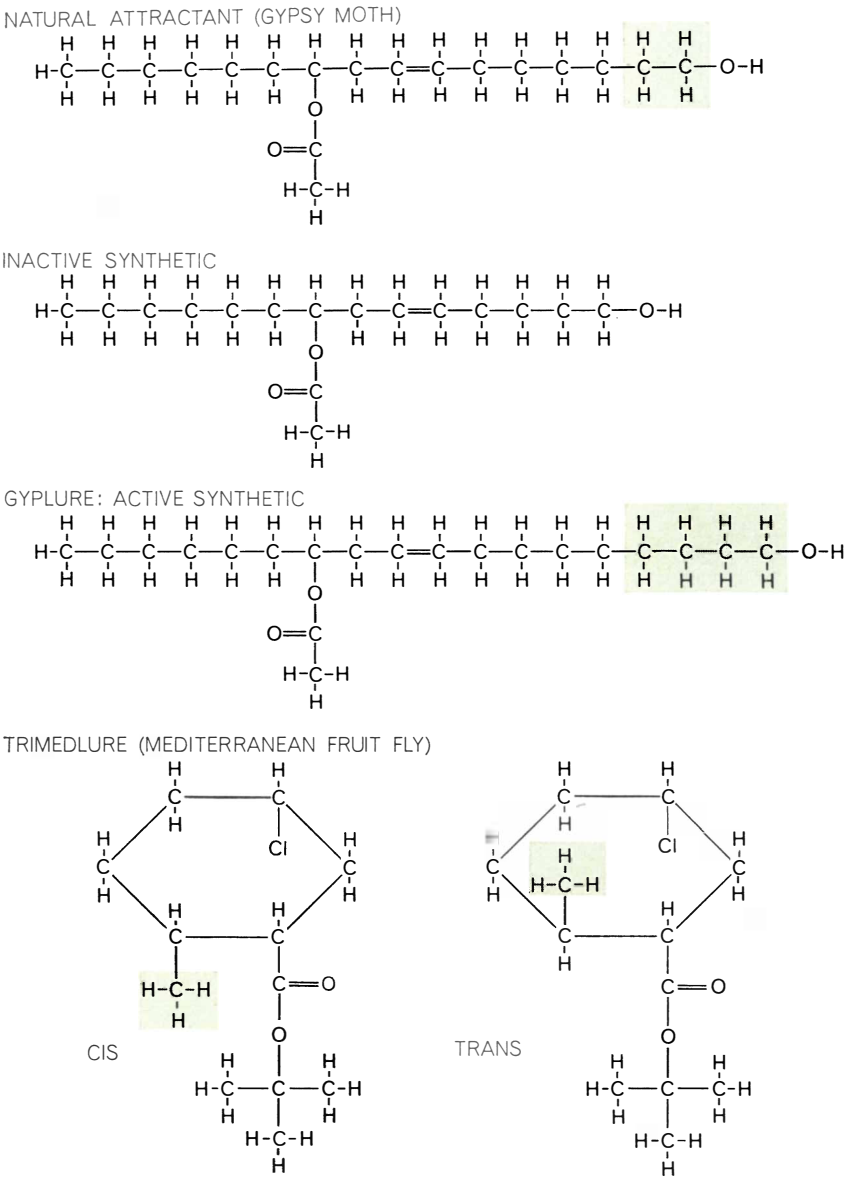

MOLECULAR STRUCTURES of attractants that affect four insect species contain 11 to 20 carbon atoms. To increase the volatility of the natural gypsy moth substance, the authors removed two carbons from the chain (*color in top diagram*) and found they had rendered it inactive. When, instead, they added two carbons (*color in diagram third from top*), the result, named gyplure, proved to be as attractive as the natural form. In the case of two trimedlure isomers, a *trans-* configuration (*right*) proved to be more potent than a *cis-* (*left*).

such compound proved to be strongly attractive to the male Mediterranean fruit fly. The discovery was exciting because this European insect had recently invaded Florida (which in these days of incessant air travel is difficult to prevent) and infested a million acres of that fruit-growing state. Having found a substance that would lure the fruit fly, we went on to improve its attractive power by tinkering with the molecule. This work culminated in the discovery of trimedlure [*see illustration at left*]. Trimedlure has eight possible isomers (spatial arrangements), and they differ considerably in attraction for the insect: the fly is much more strongly drawn to versions in which the methyl and ester groups are on opposite sides of the ring (*trans*) than to those with the groups on the same side (*cis*). We tested 46 analogues of the compound before selecting trimedlure as the best.

In 1957 traps baited with these attractants, mixed with a volatile, fast-acting insecticide, were set out throughout the infested areas of Florida, and by pinpointing pockets of infestation they helped to eradicate the Mediterranean fruit fly. Since then trimedlure has been used to detect and suppress reinfestations by the same insect. The entire program has cost about $10 million, which is a small investment considering the damage the insect could have done to Florida's fruit crops.

That successful campaign became the forerunner of others. The Department of Agriculture, in collaboration with state agencies, is now protecting fruit-growing areas with triple traps containing lures designed to detect invasions by three different foreign insects: the Mediterranean fruit fly, the oriental fruit fly and the melon fly. A trap baited with another attractant is helping to prevent the Mexican fruit fly from becoming established in California. The European chafer is being kept under surveillance by traps baited with butyl sorbate, and control measures are applied where necessary. All these campaigns illustrate the kind of situation in which attractants are most effective: early detection of the introduction of a destructive insect, prevention of its spread into a new area and its prompt eradication while the numbers involved are still small.

Elimination of an insect from a large area in which it is already well established is a much more difficult problem. An important success has recently been reported, however. Rota, a 35-square-mile island in the Mariana group of the

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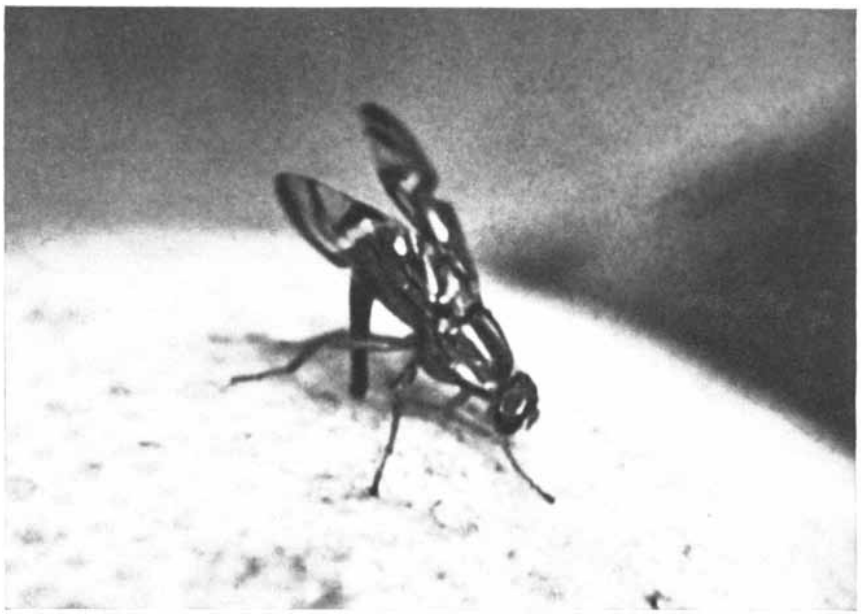
Pacific, was heavily infested with the oriental fruit fly. As a test the Honolulu Fruit Fly Laboratory of the Department of Agriculture dispersed over the island from the air small absorbent boards containing a lure (methyleugenol) and an insecticide. The attack eradicated the fly from the entire island at a cost of only 50 cents per acre. This demonstration has raised the hope that perhaps the insect can be eliminated from the Hawaiian Islands and other such areas.

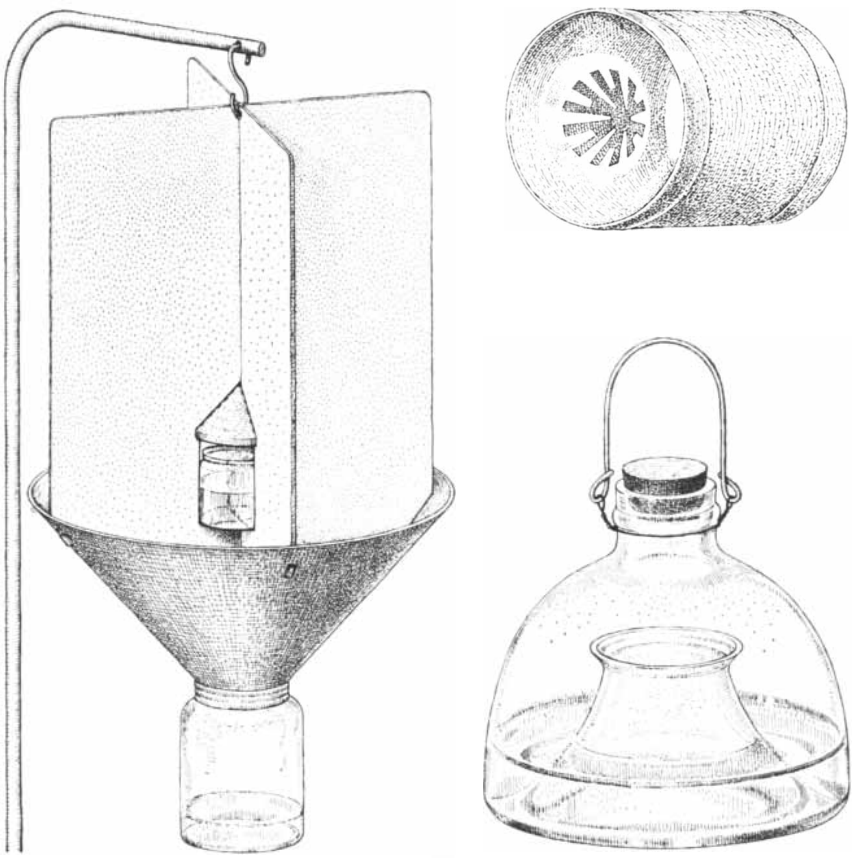
Steady progress in the discovery of insect attractants is continuing. Last year the authors identified the sex attractant of the American cockroach. The source of the substance has not yet been located in the cockroach's body, but it has been isolated from a vapor emitted by virgin female roaches. Robert T. Yamamoto of our division ran a stream of air through large cans containing thousands of females for a nine-month period, trapping the vapor by freezing it with dry ice. From the condensate we obtained 12.2 milligrams of the pure attractant. It turned out to be a volatile yellow substance with a strong floral odor. Male cockroaches responded to the odor with intense excitement, raising their wings and making mating attempts [*see illustration on page 23*].

The identification and testing of attractants is a sophisticated art. We have already mentioned that in many insects the lure is released only at certain times of the day or night. The strength of the odor is important: we have found that in very strong concentration some lures may repel rather than attract. Conditions such as the amount of light, humidity, temperature and air movement are likely to affect insects' responses. Much thought and experimental effort have been devoted to the design of traps for the various insects [*see illustration at right*].

With the sensitive devices that chemists now have for analyzing extremely tiny amounts of material, the prospects for fighting the insects with their own lures and for investigating their behavior have suddenly become much brighter than they have been in the past. We can now mark insects and recall them at some later time by means of attractants. Thus armed with the ability to follow the lives of individual insects, we are in a position to learn more about the ecology, flight habits, longevity and other attributes of the insects, which in number of species constitute four-fifths of the animals that inhabit the earth.



FEMALE MEXICAN FRUIT FLY buries the tip of its ovipositor in a lemon. Attractant-baited traps are widely distributed in California groves to detect infestations of this fly.



TRAPS FOR DIFFERENT PURPOSES use different attractants. At left butyl sorbate is placed at the intersection of twin baffles above a collecting cone. The European chafer, a heavy beetle, strikes the baffle and falls into the poison jar. At lower right a glass trap with an open bottom contains a liquid lure that attracts Mexican fruit flies. These McPhail traps are not used to control the flies; instead they are placed in suspect areas and checked regularly to see if an infestation has occurred. At the upper right is a cardboard trap with a plastic one-way entrance at each end. Sticky on the inside, it is baited with a synthetic analogue of the female gypsy moth's natural sex attractant. Air-dropped into infested areas, these traps are designed to attract male gypsy moths, which thus will be kept from mating.

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The Great Infra-Cambrian Ice Age

There is considerable geological evidence for an extensive glaciation some 600 million years ago. Its end caused an alteration of climate that made possible the proliferation of animal life in Cambrian times

by W. Brian Harland and Martin J. S. Rudwick

The best-known of the ice ages, since it is the most recent and has been the most intensively studied, is the one that began early in the Pleistocene epoch of the past one or two million years. At least two series of glaciations of comparable or even greater extent preceded the Pleistocene ice age by many millions of years. One series occurred between 300 million and 250 million years ago during the Permian and Upper Carboniferous periods. The other goes back to Infra-Cambrian times: just before the beginning of the Cambrian period some 600 million years ago. There is evidence for still earlier glaciations, but little is known about them.

Recent investigations indicate that the Infra-Cambrian ice age was an event of the first magnitude that preceded a critical time in the evolution of life. It is highly probable that there was a cause-and-effect relation between the ending of this prolonged period of cold climate and the rapid emergence of advanced forms of animal life. We shall concern ourselves with two main themes: the evidence for a major glaciation in Infra-Cambrian times, and the evidence that the climatic change at the end of the glacial period resulted in a substantial new fauna. First, however, it will be helpful to review some aspects of the other ice ages.

The Pleistocene ice age produced the massive ice sheets that are still represented by remnants in the polar regions of the earth. Indeed, the Pleistocene ice age may not have ended; the pattern of climate that has prevailed over the past few thousand years may be characteristic of a relatively short interglacial period. The extent to which the Pleistocene ice had spread at one time was first recognized in the 1840's, when Louis Agassiz showed that the distinctive landscape produced by glacial action could be found at some distance from the glaciers of the Alps and was even evident in the hilly regions of Wales and Scotland, which now support no glaciers at all.

Agassiz is perhaps best known for his demonstration that the Pleistocene ice had also spread widely over low-lying areas both in northern Europe and in North America. He argued that the till, or boulder clay, that is the characteristic deposit in these areas was not, as was commonly supposed, left behind by running water (and sometimes deemed a result of the biblical Flood). Agassiz proposed that this material was the debris left behind by vast sheets of glacial ice. Tills consist of boulders and pebbles, many of them angular rather than rounded, embedded in a matrix usually made up of sand and clay. The boulders are often scratched, and the rock on which the till rests may be polished and incised with scratches and grooves.

A century's work on glacial geology has confirmed the validity of Agassiz' views. It has also revealed that the Pleistocene ice age was a highly complex event. The margins of the ice sheets advanced and retreated several times, and the glacial advances alternated with warmer interglacial periods, some of which lasted for tens of thousands of years.

Going backward in time from the Pleistocene, the next unambiguous evidence of extensive glacial action dates from the Permian and Upper Carboniferous periods. This evidence is found largely in the Southern Hemisphere; it consists of rocks called tillites—mixtures of pebbles, boulders and clay consolidated into rock. The tillites are interpreted as the products of glacial transport; in places they rest on striated pavements of older rock, and the tillite boulders themselves may be striated. Other tillites are interbedded with marine sediments. In these formations some of the boulders and pebbles are found distorting the parallel layers of finer sediment in which they lie, and it appears that the boulders fell into the sediment from above. This can be explained if floating ice sheets extended outward from the land in Permo-Carboniferous times, as they do today in the Ross Sea of Antarctica. As the icebergs drifting away from the ice sheet melted, the debris embedded in the ice would have dropped into the sediment on the ocean bottom over a wide area. Marine tillites that appear to have been formed in just this way extend over thousands of square miles as uniform and distinctive strata. Similar marine tills, not yet consolidated into rock, have now been recognized on the floor of modern oceans.

The glacial origin of most Permo-Carboniferous tillites is clearly established, but their distribution—throughout the continents of the Southern Hemisphere and even north of the Equator into India—is puzzling. This distribution has long been one of the strongest arguments in favor of the hypothesis that the continents have drifted across the surface of the earth [see "Continental Drift," by J. Tuzo Wilson; SCIENTIFIC AMERICAN, April, 1963]. If, as the hypothesis postulates, South America, Africa, Australia and India were once joined in a single compact continent that has been named Gondwanaland, the glaciation would obviously have extended over a much smaller area than if these continents had been in their present position. Similarly, if the continents

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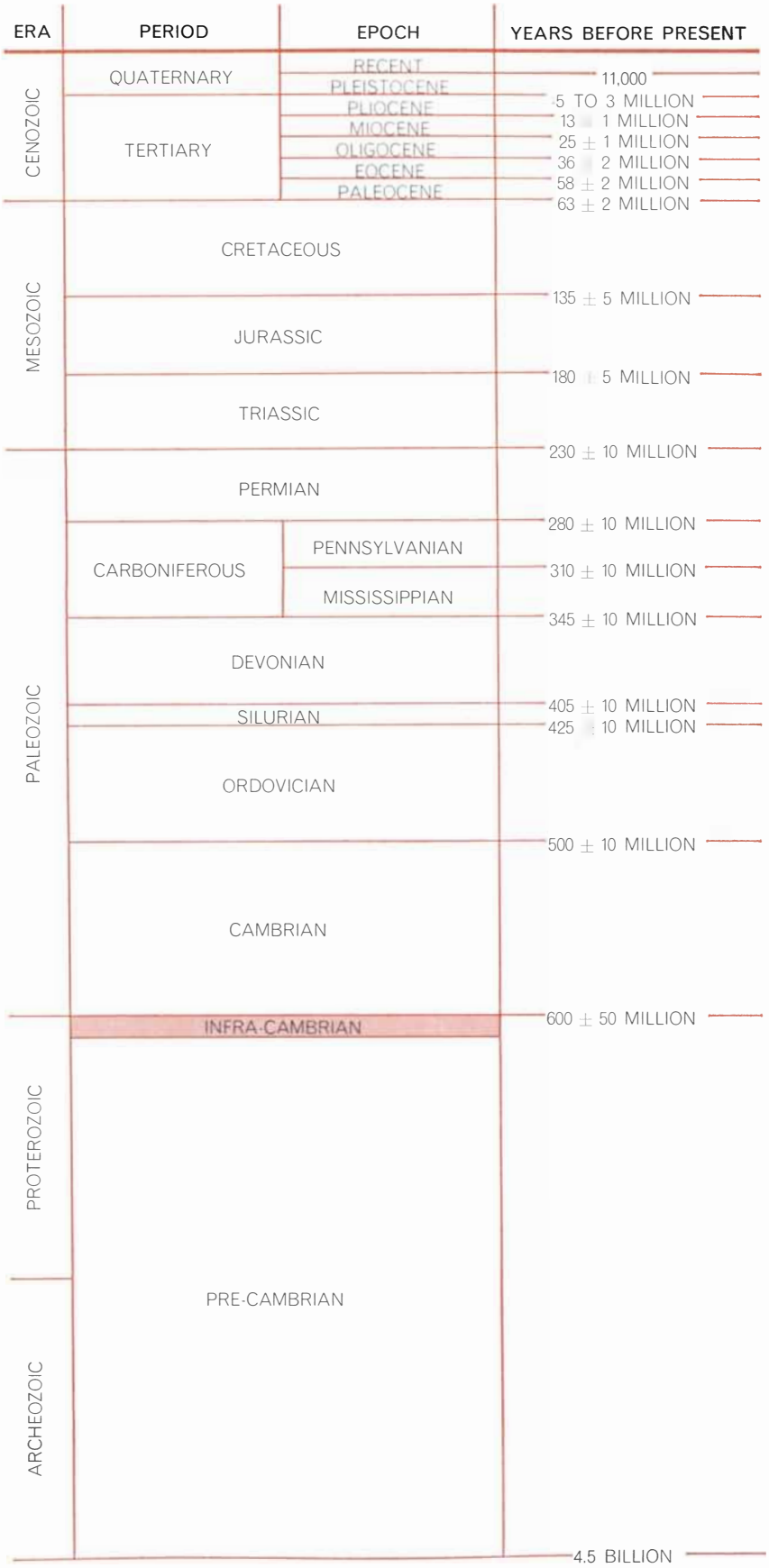
were joined in Gondwanaland, it is possible to attribute the direction of striations on some pavement rocks in Africa and India to the action of a single large ice sheet; otherwise it is necessary to assume that there were many widely separated centers of glaciation. It seems likely, moreover, that there was a succession of Permo-Carboniferous glaciations, because some formations dating from those periods contain many distinct tillite strata.

Over the past decade the Gondwanaland hypothesis has been strongly supported by studies of paleomagnetism. Such studies are based on the fact that during the formation of certain rocks magnetic constituents of the rock are "frozen" in the earth's magnetic field and so point in consistent directions. It is found that the magnetic constituents in continental rocks are consistently out of line with the earth's present field; this may be taken as evidence that the poles have wandered with respect to the continents or that the continent has drifted with respect to other continents. Generally the evidence indicates both that the continents have slowly changed their position with respect to the poles and the Equator (which is to say that there has been polar wandering) and that the continents have changed their positions with respect to each other (which is to say that there has been continental drift).

Support for the Gondwanaland hypothesis has come from many other lines of evidence, but the paleomagnetic evidence is decisive. It indicates that the rocks associated with tillites were formed at high latitudes, that is, at latitudes near poles. Thus a reconstruction of the continental positions in Permo-Carboniferous times would place the South Pole somewhere in Gondwanaland and the North Pole in an enlarged Pacific Ocean. Paleomagnetic evidence also shows that both Europe and North America were then situated in lower latitudes. The extensive coal beds and salt deposits formed in those times in both regions confirm that the climate there was warmer.

We turn now to the tillites of Infra-Cambrian times, the most notable of the many rocks older than the Permo-Carboniferous formations that have been identified as tillites. In 1891 the Norwegian geologist Hans Henrik Reusch found an ancient deposit he interpreted as being a glacial moraine. The deposit, now believed to be a tillite, lay atop a striated rock surface be-



GEOLOGIC TIME CHART indicates the chronological relation of the great Infra-Cambrian ice age to two other major glaciations: in Permo-Carboniferous and Pleistocene times.

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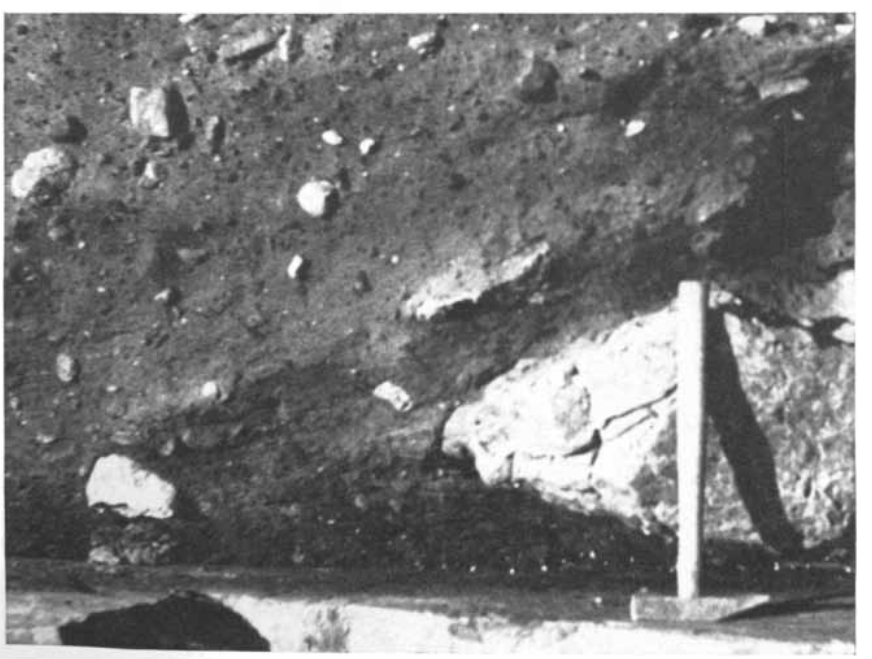
side Varanger Fjord in northern Norway. Both the tillite and the rock surface are demonstrably Pre-Cambrian. Since then tillites of about the same age have been reported from many other parts of the world. Indeed, the term "Varangian," from Varanger Fjord, is used increasingly to refer to rocks of this age. Until fairly recently the glacial origin of these tillites was not disputed, and they were generally taken as evidence for widespread ice sheets in late Pre-Cambrian times.

During the past generation, however, doubt has been thrown on the glacial origin of these deposits, chiefly because it is now recognized that there are ways other than ice action in which tillite-like rocks might be formed. These alternatives are as follows. First, where steep submarine slopes or cliffs exist, earth tremors may detach large angular blocks of rock, which may slide down the slope, possibly becoming striated, and then be embedded in finer sediment. Second, sediments newly deposited on a gentle submarine slope may become unstable and move downward in various ways. They may shear into large slices, glide downward with smaller lumps of mud and become embedded in other sediments in deeper water. It would be unusual for such "slump deposits" to resemble boulder-filled strata. If boulders should happen to be present on the slope, however, they could be intimately mixed with finer sediments in a mudflow that would look much like a till; this is the third alternative. Such mudflows have been found in nonglacial environments. Since a relatively steep slope is needed, boulder beds of this kind would be restricted to belts a few kilometers, or at most a few tens of kilometers, wide.

The fourth alternative involves the disintegration of sediments on a submarine slope, which then flow downward as a "turbidity current." Such dense mixtures of sediment and water have been shown to be capable of flowing for scores or even hundreds of kilometers into the ocean basins down inclines with a slope of less than one degree. Deposits formed in this way could extend over very wide areas. "Turbidites" have in fact been recognized in many successions of rock strata, particularly by their "graded bedding." This results from the faster settling of the coarser material after the disturbance has ceased, so that each stratum is graded upward into sediments of decreasing grain size. Turbidity currents are known to be capable of transporting pebbles, but the largest pebbles yet found in unquestioned turbidites are not more than a few centimeters across.

EFFECTS OF GLACIATION from Infra-Cambrian times appear at a site in Norway discovered in 1891 by the Norwegian geologist Hans Henrik Reusch. Shown here is a section of bedrock striated either by movement of a glacier or by later sliding of the glacial deposit; the larger holes were made by boulders in the till, or boulder clay, of the deposit.



RELATED VIEW shows the same quartzite bed overlain by a tillite, which is a till that has consolidated into rock. The till was made up of boulders and pebbles in a clay matrix.

Some of the supposedly glacial Infra-Cambrian tillites have been re-examined in the light of these alternative explanations. For instance, one of us (Harland) has investigated some of the tillites in Scandinavia, Spitsbergen and Greenland. These are distinct and conspicuous strata, generally between 10 and 100 meters thick and with little variation in thickness or composition over areas exceeding 1,000 square kilometers. The boulders in the strata are commonly a few tens of centimeters across, although a few exceed a meter in diameter. Their shape varies from sharply angular to rounded, and

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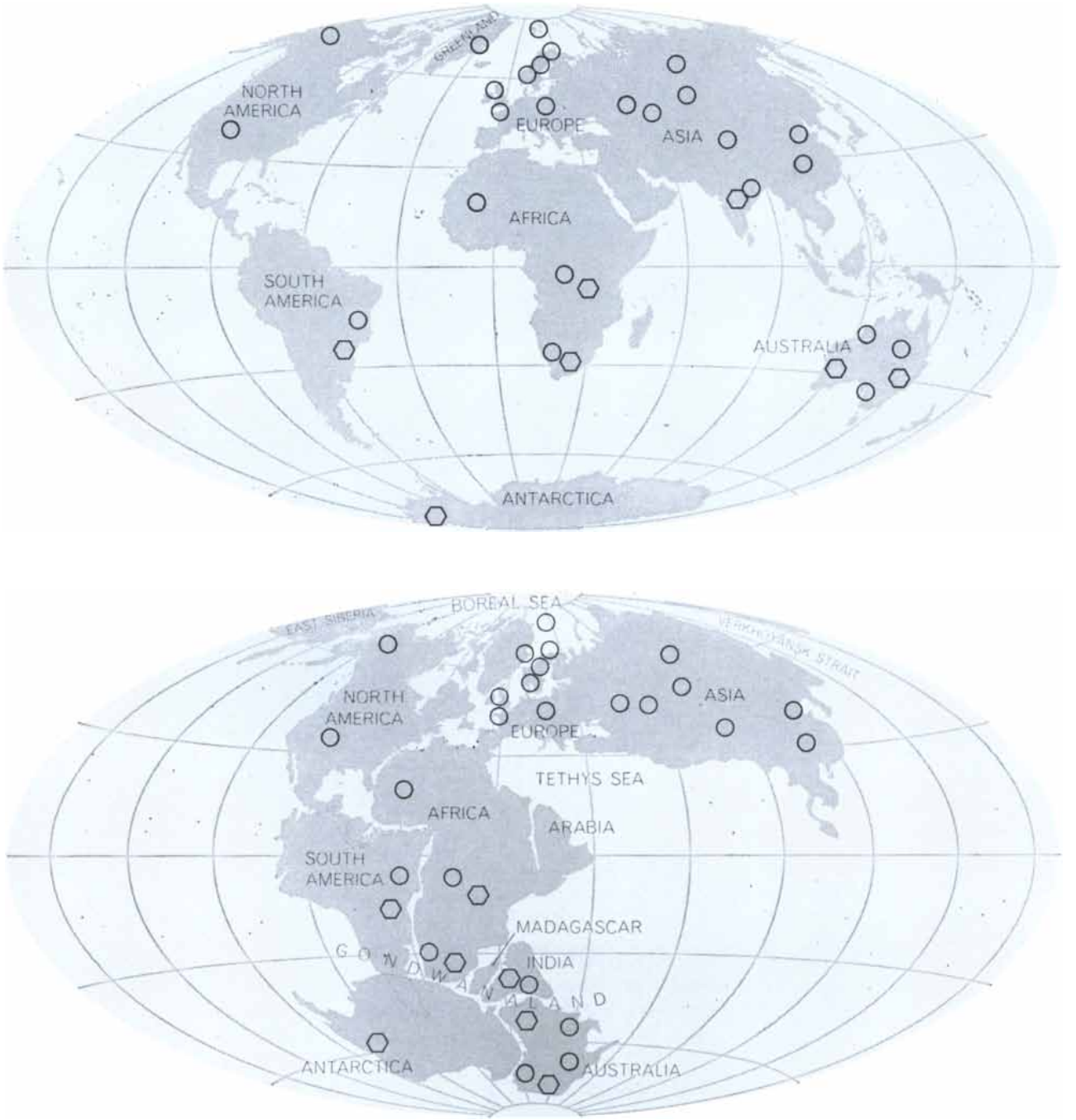

DISTRIBUTION OF TILLITES provides an indication of glacial action. The upper map shows the present distribution of Infra-Cambrian tillites, represented by circles, and of Permo-Carboniferous tillites, represented by hexagons. On the lower map the tillites are shown as they may have been distributed in the Infra-Cambrian age. The continents are arranged according to a hypothesis for Permo-Carboniferous times; presumably that is closer to the Infra-Cambrian arrangement than is the map for present time.

a few are striated. In the main the boulders are composed of sedimentary rocks, many of which can be matched to the lower strata of the Infra-Cambrian period, but there are in addition many nonsedimentary boulders. These are probably "erratics," derived from still older formations that were exposed in more distant areas.

The fairly constant thickness and the boulder content of these northern Infra-Cambrian formations over a wide area seem to eliminate the mudflow hypothesis. The evidence favoring a slump-deposit origin for the formations is not much more persuasive, and the presence of large boulders seems to rule out an origin based on turbidity currents. These considerations, however, do not eliminate the possibility that mudflows and turbidity currents played a secondary role. Indeed, today mudflows and slides are an inseparable part of the formation of tills at the margins of glaciers and of the erosion of Pleistocene tills [see "Quick Clay," by Paul F. Kerr; SCIENTIFIC AMERICAN, November, 1963]. The same material could move even farther underwater; it would be likely to undergo sliding and slumping and even to initiate turbidity currents. Thus if the Infra-Cambrian boulder beds are true tillites, it is hardly surpris-

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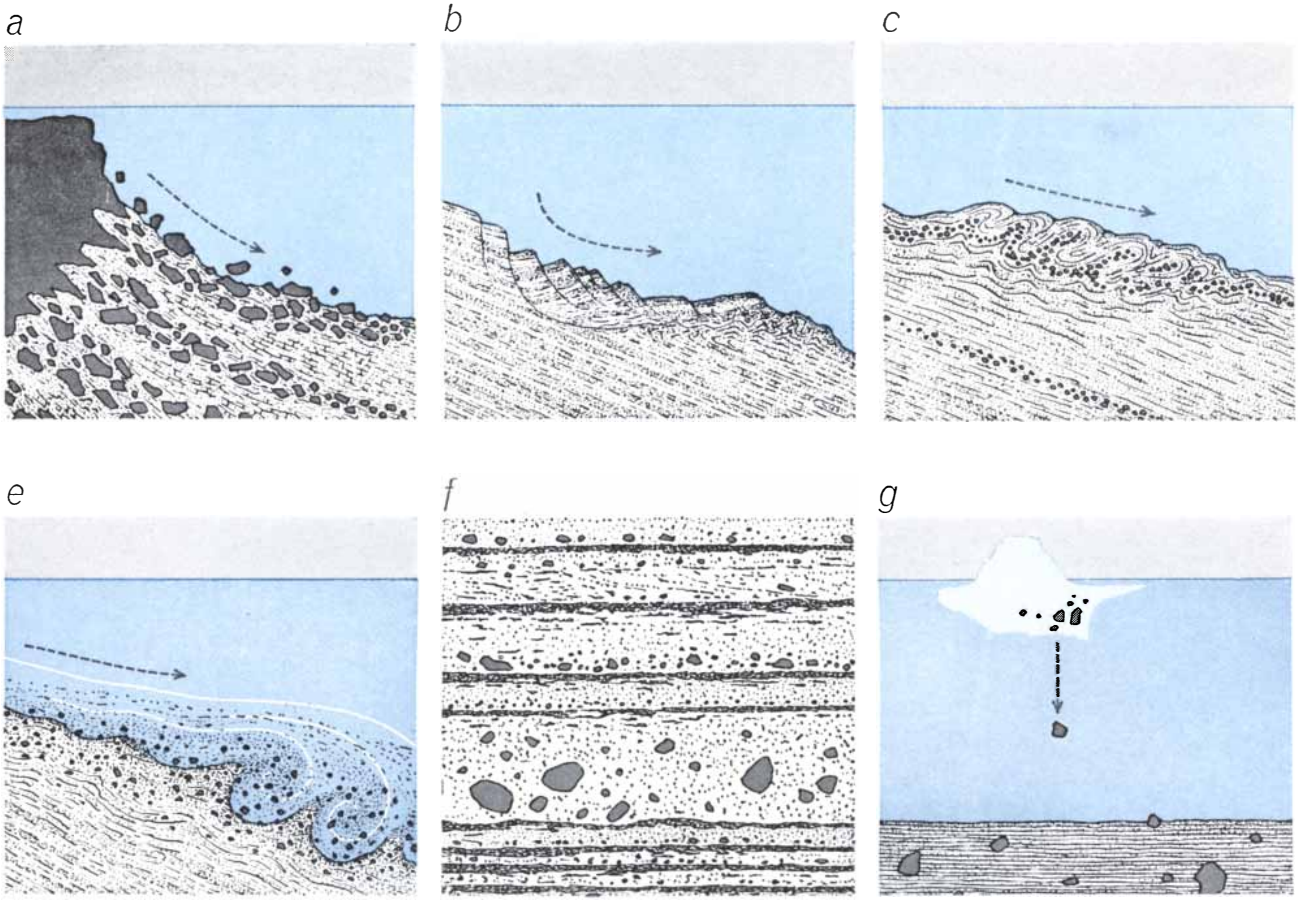
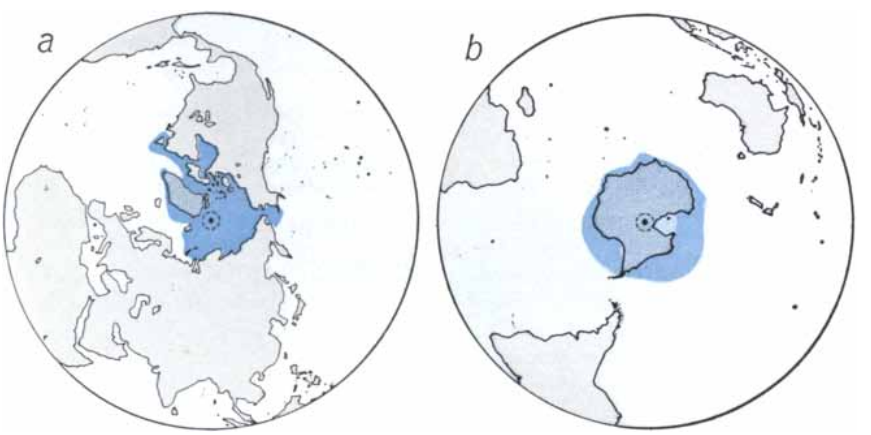


FORMATION OF TILLS may in some cases have occurred by means other than glacial action, or those means may have supplemented the action of glaciers. All involve events occurring in water. At top are (*a*) a rockfall; (*b*) slumping and sliding; (*c*) a mass flow; (*d*) obliteration of previous structure by mass flow, producing a structureless till. At bottom are (*e*) turbidity current; (*f*) the

ing to find local evidence of slumping or even graded bedding. Reusch's moraine with its striated pavement, for example, appears instead to be a lens-shaped deposit of slumped tillite resting on contemporary sandstone grooved only by the submarine slumping of the till itself.

Both the extent of the Infra-Cambrian tillites and the size of the boulders included in them seem to be powerful arguments in favor of their glacial origin. Even more decisive evidence can be found. In some of the tillites that show a fine stratification individual pebbles and boulders can be seen to have distorted the layers of finer material below and around them. The only adequate explanation for this is that the pebbles and boulders dropped from floating ice. At least some of the Infra-Cambrian boulder beds must therefore be accepted as true tillites.

In addition to those boulder beds now situated in Arctic regions, many tillites have been reported from Infra-Cambrian strata in other parts of the world. For most of them the possibility of a glacial origin is also worthy of serious consideration. It is necessary to confine the argument to tillites laid down in water; this eliminates mountain glacial tillites, which might have been deposited in any latitude and at any time. Also ruled out of consideration are the many alleged tillites known to belong to strata much older than the Infra-Cambrian. We shall thus focus attention on those water-deposited tillites that lie within a few hundred meters below Cambrian rocks, which are identifiable as the oldest strata that are



DISTRIBUTION OF ICE at various periods is shown in these polar projections. Land ice is represented by the lighter color; sea ice, by the darker. Maps *a* and *b* show respectively the Northern and Southern hemispheres as they appear at present. Map *c* depicts the situation in the Northern Hemisphere during the Pleistocene ice age, the most recent major glaciation. Map *d* shows the Southern Hemisphere during the next preceding major ice age,

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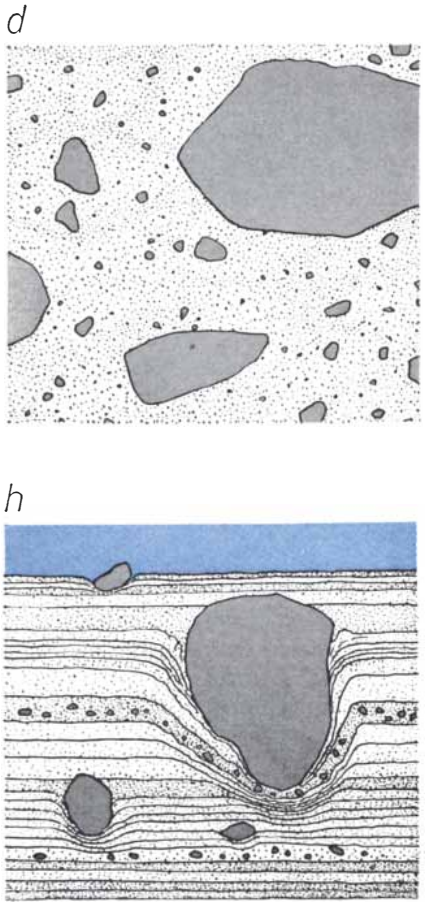


resulting turbidite, with graded bedding; (*g*) iceberg dropping rafted boulder; (*h*) same boulder penetrating bottom sediment.

found to contain fairly abundant fossils.

Even if the argument is restricted in this way, one is left with many substantial formations. This in itself is a remarkable fact. The distribution of Infra-Cambrian water-deposited tillites is almost worldwide. Whether they are considered according to the present position of the continents or according to a possible Pre-Cambrian arrangement [*see illustration on page 31*], it is difficult to confine them, as is possible with the Permo-Carboniferous tillites, to a restricted portion of the globe.

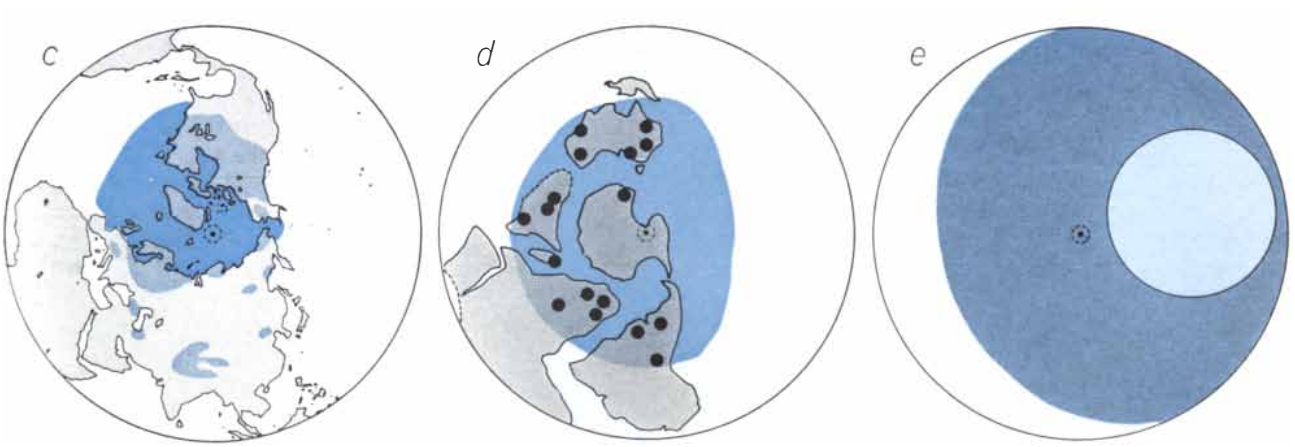
There are two alternative hypotheses to account for this fact. One states that the ice was widespread at all latitudes. The other prefers to accept a period of rapid polar wandering, which brought many different areas successively into high latitudes. The latter hypothesis is not supported by any evidence; indeed, it seems to have been suggested only in order to avoid postulating the presence of ice in the tropics. Yet paleomagnetic evidence indicates that some tillites were formed at quite low latitudes. It is therefore simplest to postulate a single complex ice age during which, on at least two occasions, ice drifted into the Infra-Cambrian tropics.

The argument can be put another way. Various attempts to reconstruct Cambrian climates suggest that generally warm conditions, with extensive deposition of limestones and the formation of salt deposits, prevailed in a belt extending from, say, the Indian Ocean to Scandinavia and Greenland. Such reconstructions are only approximate at best, but in this case (as in most others) they are consistent with the paleomagnetic evidence. The location of the North Pole, obtained from paleomagnetic readings of Cambrian and late Pre-Cambrian rocks in northern Europe, Greenland and North America, was in an area near the Equator in the present Pacific. Therefore the ancient latitude of rocks in the strata above and below many Infra-Cambrian tillite formations was nearly equatorial, and the tillites themselves would seem to have been formed in the tropics.

To check this point magnetic determinations have been made for sedimentary rocks closely associated with the tillites in Greenland and Scandinavia. These too yielded readings that pointed toward an equatorial position. The only difficulty, then, is the indication that ice existed near the Infra-Cambrian Equator. Failing any other explanation, however, we are prepared to accept that it did exist there.

Although the Infra-Cambrian glacial deposits, and other deposits derived from them, are extremely widespread, this does not mean that the entire earth was covered with ice; indeed, that would be most unlikely. During an intense glacial period increasing cold would extend the total area of sea ice, although large areas of ocean at low latitudes probably would remain open. On land the ice sheets might develop mostly at middle latitudes. Whatever the exact distribution of ice, the water-deposited tillites clearly indicate that icebergs or sea ice transported material from the land or shallow seas into warmer waters.

It is difficult enough to know the positions of continents in, say, Permian times; there is even less certainty about these positions in Pre-Cambrian times. We are obliged to use the best possible Permian reconstruction, rather than a map of the earth today, as a basis for reconstructing a still earlier map. We infer that the Infra-Cambrian Equator ran somewhere near the Arctic rocks that have been mentioned. In addition it seems that one pole may have been



which occurred in Permo-Carboniferous times. The continents are arranged as in the lower map on page 31, according to the hypothesis that several of them were close together in a single area now called Gondwanaland. The circles represent tillite occurrences; since the South Pole presumably was shifting, the tillites formed at any one time would have occupied a relatively small area. Map *e* shows Infra-Cambrian ice; with a dominant continental area (represented symbolically by the large circle since the actual configuration is unknown) and with much sea ice tillites could have formed along the Equator in spite of the warmer climate in that region.

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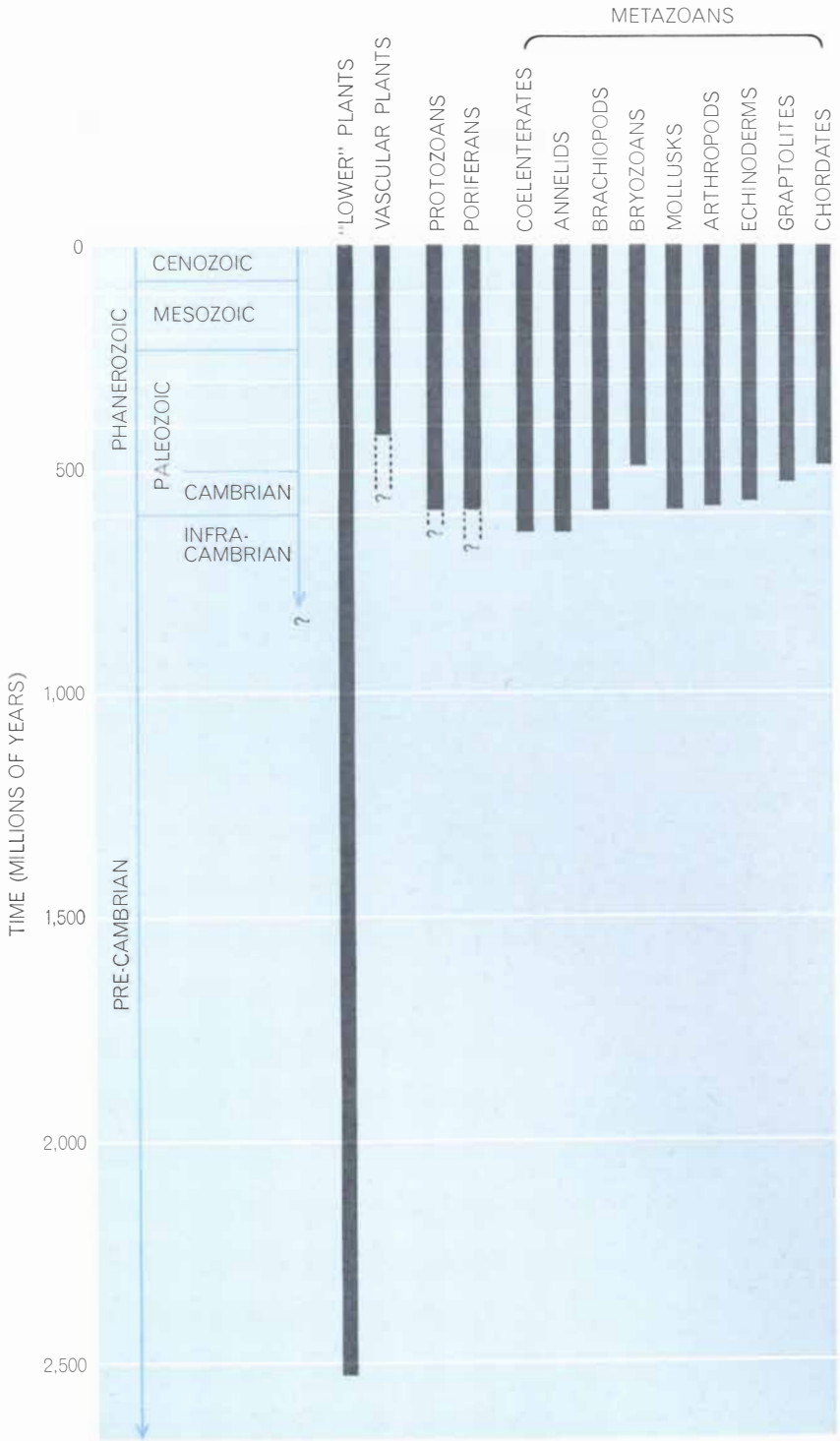
located for a long time near Central Africa and South America; this would account for the evidence of repeated ice action in late Pre-Cambrian rocks in those areas.

What of the ice ages before the Infra-Cambrian? Although many tillites in much older Pre-Cambrian rocks have been described, their exact ages and original latitudes are not yet known. They are fairly clearly separated from the Infra-Cambrian glaciation; the Infra-Cambrian tillites are in many places underlain by a succession of more than 10 kilometers of strata without a trace of glacial action. It seems that glacial periods have been infrequent, exceptional and only occasionally widespread events in the history of the earth. If tillites can be correlated or distinguished from one another, such as by dating them through the decay of radioactive elements in associated rocks, they may come to be an important means of dividing up the long Pre-Cambrian record by showing that it was punctuated by distinctive climatic episodes. And if ice ages are to be explained by changes in the amount of radiation from the sun (there is as yet no obviously better explanation), then the chronological pattern of ice ages will provide a valuable clue to the timing and magnitude of solar events.



DISTRIBUTION OF FOSSILS through time indicates that there was a proliferation of animals early in the Cambrian period. By contrast, in the long Pre-Cambrian period living things were few and simple. Apparently the cause of the rapid evolutionary development was the change of climate occurring after the ending of the Infra-Cambrian ice age.

The usual conception of an ice age is too much molded by what is known of the Pleistocene glaciation. The preceding Permo-Carboniferous ice age seems to have been spread over some tens of millions of years. The Infra-Cambrian ice age may well have lasted as long, but it far surpassed the Permo-Carboniferous in geographical extent.

An ice age of such severity would explain much that is otherwise puzzling about Infra-Cambrian history. The withdrawal of water into huge ice sheets on the land would have led to a general drop in the sea level. This would have exposed newly deposited shallow-water sediments, which would then have been subject to erosion, slumping and flow. Older, consolidated rocks would also have been eroded by the ice sheets; from that action would have come most of the boulders in the tills on the sea floor. The location of the land ice probably varied from high latitudes at the beginning and end of the glacial cycle to middle latitudes at the coldest part of the cycle. It may not be necessary to postulate land ice at low latitudes: floating sea ice and drifting icebergs could have carried material far beyond the boundaries of the continental ice sheets, depositing sediments of similar composition over wide areas of the sea floor. Such deposition would account both for the existence of tillites in the Infra-Cambrian tropics and for the observed similarities and extent of the tillite formations.

If our interpretation of the Infra-Cambrian ice age is correct, at least in broad outline, it can hardly be mere coincidence that a geological event of such intensity was followed, after a relatively short interval, by a biological event of equally striking character. Both the sudden appearance and the

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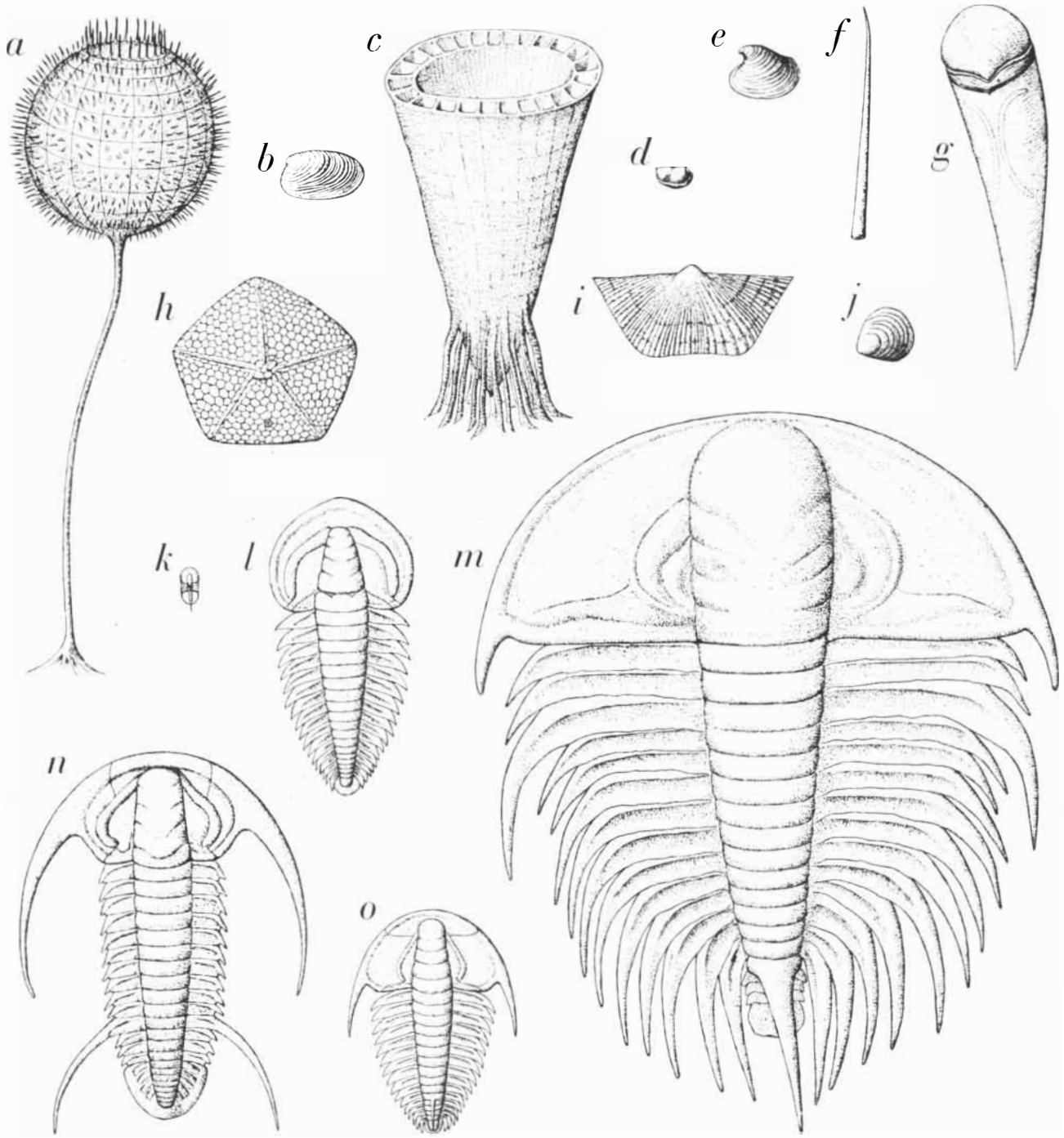

FOSSIL RECORD of early Cambrian times, immediately after the end of the prolonged cold of the Infra-Cambrian ice age, shows many new animals. Some are drawn here nearly life-size. Among them are arthropods ("*d*" *and* "*k*" *through* "*o*"); mollusks ("*b*," "*e*" *and perhaps* "*f*" *and* "*g*"); brachiopods (*i*, *j*); echinoderms (*h*); sponges (*a*), and other organisms (*such as* "*c*") that probably belong to phyla, or animal groups, that became extinct long ago. Rocks of Cambrian times are the earliest to show such a varied fauna.

remarkable composition of the animal life characteristic of Cambrian times are sometimes explained away or overlooked by biologists. Yet recent paleontological research has made the puzzle of this sudden proliferation of living organisms increasingly difficult for anyone to evade.

In contrast to the burgeoning of animal life in the Cambrian period, the only kind of life for which Pre-Cambrian rock strata (including those of Infra-Cambrian age) provide clear evidence is plant life, chiefly lime-secreting algae. The strata of Cambrian age, however, contain the fossils of a remarkably varied array of multicellular animals. These animals were neither primitive nor generalized in anatomy: they were complex organisms that clearly belonged to the various distinct phyla, or major groups of animals, now classified as metazoan [*see illustration above*]. In fact, they are now known to include representatives of nearly every major phylum that possessed skeletal structures capable of fossilization; the only important exception is the phylum of chordates, which includes the vertebrates.

Moreover, most of these phyla first appear in the fossil record during the early part of the Cambrian period, the 40-million-year Lower Cambrian. Their

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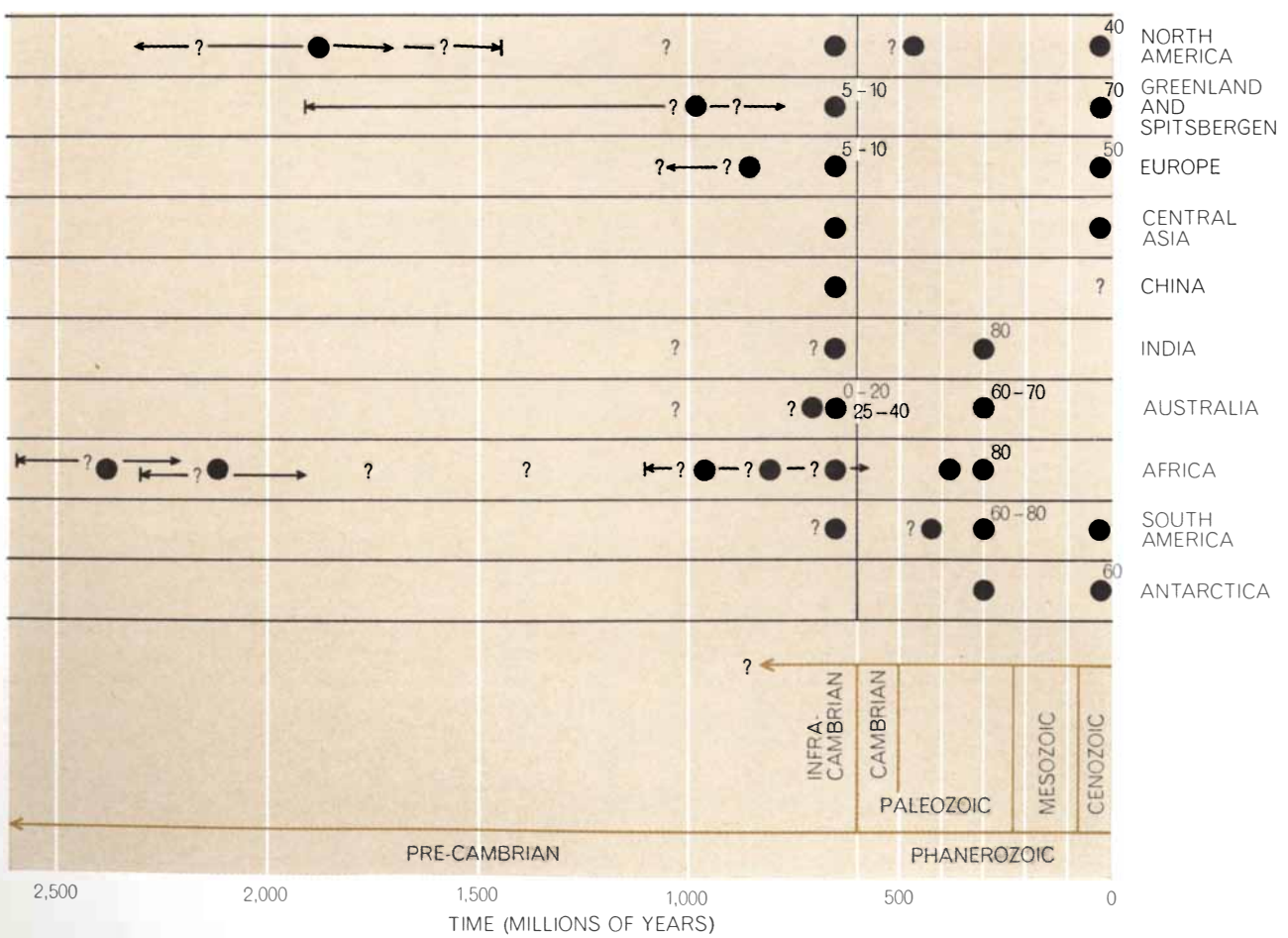
record extends more or less unbroken from then up to the present day. Yet before the Lower Cambrian there is scarcely a trace of them. The appearance of the Lower Cambrian fauna is thus a uniquely important event in the history of animal life. Moreover, on the time scale of the fossil record as a whole the emergence of the fauna can reasonably be called a "sudden" event [*see illustration on page 34*].

One can no longer dismiss this event by assuming that all Pre-Cambrian rocks have been too greatly altered by time to allow the fossils ancestral to the Cambrian metazoans to be preserved. It is true that one peculiar soft-bodied fauna has been found in Australia in strata that appear to be Infra-Cambrian, although they are younger than the Infra-Cambrian tillites [see "Pre-Cambrian Animals," by Martin F. Glaessner; SCIENTIFIC AMERICAN, March, 1961]. But even if all the Pre-Cambrian ancestors of the Cambrian metazoans were similarly soft-bodied and therefore rarely preserved, far more abundant traces of their activities should have been found in the Pre-Cambrian strata than has proved to be the case. Neither can the general failure to find Pre-Cambrian animal fossils be charged to any lack of trying.

If all the evidence is viewed without preconceptions about evolutionary processes, the suggestion is clear that at the end of the Infra-Cambrian period there was a phase of rapid and radical evolutionary change in animal life. In this period of a few millions of years, or at most a few tens of millions, the metazoan phyla evolved into the relatively large and complex organisms that are found as fossils in Cambrian rocks. Perhaps ancestral metazoans had existed previously. If so, however, it seems probable to us that only a few of them were of a size larger than microscopic until the very end of the Infra-Cambrian period.

Whatever other factors may have been involved in this evolutionary event, some trigger mechanism seems required to have set it in action. This impetus could have been the major climatic change that came at the end of the Infra-Cambrian ice age. The ice age itself would have created extremely adverse conditions for life. In particular the lowering of the sea level would have sharply reduced the area of the shallow seas, which include many of the most favorable habitats for marine life. In contrast, at the end of the ice age the improvement in climate and the rise of the sea level would have re-created a variety of favorable but biologically empty environments, in which the opportunity would exist for radical evolutionary changes to take place.

A causal connection between the Infra-Cambrian ice age and the appearance of the Cambrian fauna thus appears at least possible, and perhaps probable. Certainly a climatic event of an intensity unparalleled in the later history of the earth seems to have been closely followed by a biological event of profound significance in the history of life.



TILLITE TIME PATTERN indicates the periods in which tillite deposits were made. Each circle represents one or more such deposits. Question marks indicate some uncertainty about the age of the deposits; radiometric techniques have provided some limits to the uncertainty, as shown by arrows. Latitude indications show where in relation to the Equator of that time a deposit was formed.

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A **Kodak** advertisement which recognizes that all are laymen, except in some small respect or other

Why CEC now sells Genesee River tape

A certain kind of sausage that must have originated in the Italian city of Bologna brings joy to unnumbered millions. Quite a different kind, identified with the Thuringian duchies of olden Germany, also sells very well. Wieners, still another kind of sausage, are loved by virtually every American with little thought to the Austrian capital or its possible rival Frankfurts on the Main or Oder.

Inedible but more up-to-date commodities can likewise be geographically identified, though manufactured by companies instead of guilds. One such is magnetic tape for aerospace telemetry and other raw-data recording applications. One company on the Mississippi and a smaller rival near the Pacific shore have won eminence in the field. Now an unfettered economy further widens the choice that faces the instrumentation-tape buyer. He must now consider tape from the banks of the Genesee in New York State.

For the benefit of his conscience as an engineer, he must be told that while the three principal sources of supply can equally assuage the hunger of his data recorders, their products are no more identical than are wieners, thuringer, and bologna. The engineers of Consolidated Electrodynamics Corporation, a leading manufacturer of recorder/reproducers that use instrumentation tape, now announce their decision to give their preference and "CEC" name to our Rochester-made tape on the following grounds:

• **Smoothness:** Pleasant in shaving, drinking, or riding and essential in recording frequencies up to 1.5 mc. Well known rule-of-thumb says you lose 55 db when oxide surface jumps one wavelength from polepiece. At 1.5 mc and 120 in/sec, a wavelength is 0.00008″. Pimples had better be low, few, and far between on "wideband"-class tape. We also do very well by CEC in this respect on the three other classes down to "standard telemetry," which claims only 100 kc at 60 in/sec. Differences come in particle-size distribution. Each of our classes excels in response out to its frequency limit. When you can afford to reduce gain in the amplifier at high frequencies, you are cutting broad-band noise. Signal-to-noise ratio is the cause worth fighting for. In audio tape, which we also make, it's low print-through. The human brain balks at strange echoes. The human ear needs no frequencies above 20 kc and little power above 5 kc. But signal power at high frequency keeps the instrumentation-tape user in business.

• **Straightness of edge:** Wandering out of alignment with the polepiece gap after a few thousand feet can be as fatal as a coating defect. We have slit film to better accuracy than that from time immemorial.

We don't even have to slit in the dark.

• **Uniformity of characteristics end-to-end and reel-to-reel:** CEC, who have tested plenty of tape in their day, say they have never before encountered any so uniform. We think we can do better later.

• **Little things:** Extreme cleanliness is the price of admission to the tape-making game. We had to pay it a generation before magnetic tape came in. It seems a pity to risk sifting dust from paperboard packaging over such a clean product. Therefore we put all our tape for CEC in metal cans and the cans in rectangular cartons that can be stored on edge and marked for identification. On the tape itself we print our name and a code number every few inches. We wonder why the others don't.

Any questions? Ask Eastman Kodak Company, Magnetic Products Division, Rochester, N. Y. 14650.

Notice to x-ray labs

A request for a duplicate of a radiograph need no longer arouse the old resentment. Far more rational it is to ask the Kodak X-ray Representative or dealer to explain how to copy on the new KODAK Radiograph Duplicating Film. The result rolls right out of the KODAK X-OMAT Processor (or manual processing system) just like whatever originals are going through at the moment.

So what:

Creativity is beyond price and inspiration sometimes saves lives, but mostly hospitals (and industrial inspection departments) have to run on routine or chaos reigns. X-ray labs handle x-ray film. Rarely can they spare time, staff, or facilities to fuss with other kinds of film and exposure methods. Copying a radiograph, since it is done with light, has been considered photographic technique, not radiographic.

That's why you may have found a duplicate of a radiograph exasperating to come by.*

Ordinary paper prints simply don't deliver the information that an experienced x-ray man gets from film. Now the x-ray department routine can crank out film duplicates easier than paper prints. From now on, simply as a consequence of our normal thirst for sales, the film images that the experts have trained themselves to read can multiply and yet not lose value.

In industry, ever-reassessable proof of the soundness of structures, parts, and designs can freely pass up and down the chain of business relationships. Patients passing from Dr. A's care to Dr. B's can come complete with radiographs and no robbery of Dr. A's files. The radiologist, the surgeon or other specialist who must plot procedures or therapy, and the family physician who calls his colleagues in, can all be looking at the same picture in their separate offices while the radiologist interprets it.

Perhaps the biggest benefit from this dull commercial development will be that a young doctor preparing to convince the American Board of Radiology of his fitness to practice diagnosis by x-ray will have digested even more of other doctors' radiographs than he manages to wangle now.

*Oldtime x-ray technicians when they found time often used to check a new batch of film to see if it solarized well. i.e. could be made to work like a direct positive by enormously exaggerated exposure to light. When they found such an emulsion, they set some aside for making duplicates. Modern x-ray film has better things to do than solarize. Nor does it vary much. Nor do the technicians find time. The real oldtimers have retired.

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Put a flame to rigid Geon vinyl, then take it away—and no flame remains. Reason: the high halogen content acts as a flame inhibitor. Many products—building panels, for instance—are now greatly improved by this property and others inherent in Geon polyvinyl chloride.

Can you use such a material that is also low in cost, light in weight, structurally strong, corrosion resistant, impervious to moisture, has color clear through, won't warp or rust, is easy to fabricate and consistently uniform in quality? If so, write for data plus a set of color chips as illustrated above: B.F.Goodrich Chemical Company, Dept. EA-8, 3135 Euclid Avenue, Cleveland 15, Ohio. In Canada: Kitchener, Ontario.

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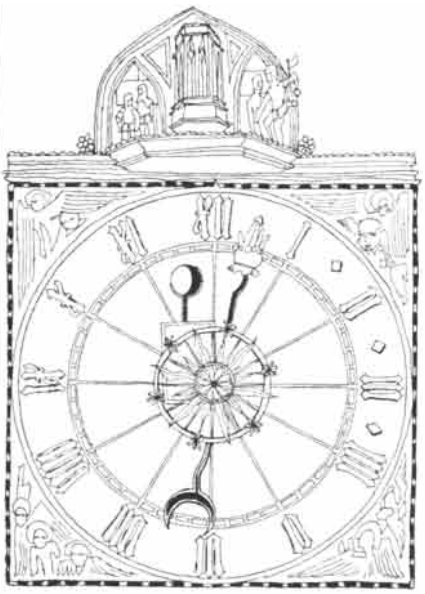

Quasar Hypotheses

The problem of accounting for the enormous energy radiated by quasi-stellar radio sources has recently stimulated the development of two new hypotheses, one fairly conservative, the other highly speculative. Quasi-stellar radio sources, now sometimes called quasars, are about 100 times brighter than a typical galaxy but have at most a fifth, and perhaps only a hundredth, of its diameter (see "Quasi-stellar Radio Sources," by Jesse L. Greenstein; SCIENTIFIC AMERICAN, December, 1963). About 10 quasars are now well established. One of them, the object designated 3*C* 147, is the most distant object known.

Quasars appear to have originated in titanic explosions that released between 10^{59} and 10^{60} ergs, an amount of energy equivalent to that contained in the substance of between 10 million and 100 million suns. One early proposal was that the energy might be released by a chain reaction of supernova explosions in a crowded region of a galaxy. Another proposal invoked the gravitational collapse of a single enormous star with a mass of 100 million suns.

A more conservative hypothesis has now been put forward in *Nature* by G. B. Field of Princeton University. He suggests that a quasi-stellar radio source may represent an early stage in the evolution of a normal spherical galaxy. Such a galaxy would originate as a tenuous cloud of hydrogen gas with a mass of some 100 billion suns. It would contract slowly at first, then more swiftly, finally reaching a minimum radius of only a few hundred light-years before it was stabilized by rotational forces. By that time, in a protogalaxy destined to become a spherical galaxy, stars would have condensed out of the gas on a large scale and the system would begin to reexpand. Of some 50 billion stars created in this early stage about one in 500, or 100 million, would be of the brightest type. As a result they would all burn out at nearly the same rate and meet their end as supernovae, with a combined release of 10^{60} ergs, over the relatively brief interval of about a million years. This works out to an average rate of 100 supernova explosions a year. Statistical fluctuations would vary this number from 60 to 140 a year, thereby accounting for the puzzling variation of plus or minus 40 percent observed in the light output of quasars.

A more radical explanation for the source of quasar energy is proposed by Banesh Hoffmann of Queens College of the City University of New York. His paper, entitled "Negative Mass as a Gravitational Source of Energy in the Quasi-stellar Radio Sources," received a first prize of $1,000 in the annual competition sponsored by the Gravity Research Foundation.

Hoffmann, who once collaborated with Albert Einstein and Leopold Infeld, explores the consequences of assuming the existence of negative mass (not to be confused with antimatter, which has been demonstrated to exist). He points out that the idea of negative mass is "extremely natural" in the general theory of relativity and, in fact, can be excluded only by certain *ad hoc* assumptions.

According to the equations of both Newton and Einstein, positive mass must attract negative mass as well as positive mass. Negative mass, however, should repel both types of mass. Hoffmann assumes that in accordance with general relativity the two types of mass can radiate gravitational waves. General relativity suggests further that the energy transported by such waves is positive regardless of the sign of the originating mass. This has the peculiar result that a particle of positive mass should be able to turn into one of nega-

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tive mass by radiating enough energy in the form of gravitational waves, and that further radiation should make its mass increasingly negative.

Hoffmann suggests that a conservation law may normally prevent particles of positive mass from "decaying" in this fashion into particles of negative mass, but that this law may be violated under the "extreme and unusual conditions" inside a quasar. The violation may be induced by a combination of strong gravitational fields and extremely dense packing of particles. The latter would enable the nuclear force, the strongest of the four natural forces, to "shake" particles of positive mass so violently that they would radiate gravitational waves. The quasar's intense gravitational field, acting as a "symmetry breaker," would then allow the particles of positive mass to decay into particles of negative mass. As a result vast amounts of positive energy could be made available through the creation of a corresponding amount of negative mass. "It is precisely because quasi-stellar objects emit amounts of energy so prodigious as to defy conventional explanation," Hoffmann writes, "that the concept of negative mass deserves to be taken seriously."

Superconducting Plastics

The arresting prediction that it should be possible to create plastics that are superconducting at room temperature or above has been made by William A. Little of Stanford University. Little reached his conclusion after analyzing the structure of organic molecules in the light of the theory of superconductivity developed by John Bardeen and J. R. Schrieffer of the University of Illinois and L. N. Cooper of the University of Pennsylvania.

All superconducting materials known at present are metals or metal alloys; they become superconducting only when they are chilled to within 18 degrees centigrade, or less, of absolute zero. Only at these temperatures are the random vibrations of atoms in the metal damped to the point where certain electron-pairing processes can take place that result in the conduction of electric current without resistance.

This stunning composition is worthy of John James Audubon. Arrow points to the nervous but unafraid Water Turkey, hundreds of feet from a standard Questar. Above is image Questar reached out and delivered to 35-mm. negative ready for enlargement. Tri-X, 1/250 second.

We included the sprocket holes of this 35-mm. negative for clarity. Beautiful 11x14 enlargements are practically grainless. Questar telescopes are priced from $795. They make possible sharp wildlife photographs like this without tents or towers or stalking blinds. At left the versatile Standard Wide-Angle Model. The latest Questar booklet now has 40 pages, 8 of them in color, and has a long essay on what we have learned about telescopic photography in 10 years. One dollar postpaid in U.S., Mexico and Canada. By air to West Indies and Central America, $2.30. By air to Europe, N. Africa and S. America, $2.50. By air to Australia and elsewhere, $3.50.

QUESTAR

BOX 20 NEW HOPE, PENNSYLVANIA

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Little, who makes his prediction in *The Physical Review*, has calculated that an analogous kind of charge pairing should occur in a properly designed organic molecule. He predicts that a molecule of the following configuration should be a superconductor. Its backbone would consist of a long chain of carbon atoms alternately connected by single and double bonds; periodically along the chain, say at every fourth carbon atom, there would be dyelike side chains. For this role Little suggests trying diethyl-cyanine iodide, a dye commonly used to sensitize photographic plates. He believes the superconducting state will arise from an interaction between positive charges oscillating in the side chains and electrons moving along the spine of the molecule.

Efforts will doubtless be made to synthesize a molecule meeting Little's specifications, even though chemists can predict that it will be extremely sensitive to oxidation and highly unstable. The real question is whether the interaction of charges will take place as Little predicts and whether they will actually lead to the superconduction of a measurable electric current.

Predictable Alloys

A new theory that makes it possible to predict the characteristics of any combination, in any quantity, of 30 transition metals has been developed by Leo Brewer of the University of California's Lawrence Radiation Laboratory. A theory of the behavior of electrons in crystal structures, it takes into account all temperatures up to the melting point, and it could be extended to higher temperatures. Because the 30 transition metals can be combined in two billion ways, not counting the infinite number of combinations involving different quantities, laboratory studies of all the hypothetical alloys are impossible. Thus the theory promises a great acceleration in the search for the new materials needed in many advanced technologies. In addition the theory is expected to play an important role in the design of high-temperature-purification processes essential to the production of superconductors and semiconductors, which are made from transition metals.

The metals covered by the theory fall into three groups, from element 19 (potassium) through element 28 (nickel), from element 37 (rubidium) through element 46 (palladium) and from element 55 (cesium) through element 78 (platinum). Among these metals are iron and chromium and exotic elements of increasing utility, such as titanium, zirconium, niobium, tantalum and molybdenum. Alloys of some transition metals provide lightweight materials of great strength and resistance to high temperatures and radiation. Until now the search for such alloys has had to be conducted largely on a hit-or-miss basis.

For four decades chemists have had a rule developed in Britain by W. Hume-Rothery for predicting the structure of compounds of the nontransition metals, which include aluminum, zinc and tin. The greater variety of electron states in the transition metals had precluded the development of a similar theory for them. Brewer's new conception is based on the work of Linus Pauling and Hume-Rothery and particularly on a theory of Niels Engel, a Danish chemist now working on the faculty of the Georgia Institute of Technology and at the Oak Ridge National Laboratory. Brewer combined Engel's ideas with known information on the size of atoms and on the effect of heat on various combinations of metals. He also made use of predictions from theories of solubility.

The new theory is expressed in several ways involving tables and charts. A chemist can look at these and determine the properties of a given proposed mixture. Among other things, the charts show that it is possible to make compounds that violate earlier chemical laws of definite combining proportions.

Acoustic Waves from a Laser Beam

A prediction that an intense light beam from a laser should generate intense acoustic waves of extremely high frequency has now been verified. The prediction had been made by Charles H. Townes and his associates at the Massachusetts Institute of Technology (see "The Interaction of Light with Light," by J. A. Giordmaine; SCIENTIFIC AMERICAN, April). The demonstration, reported in *Physical Review Letters,* was made by Townes and R. Y. Chiao of M.I.T. and a visiting associate, B. P. Stoicheff of the Canadian National Research Council.

In their demonstration the M.I.T. workers focused a giant pulse of red laser light with a wavelength of 6,940 angstrom units into crystal targets of quartz or sapphire. The power output of the laser was about 50 megawatts for 30 billionths of a second, which, after focusing, reached an intensity of about a million megawatts per square centimeter inside the target.

A special optical system collected the light scattered at specific angles from the crystal and indicated that some of the scattered light had been shifted to a lower frequency. From the extent of the shift it could be inferred that acoustic waves with a frequency of 3×10^{10} cycles per second had been generated within quartz and waves of twice that frequency within sapphire. The acoustic waves are created when energy carried by light radiation is partially transferred to mechanical vibrations of the crystal lattice. The length of the acoustic waves is about 2,000 angstroms, or about half the wavelength of the laser light inside the crystal. Only about one part in 50,000 of the incident light energy was converted into acoustic energy, but even so the power of the acoustic waves reached the kilowatt level. This was enough to fracture the crystals extensively. Townes and his associates believe fracturing can be prevented by chilling the crystals and that controlled acoustic waves of high intensity can be generated for a variety of experimental purposes.

The 2,500-Mile Revolution

One of mankind's most significant advances—the Neolithic revolution, which introduced organized agriculture and animal husbandry—took place somewhere in the hills of the Middle East about 9,000 years ago. Now evidence from Afghanistan and Macedonia, at opposite ends of the region, indicates that the transition from seminomadic hunting and foraging to the more settled life of farmer and herdsman may have occurred almost simultaneously across the entire 2,500-mile-wide highland zone.

Digging in a limestone cave site in northern Afghanistan, Louis Dupree of Pennsylvania State University has unearthed flint blades, associated with charcoal that yielded a carbon-14 date of 7000 B.C., from tools that were used to harvest grain. The cave, which shows evidence of occupation for some 15,000 years, has now been trenched to a depth of 38 feet without reaching bottom. Dupree hopes to find Paleolithic material below that level in coming seasons.

Excavations begun in 1961 of a mound at Nea Nikomedeia, 45 miles west of Thessaloníke on the Macedonian plain of Greece, and continued last

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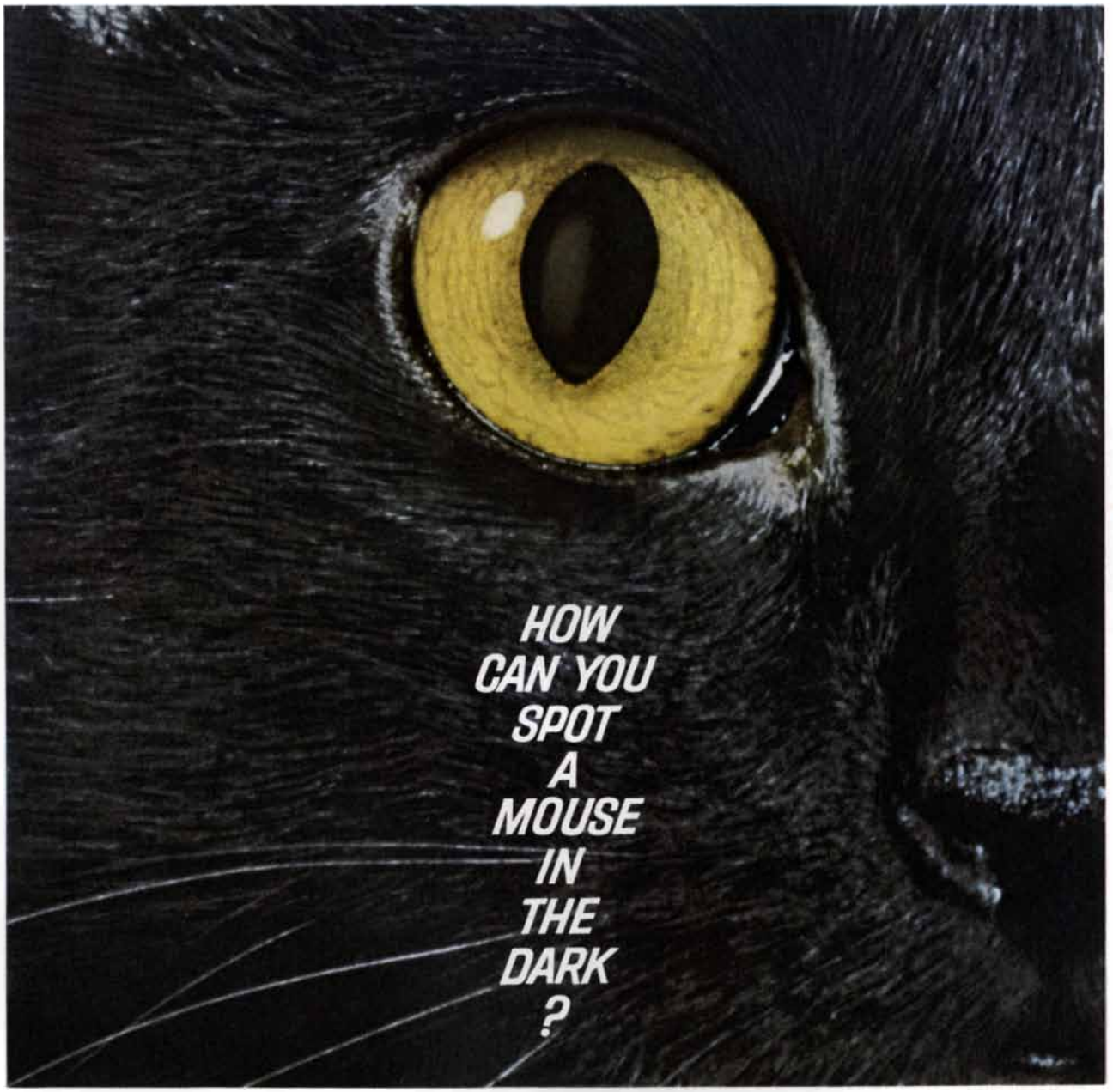

Sylvania/ECG has the answer

Standard photoconductors respond primarily to visible light. Recently, the Sylvania Electronic Components Group tackled the tricky problem of making these cells "see in the dark."

The answer is ingenious. Sylvania developed a photoconductor with a special phosphor that emits visible light when subjected to the invisible rays of ultraviolet.

The new Sylvania UV photoconductor has numerous applications. For instance, it can accurately detect the presence of a man or a mouse in a dark room flooded with "black light," or monitor your furnace by the color of its flame.

Advanced component design such as this is the result of integrated research and engineering in all of the basic sciences.

One of the components developed by Sylvania ECG may solve a problem you have in system design.

Sylvania Electronic Components Group, Sylvania Electric Products Inc., 730 Third Avenue, New York, N. Y. 10017.

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what's a chemical company doing painting on a rainy day?

Oil-based paints used to hate water. Not now. While you still can't paint a surface exposed to the rain, the new urethane oil paints do love humid weather; in fact, they actually *depend* on moisture in the air to cure and harden. Solvents tried in early formulations, however, had two serious drawbacks. Paints yellowed in the can, and moisture pick-up reduced shelf life. Enjay solved the problem with hexyl acetate, a brand-new solvent. Colors now stay bright and clear, and shelf life is excellent. If your company has a materials problem, perhaps we can help solve it, too. Write: Enjay Chemical Company, 60 West 49th St., New York 10020

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year by a joint expedition of the University of Cambridge and Harvard University have brought to light two successive village sites, together with abundant remains of pottery, of cultivated wheat, barley and lentils, and of domesticated sheep, goats, cattle and pigs. Here, as in Afghanistan, flint-bladed tools were used to harvest grain. Charcoal from the earliest level at Nea Nikomedeia gives a carbon-14 date of 6220 B.C. Ritual objects and pottery decorations strongly suggest links with the Neolithic cultures of highland Turkey; in particular, representations of the female figure and a number of clay seal-stamps show affinities with Çatal Hüyük (see "A Neolithic City in Turkey," by James Mellaart; SCIENTIFIC AMERICAN, April), where the earliest levels excavated thus far date to about 7000 B.C.

Trans-Neptunian Comet Belt

Slight perturbations in the orbit of Neptune, previously attributed to the gravitational attraction of neighboring Pluto, may in fact be caused by an invisible belt of comets that rings the sun just beyond the orbit of Neptune. This hypothesis was advanced recently by Fred L. Whipple, director of the Smithsonian Astrophysical Observatory, in *Proceedings of the National Academy of Sciences*. As a corollary to his hypothesis, Whipple suggests that the mass of Pluto may be much smaller than has been supposed.

Current theories of the formation of the sun and the planets point to the existence of a large mass of small solid bodies at the outskirts of the solar system. The composition of these bodies is presumably similar to that of the outermost planets—Uranus, Neptune and Pluto—and these in turn appear to be comparable in composition to comets, which are believed to be icy conglomerates composed chiefly of frozen methane, ammonia and water. According to one theory the outermost planets are themselves accumulations of cometary material. Because of the low density of the outer parts of the primordial gas cloud, cometary material beyond the gravitational reach of Neptune would not coalesce into planets but would remain in a trans-Neptunian ring approximately in the plane of the planets.

Whipple estimates this belt of comets to have a total mass about 10 to 20 times that of the earth. If the diameter of the largest members of the belt does not exceed about 125 miles, roughly a thirtieth of the observed diameter of Pluto, they would have an apparent visual magnitude of 22 and be invisible to the largest telescopes. The belt would not contribute appreciably to the observable comets, which were probably formed inside the planetary region and thrown into their extremely elongated orbits after wandering into the gravitational domain of a massive planet such as Jupiter.

The gravitational effect on Neptune of such a belt of comets would account for the observed perturbations in Neptune's orbit more satisfactorily than the effect produced by a massive Pluto. Moreover, such a solution would avoid a long-standing dilemma regarding the mass of Pluto: if Pluto is responsible for the perturbations in Neptune's orbit, it would have to have a mass comparable to that of the earth, yet direct observations indicate a much smaller mass. By postulating the comet belt the mass of the more distant planet can now be considered to be as small as it appears to be.

Hominids and Humans

A British taxonomist has challenged the recent addition of a third human species to the hominid fossil record and a British archaeologist has proposed that the ranks of living hominids be widened to include two of the three species of great apes. The third human species—*Homo habilis*—was proposed this spring by L. S. B. Leakey and applied to a number of hominid bones and skull fragments found in two separate strata at Olduvai Gorge in Tanganyika. Writing in *Discovery*, Bernard Campbell points out that most students of human evolution now see a smooth transition from the hominid australopithecines, by way of *Homo erectus*, to the sole living hominid species: *Homo sapiens*. Campbell is unable to find enough "morphological space" between the australopithecines and *Homo erectus* for the proposed transitional species.

At the heart of Campbell's challenge lies an increasingly troublesome question: Which fossil hominids properly belong within the genus *Homo*? Cultural criteria—for example, the new remains at Olduvai were associated with stone tools—appear invalidated by the fact that stone tools have also been found with australopithecine remains. The basic distinction between *Homo erectus* and *Homo sapiens* is anatomi-

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IDEAS

What happens when you ask 10,468 engineers the same questions?

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Surprise! We found out that RTV-102 does a terrific job in nearly 10,468 applications! "RTV-102 is unusually versatile," wrote one engineer, "I used it to seal around doors on wet rubber systems." "Used it for sealing signal conditioner packages against high humidity environments," wrote another, "good moisture-tight bond to aluminum." An R&D man used it to hold interconnection wiring in position on a harness design mockup. "RTV-102 has high resiliency and strength," he commented, "and is readily removed if necessary." A botanist used it to make holders (bonded to glass) for marine algae specimens and praised "its resistance to the action of sea water." An engineer at CALTECH was delighted with RTV-102's performance in two separate gasketing applications for freon pressure, a high-voltage R.F. dielectric application, and "one instance where we wanted a smog-resistant resilient mounting for a large precision mirror." He likes RTV-102 because it has "excellent adhesion, high strength, and resistance to chemical attack."

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GENERAL ELECTRIC

cal: the average cranial capacity of the former is a little more than 1,000 cubic centimeters; that of the latter is 1,500 cc. If a similar criterion is applied to *Homo habilis,* Campbell argues, the outcome is doubtful. A cranial capacity between 642 and 742 cc. has been estimated only for the larger and more fragmentary of the two Olduvai skulls. Thus the figure is far from certain, and it is not much above the australopithecine maximum and is about the same as that for living gorillas.

The gorilla and the chimpanzee may soon raise the total of living hominid species from one to three, writes Sonia Cole in the *New Scientist.* Commenting on the important evolutionary position of fossil apes in general and the genus *Proconsul* in particular, she reports that recent work on blood proteins and chromosomes has shown the two great apes of Africa to be related more nearly to man than they are to the orangutan and gibbon of Asia. She suggests that no justification exists any longer for barring the gorilla and the chimpanzee from membership in the family Hominidae.

Automatic Muse

Can a computer not only compute but also think imaginatively? Although the analogy between the computer and the brain is no longer taken as seriously as it once was, efforts are still being made to program computers for such activities as playing a good game of chess or composing music. Recently Richard Ragan of Tallahassee, Fla., who has just been graduated from high school, programed an IBM 709 computer to arrange 77 words and phrases in poetic quatrains. The resulting poetry was strangely powerful. A sample quatrain:

Darkly the peaceful trees crashed
In the serene sun
While the heart heard
The swift moon stopped silently

Obviously Ragan's program will not put poets out of business, but it may illuminate that element of poetry which achieves its effects by the association of dissonant ideas. Ragan points out that a program involving a larger assortment of words and phrases would enable the computer to write several thousand verses a minute. Presumably the programer would then find it necessary to prepare another program to do the work of an anthologist.

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This doctor never read "Gray's Anatomy"

He's more interested in celestial bodies. That's why he came to Caltech's Jet Propulsion Laboratory. And that's why he spends a lot of his time in JPL's quarter-million volume library.

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WINE

This happy invention of man is a solution of hundreds of subtly interacting substances. Modern understanding of the wine-making process cannot explain a great wine but guarantees a good one

by Maynard A. Amerine

Wine is a chemical symphony composed of ethyl alcohol, several other alcohols, sugars, other carbohydrates, polyphenols, aldehydes, ketones, enzymes, pigments, at least half a dozen vitamins, 15 to 20 minerals, more than 22 organic acids and other grace notes that have not yet been identified. The number of possible permutations and combinations of these ingredients is enormous, and so, of course, are the varieties and qualities of wines. Considering the complexity of the subject, it is not surprising that perhaps more nonsense has been written about the making, uses and appreciation of wine than about any other product of man or nature.

Nevertheless, it can be said that in the 20th century wine making has become a reasonably well-understood art. The chemical processes involved are now sufficiently known so that the production of a sound wine is no longer an accident (although the production of a great wine may still be). For this we are indebted primarily to Louis Pasteur, who founded the modern technology of wine making along with several branches of chemistry, microbiology and medicine. Pasteur put the making of wine (and of beer as well) on a rational basis by explaining fermentation, which for thousands of years had been an unsolved mystery.

It seems likely that man's discovery of wine came later than that of beer (a fermentation product of grain) or of mead (a fermentation product of honey), because grapes grow only in certain climates and environments. By Neolithic times, however, the peoples of the Middle East were well acquainted with the fermented juice of the grape, and one of the oldest inscriptions in Egypt (on the tomb of Ptahhotep, who lived about 2500 B.C.) depicts the making of wine. The "blood of the grape" attracted ancient man not only as a beverage but also as a medicine and a symbolic offering to the gods.

The grape is its own wine maker. One simply pressed out the juice, let it stand, and its sugars turned into alcohol. Not until the 19th century did chemists begin to unravel the nature of this process. In 1810 Joseph Louis Gay-Lussac made the first crucial contribution toward solution of the mystery by discovering the general chemical formula of the breakdown of sugar into alcohol and carbon dioxide: $C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$. Plainly this change did not take place spontaneously. What caused the sugar to break down? Gay-Lussac conjectured from his experiments that the process was stimulated somehow by oxygen. The German chemist Justus von Liebig put forward another hypothesis: that the fermentation arose from the "vibrations" of a decomposing "albuminoid" substance. Liebig's authority was so powerful that his view was not seriously challenged until the young Pasteur embarked on his studies of fermentation in the 1850's.

The Role of Yeast

"How account," Pasteur asked, "for the working of the vintage in the vat?" With his gift for designing experiments that went to the heart of the matter, Pasteur soon demonstrated that the working was produced by the microscopic organisms known as yeast. "Fermentation," he concluded, "is correlative with life." He showed that an infusion of yeast would convert even a simple sugar solution into alcohol, and he went on to identify some of the factors, such as acidity or alkalinity, that controlled the metabolic activities of the yeast organisms and thus determined the properties of a wine. Pasteur announced his main discoveries in two historic papers: *Mémoire sur la fermentation appelée lactique* (published in 1857) and *Études sur le vin* (1866).

How does the grape acquire its yeast? As every gardener knows, the skin of growing grapes is covered with a delicate natural bloom. It consists of a waxy film that collects cells of molds and wild yeasts, which are deposited on the grape by agencies such as the wind and insects. The skin of a single grape may bear as many as 10 million yeast cells. Of these, 100,000 or more are cells of the varieties called wine yeasts, of which the principal one is *Saccharomyces cerevisiae* var. *ellipsoideus*. It is the enzymes of the wine yeasts that are responsible for the fermentation of the grape's sugars to alcohol and for the creation of the numerous by-products that partially account for the flavor and other properties of the wine. The nature of the activity of the yeasts importantly affects the wine's quality, consequently it is one of the factors modern wineries are careful to control. In some old European vineyards the grapes and yeasts seem to have established over the centuries a natural harmony that brings out the grapes' best qualities in the wine. But most wineries, even in Europe, now improve on nature by adding pure cultures of desirable yeasts and using chemicals to sup-

CALIFORNIA VINEYARDS cover the hills surrounding the Napa Valley. Varieties of *Vitis vinifera*, the species of grape from which most European wines are made, adapt readily to the warm California environment.

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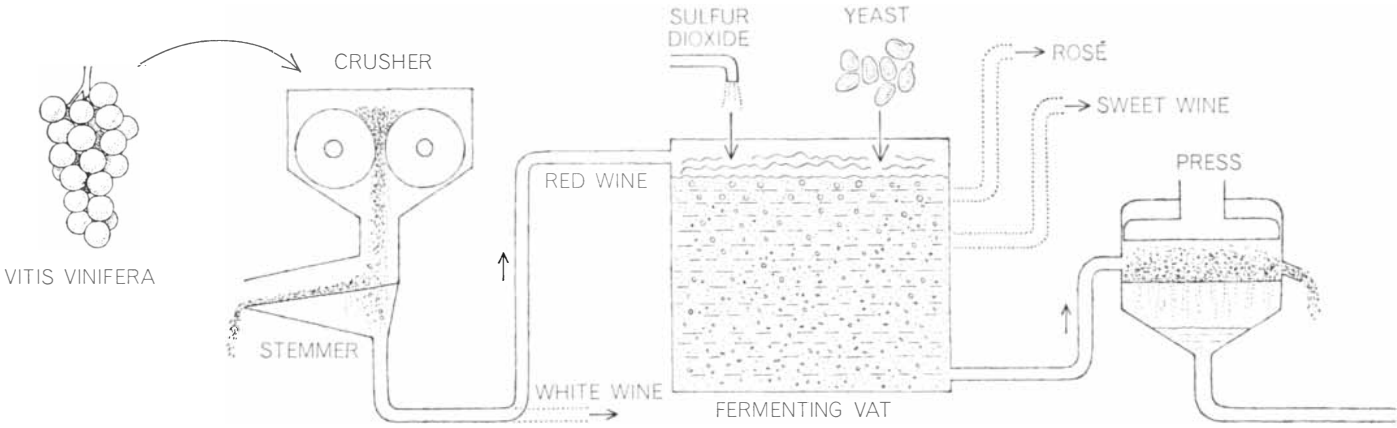


WESTERN U.S. METHOD of producing red wine duplicates the European process. The grapes are crushed between rollers (*left*), forming an intermediate product known as "must." The must is piped to a fermenting vat where yeasts speed the transformation

press the growth of undesirable yeasts present on the grape skins.

The Effect of Climate

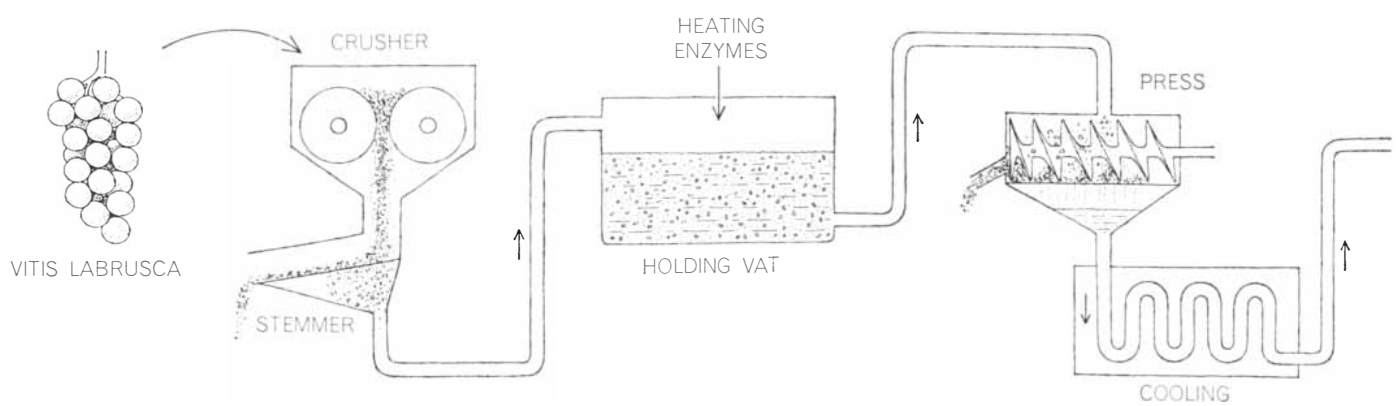
The making of a wine starts long before the grapes reach the winery—indeed, long before the grapes are harvested from the vine. The grape is a complex product of soil, water, sun and temperature. Of these factors, the most significant single one is temperature. Grapes will grow only within the belts of the Northern and Southern hemispheres where the average annual temperature is between 50 and 68 degrees Fahrenheit [*see lower illustration on page 56*]. Even in these regions the European grape *Vitis vinifera* does not survive in areas marked by certain unfavorable conditions: summer temperatures not warm enough to ripen the fruit (as in most of Britain), high summer humidity that excessively exposes it to mold diseases or insect predators (as in the southeastern U.S.) or late spring frosts (as in the northwestern U.S.).

The ideal climate for wine grapes is one that is warm but not too warm, cool but not too cool. On the one hand, a long growing season is required so that the grapes will produce a high content of sugar for conversion into alcohol. On the other hand, comparatively cool temperatures are desirable because they produce grapes with high acidity, an important contributor to the quality of wine, particularly the dry table wines. Both of these climatic conditions are well fulfilled in areas such as the Bordeaux district of France, northern Spain, central and northern Italy, Yugoslavia and northern California—and those areas produce fine red table wines. In areas with cooler or shorter growing seasons, such as Germany, Switzerland, Austria, the eastern U.S. and even the Burgundy district of France, the grapes in some years do not develop enough sugar, and sugar must be added when they are brought to the winery. This addition cannot, however, replace flavor components that are missing when the grapes have not ripened fully. The variability of the summer climate in Europe is the main reason for the fluctuation in the quality of its wines from year to year and for the emphasis on vintage years.

Although a warm climate (such as that of southern Spain, Sicily, Cyprus and southern California) produces grapes with a high sugar content, they have the handicap of comparatively low acidity. These grapes are suitable for the sweet dessert wines, but they lack the subtle flavors and color of grapes grown in cooler areas. Moreover, they are sometimes overripe when they come to the fermenting vats, with sad effects on quality if one attempts to produce a table wine from them.

The Grape

No less important than the characteristics of the climate are the char-



EASTERN U.S. METHOD of producing red wine begins with the crushing (*left*) of *Vitis labrusca* grape, a species low in sugar. Must is piped into a holding vat, where enzymes are added to break down mucilaginous substances in and around the pulp. The desired color

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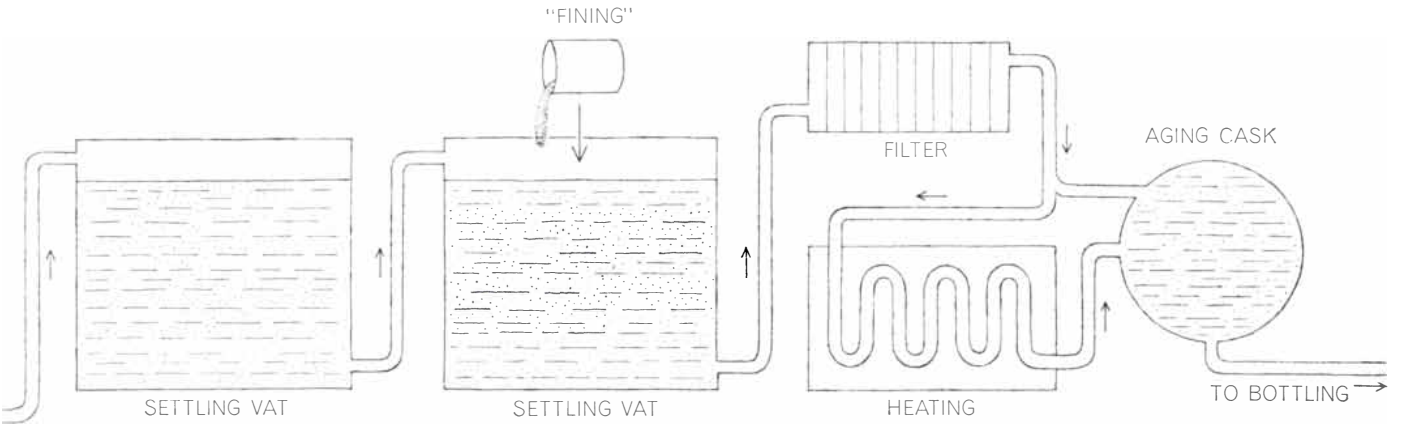


of sugars into alcohol, and then to a press where skin and seeds are separated out. The juice proceeds through two settling vats, wherein the "fining" process removes impurities. It is filtered, sometimes heated and cooled, and aged in casks prior to bottling.

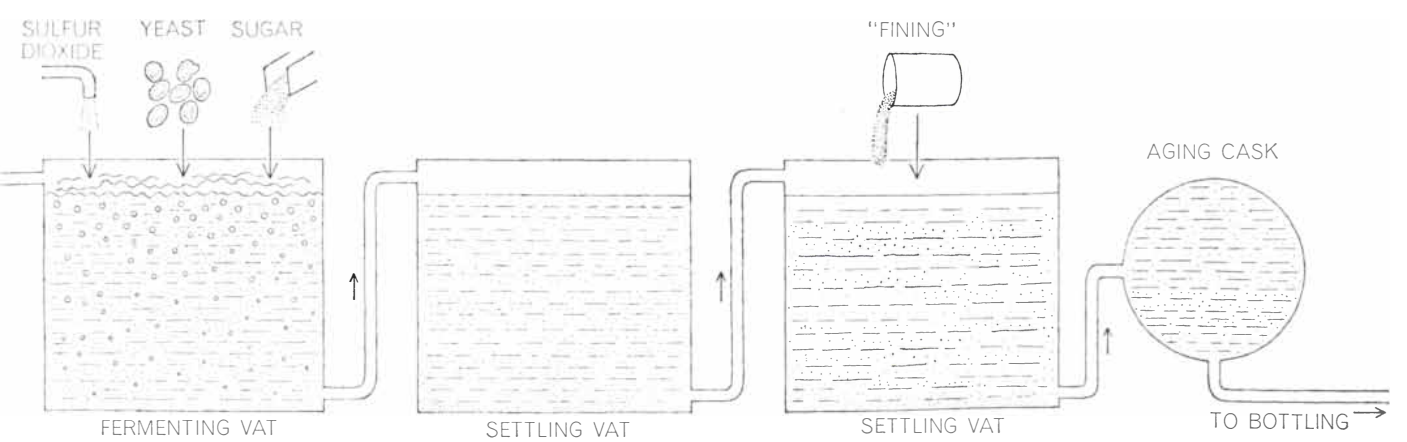
acteristics of the grape. One of the benign aspects of the grape plant—which holds much promise for future wines—is its great variability. One species alone, *Vitis vinifera,* has some 5,000 known varieties, and even the less popular species are available in about 2,000 varieties. Grape breeders have also produced many hybrids between the species. The grape varieties differ in color (white, green, pink, red or purple), in the size of the grape clusters, in the texture of the grape (firm and pulpy or soft and liquid), in sugar content, in acidity, in earliness or lateness of ripening and in susceptibility to insects and diseases. With this variability in the material, plant geneticists look forward to breeding new varieties of grapes that will be tailored to specific climates, to the types of wine and to new heights of taste, aroma and bouquet. (As wine experts define the terms, aroma refers to the fragrance of the grape; bouquet, to the fragrance imparted by fermentation and aging.)

Vitis vinifera is by far the preponderant species of wine grape grown in vineyards throughout the world. The plant is believed to have originated near the shores of the Caspian Sea in what is now the southern U.S.S.R. From there early travelers and traders spread it around the Mediterranean, then to northern Europe and eventually explorers transported it to continents overseas. (More than 81 percent of the world's vineyard acreage and wine production are still concentrated, however, in Europe and North Africa, with France the leader.) In the U.S. the *vinifera* species has found a hospitable home in California, and some 100 varieties of this species are cultivated commercially there. *Vinifera* is vulnerable to the diseases and insects that thrive in a hot and humid summer climate; for this reason many vineyards in the eastern U.S., Canada, Brazil and certain areas in Europe cultivate other species, such as *Vitis labrusca* or *Vitis rotundifolia.*

Now let us examine the wine-making process. To follow it in detail we shall consider the typical procedure in a modern California winery.

The Wine-making Process

To begin, let us analyze the raw material. In a mature grape about 10 to 20 percent of the material by weight is accounted for by the skin, stem and seeds, and the remaining 80 to 90 percent is pulp and juice. The pulp and juice, when piped into the fermenting vat, is called "must." Chemically the grape must is mostly water, but between 18 and 25 percent by weight is sugar (the amount varying with the variety and ripeness of the grape). The sugar consists mainly of dextrose (that is, glucose that rotates polarized light to the right) and levulose (or fructose, which rotates polarized light to the left). The grapes from which table wines are made usually contain dextrose and levulose in about equal



is attained by heating. Must proceeds to a fermenting vat where sugar as well as yeast and sulfur dioxide are added. Removal of impurities by fining takes place in settling vats, and the wine is then aged. Some Eastern wines are pasteurized before bottling.

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amounts; for sweet wines vintners would prefer grapes with a higher proportion of levulose, because it is nearly twice as sweet as dextrose. In addition to these two principal sugars, grapes also contain small quantities of other carbohydrates, such as sucrose, pentoses and pentosans.

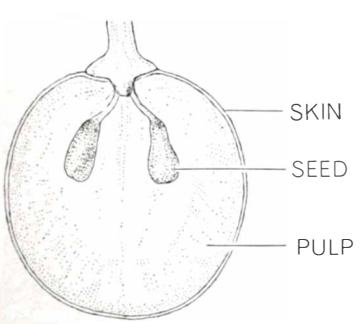
Acids make up between .3 and 1.5 percent of the grape must by weight. The two principal acids again are optically opposite forms: dextrorotatory tartaric acid and levorotatory malic acid. There are also small amounts of other acids: citric, oxalic, glucuronic, gluconic and phosphoric. The *p*H, or active acidity, of mature *Vitis vinifera* grapes in California runs between 3.1 and 3.9.

Among the many other substances that have been identified in analyses of grape must are 20 amino acids (found in the free state as well as in proteins), 13 anthocyanins (the pigments of many colored flowers), other pigments, tannins, odoriferous compounds and the various vitamins, enzymes, minerals and other ingredients already mentioned. Obviously many of these substances contribute to the making of wine by providing nutrient for the fermenting yeasts. The contributions of individual ingredients to the quality of wine, however, are imperfectly understood; presumably no one will ever be able to write a formula for a perfect wine, because personal taste is an indispensable part of the equation.

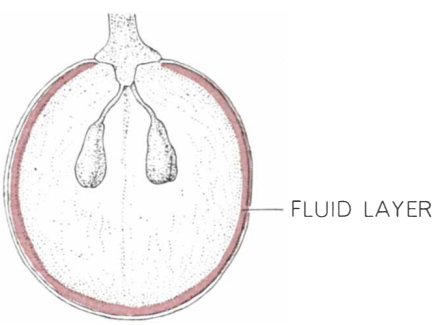
The fermentation process is enormously complicated [*see illustration on page 53*]. The breakdown of glucose alone involves no fewer than 22 enzymes, six or more coenzymes and magnesium and potassium ions. A number of other sequences, including the well-known Krebs cycle, participate in the process. From these many reactions emerges a mixed collection of other products in addition to alcohol, among them acetaldehyde, glycerol, succinic acid, esters and other aromatic compounds. The problem of the wine maker is to control the production and accumulation of this multitude of diverse products. In a modern winery this is done by various chemical and physical means.

Grapes have to be taken from the vine to the winery as quickly and carefully as possible in order to minimize their loss of water and sugar after picking and to prevent spoilage. At the winery they are immediately put in a crusher, which crushes the skins, freeing the pulp and juice (without breaking the seeds), and removes the stems. In the case of a white wine the juice is pressed out at this point and sent alone to the fermenting vat. For the making of red wine the entire contents of the crusher—juice, pulp, skins and seeds—go into the fermentation process. The red wine will take its color from the pigment in the skins and its strong flavor and astringency from tannins and other substances in the skin and seeds. (The rosé wines that have become more popular in recent years are made by starting the fermentation with the skin and pulp present, then, after about 24 hours, pressing out the juice and letting it complete the process alone.)

DELICATE BLOOM of grape skin consists of a waxy film that collects molds and yeasts. A single grape may accumulate 100,000 yeast cells with enzymes responsible for fermentation. Where the waxy film has been brushed off several grapes (*center*) a bright shine results.



CABERNET FRANC, shown here in cross section, is an Old World grape of relatively low acidity that flourishes in California.



CONCORD GRAPE of the northeastern U.S. has a mucilaginous layer separating skin and pulp, hence its "slip skin" classification.

Wine in the Vat

In the fermenting vat (in California it is usually constructed either of red-

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wood or of concrete) the first step is treatment of the must with liquefied sulfur dioxide or a sulfurous acid or salt. The main function of this chemical is to inhibit the growth of the wild yeasts on the grape skins. They are replaced by the addition of pure cultures of yeasts that will produce a better wine. Besides suppressing the deleterious yeasts the sulfur dioxide reduces oxidation (which may have a baneful effect, particularly on the quality of white wines) and also helps to acidify and clarify the wine. Sulfur dioxide is a dangerous tool—an excess of it will ruin the wine—but all in all its use has been a major 20th-century benefit to wine making, contributing in various ways to better regulation of the fermentation, a higher yield of alcohol from the sugar and a more flavorful product. When sulfur dioxide is used, the natural yeast flora from the grape are largely inhibited and an actively fermenting culture of yeast must be added.

Another recent innovation is careful control of temperature in the fermenting vat. Cooling systems are used to carry off the heat produced by fermentation so that the temperature in the vat is kept below 85 degrees F. (for red table wines) or below 60 degrees (for white wines). The slow fermentation at low temperatures produces more esters and other aromatic compounds, a higher yield of alcohol and a wine that is easier to clear and that is less susceptible to bacterial infection. In the opinion of most enologists it results in a better bouquet and aroma. The duration of the fermentation in a modern winery varies from a few days to a few weeks, depending on the temperature, the type of yeast used, the sugar content of the grapes and the kind of wine to be produced.

All wine is divided into two general classes, defined by the alcohol content. The table wines (also called "dinner," "dry" or "light" wines) contain not more than 14 percent of alcohol by volume. The "aperitif" and "dessert" wines (sherry, port, muscatel and the like) have a higher content, usually about 20 percent. They are given this high alcohol content by the addition of brandy distilled from wine. Added during the fermentation, the brandy stops the action of the yeast, and the wine is then left with some of its sugar unconverted to alcohol. In the making of muscatel, for example, the brandy is added and the fermentation halted when the juice still contains 10 to 15 percent of grape

RECEIVING TANKS at left transfer must from a crusher on the floor above to the holding vats at right, enabling the winery to process the harvest of two types of grape. This photograph and the one below were made at the Taylor Winery in Hammondsport, N.Y.

PRESSES receive crushed grapes from holding vats on the floor above through pipes (*top*). The black rubber bag visible inside the press in the foreground will be inflated with air, forcing residual skins and seeds to cling to the sides of the stainless steel cylinder.

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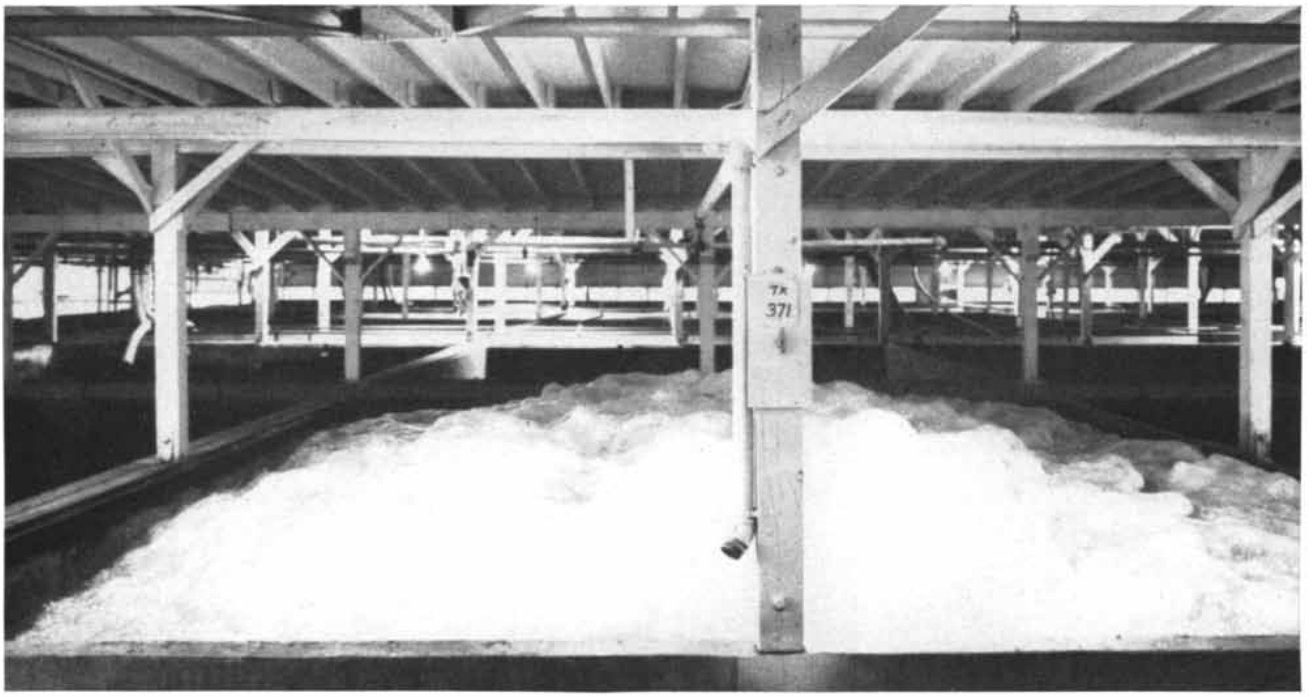
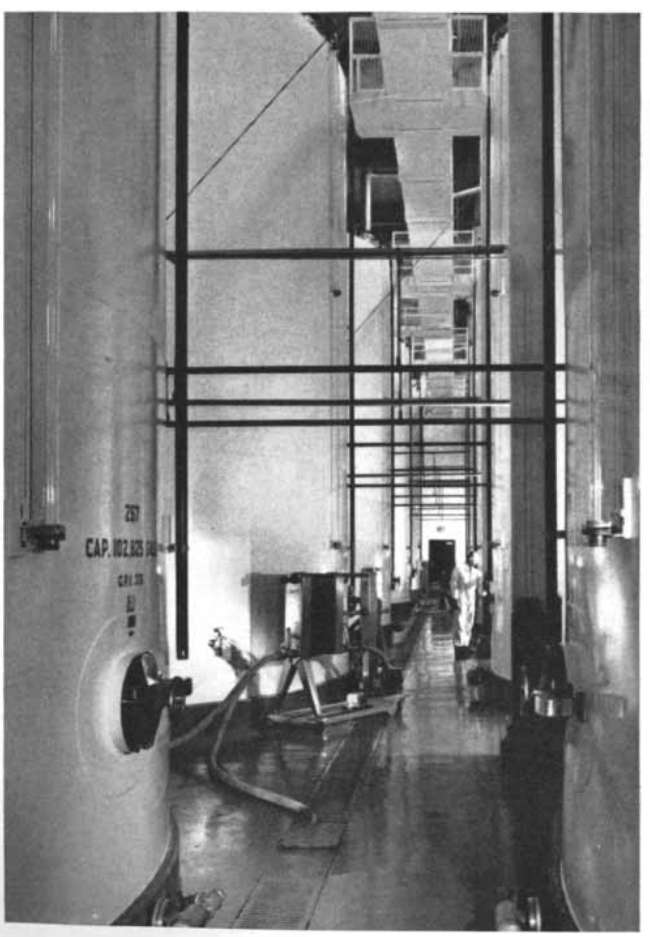


"STORMY" STAGE of fermentation is under way in this vat at the United Vintners winery in Asti, Calif. Approximately 36 hours after yeast is added the temperature of the juice rises as high as 85 degrees and carbon dioxide bubbles violently to the surface.



FERMENTING TANKS shown here can hold 100,000 gallons. They are made of concrete with a glass lining. The thin pipes between the tanks exchange heat to maintain a uniform temperature.

REDWOOD VATS house the aging wine and facilitate mellowing by admitting oxygen through redwood planks. These vats, photographed at the Taylor Winery, have a capacity of 63,000 gallons.

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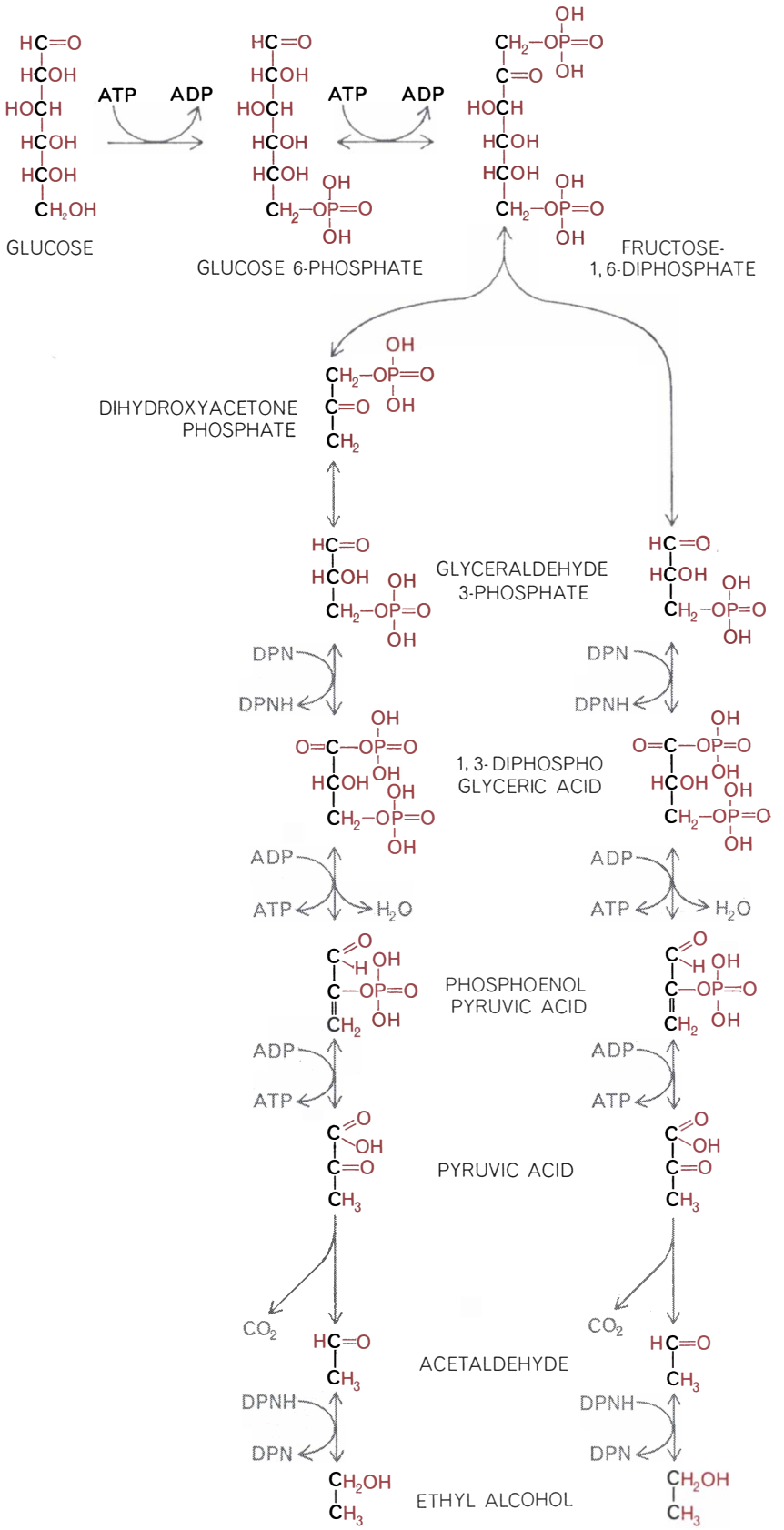
sugars by weight; the result is a very sweet wine. For port the fermentation is stopped a little later (at a sugar level of 9 to 14 percent) and for a dry sherry it may be allowed to proceed until the sugar content is 2.5 percent or less.

For the sake of simplicity let us proceed with the more typical case of a red table wine. When part of its sugar has been converted to alcohol and adequate color has been extracted from the skins, the partially fermented juice is separated from the pulp. At this time the skins are mainly free and floating on top; the liquid is drained off as "free run" and is considered to make the best wine. The rest of the juice is pressed out of the pulp by the familiar wine press (which most people confuse with the machine used to crush the grapes before they are put in the fermenting vat). The press used in many modern wineries still looks much as it has always looked—a hardwood container with a plunger—but nowadays a hydraulic ram replaces the old screw contrivance turned by hand. Recently developed cylindrical presses and roller presses are also in use.

The juice now proceeds to the completion of its fermentation and to the clearing and aging stages. Not to be guilty of omitting entirely from this account the important category of sparkling wines, I shall merely mention here that they are made from dry table wines by means of a secondary fermentation in a closed container, involving the addition of a calculated amount of sugar and 1 percent of a pure yeast culture. This fermentation produces the extra carbon dioxide—amounting to an internal pressure of four or five atmospheres in the bottle—that accounts for the fizz of champagne.

For clarification of the wine the fermented juice goes to settling vats. There the suspended yeast cells, cream of tartar and small particles of skin and pulp rapidly settle out of the liquid. Various chemical processes and a form of fermentation still continue, however. Wine, it has been said, is a living thing, and indeed in a sense it does go on growing and maturing—in the settling vats and later in its aging periods in cask and bottle. In the vats the yeast cells, as they break down, particularly in a wine juice of high acidity, stimulate the growth of *Lactobacillus* bacteria. Enzymes from these bacteria decarboxylate the wine's malic acid (that is, remove COOH groups) and convert it to lactic acid. This malo-lactic "fermentation," replacing a strong acid with



FERMENTATION entails the breakdown of the six-carbon sugar, glucose (*top left*) and the consequent production of alcohol. The splitting of the carbon backbone occurs when the intermediate product, fructose (*top right*), gives way to two molecules of glyceraldehyde phosphate. The major intermediate products are shown from top to bottom. The enzymes and coenzymes needed to power the process are represented by ATP and ADP, and DPN and DPNH. The reversible steps in the process are indicated by two-way arrows.

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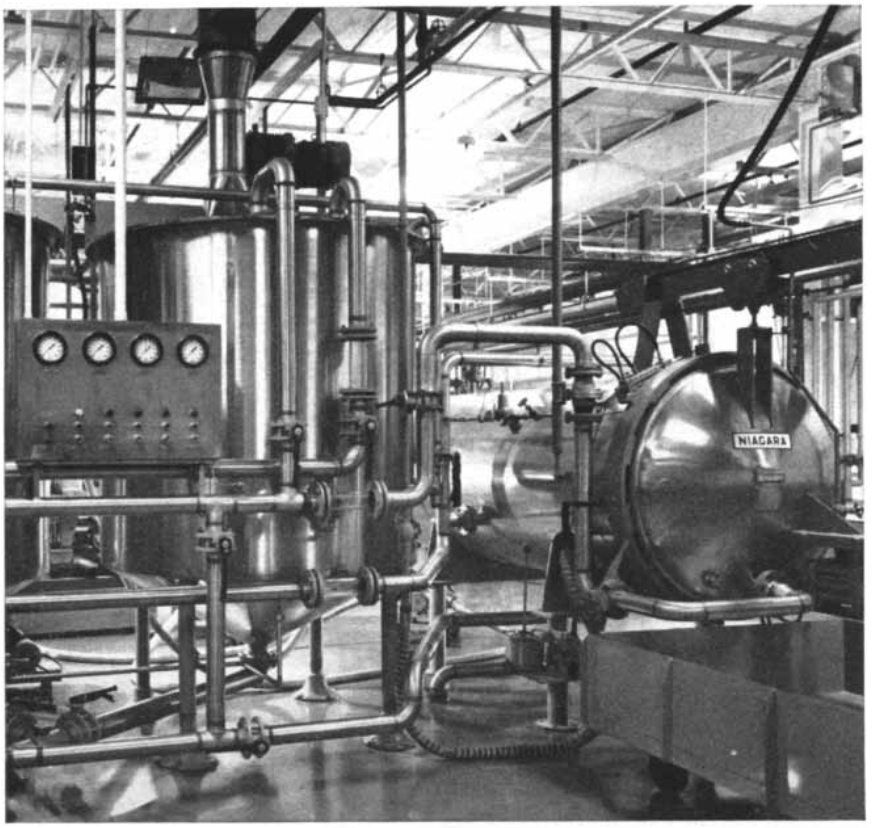

FILTERING UNIT shown at right in this photograph removes sediment from the wine in settling tanks (*left center*). Below the filter is a trough into which residue is dumped.

NEW BOTTLES containing domestic U.S. champagne are stacked on a "riddling" shelf of ash, counterpart of the French A-frame. Sediment accumulates in the neck and can be discarded by briefly uncorking the bottle. Both photographs were made at the Taylor Wineries.

a weak one, mellows the high-acid wine. Without it the high-quality wines of northern Europe could not be made.

As soon as possible the clearing wine is racked, or drawn off, from the settling lees to prevent excessive working and protect its flavor. The racking is repeated again and again, leaving behind lees at each step. During these off-pourings the wine also sheds the carbon dioxide with which it was charged in the fermentation process and absorbs oxygen from the air, which will help in its aging. To assist the clearing of the wine when racking alone does not suffice, wineries commonly inject "fining" substances (such as bentonite clay, gelatin, isinglass or egg white) that clump and precipitate the tiny particles in the wine; they may also apply pressure filtration, heat or chilling as aids to clearing.

Wine in Cask and Bottle

The aging of the wine begins in an oak cask. It is an extremely complex process of oxidation, reduction and esterification. The new wine gradually loses its yeasty flavor and harshness, declines in acidity and acquires a complex, delicate bouquet. As its pigments and tannin are oxidized, red wine turns a tawny color and white wine develops an amber hue. The amount of oxidation of its ingredients, by means of oxygen absorbed through the pores of the cask, is crucial to the eventual quality of the wine: the length of time it is left in the cask may make the difference between allowing a great wine to attain its potential and turning it into an ordinary one. If wine is bottled too soon, it may spoil or mature too slowly; if it is bottled too late, it will be vapid and off-color. The decision as to when to bottle is one of the most important in the wine maker's art. In present practice fine red table wines are kept in wooden cooperage for at least two years; white wines, from a few months to two years. Lesser-quality wines are stored in redwood, concrete or lined iron tanks.

After bottling, wine does not cease to "work." Aging in the bottle serves to eliminate the aerated odor the wine acquired at the time of bottling, reduce the wine's content of free sulfur dioxide and improve its bouquet. It is a mistake, however, to suppose the older the wine, the better, or that a bottle encrusted with the grime of many years is likely to contain a wine of rare distinction. The contents may, in fact, have become worthless long ago. Only a few

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very fine red wines benefit from prolonged aging. As a general rule, for a good red wine five to 10 years in the bottle is long enough, and a white wine will have reached its peak after two to five years. Wines of lesser quality require less time.

To summarize, the modern technology of wine making began with Pasteur's discovery that fermentation was produced by yeasts and that the process was far more complicated, with many more by-products, than Gay-Lussac's simple formula for the conversion of sugar to alcohol had suggested. The major modern developments have been the use of selected pure yeasts, the breeding and cultivation of superior varieties of grapes, the control of fermentation by certain chemicals and physical conditions (such as sulfur dioxide and cooling) and a gradual accumulation of more exact knowledge about the chemistry of the fermentation and aging processes. For all these advances, a truly great wine is still more or less a happy accident arising from time to time out of a particularly fortunate blend of the weather, the grape and the vintner's intuitive art. Much of the guesswork has been eliminated, however, from commercial wine making, and the quality of wines is a great deal more uniform than it used to be.

The Uses of Wine

Even a brief account of wine making, which can touch only on the highlights, cannot pass over the fascinating subject of the consumption of the product. The wine maker and the wine consumer are themselves partners in a peculiarly intimate symbiosis; indeed, historically they used to be one and the same person! Modern enology sheds interesting light on some of the folklore of wine drinking.

The matching of wines to food (red wine with red meat, white wine with fish) cannot be defended, objectively speaking, as much more than a superstition. It is true that red wine shares with meat a complexity of taste and texture, and that the high acidity of white wine may add spice to the blandness of fresh fish and, in earlier times of nonrefrigeration, may have helped to mask the odor and taste of decaying fish. Most likely, however, the traditional ideas about food-wine pairing grew originally out of the simple geographical fact that a particular type of wine happened to be grown in a region that favored a particular food; that is, the coupling developed from agricul-

SCIENTIFIC AMERICAN CUMULATIVE INDEX 1948–1963

The editors of SCIENTIFIC AMERICAN take pleasure in announcing the publication of a cumulative Index to all 180 issues published from May, 1948, through April, 1963. The Index covers all the issues published under SCIENTIFIC AMERICAN's present editorial direction and marks the fifteenth anniversary of the "new" SCIENTIFIC AMERICAN.

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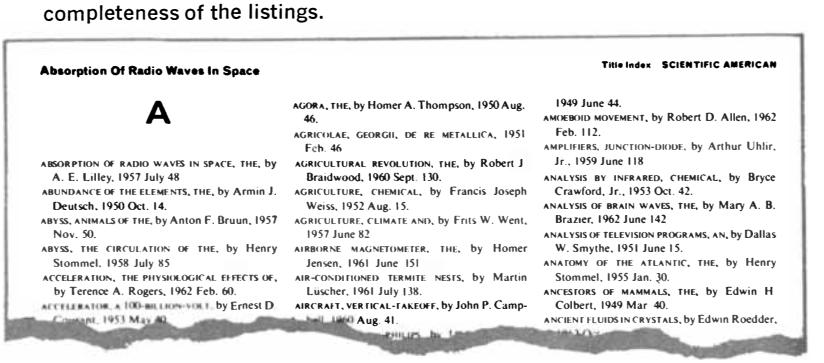

Absorption Of Radio Waves In Space — Title Index SCIENTIFIC AMERICAN

A

ABSORPTION OF RADIO WAVES IN SPACE, THE, by A. E. Lilley, 1957 July 48
ABUNDANCE OF THE ELEMENTS, THE, by Armin J. Deutsch, 1950 Oct. 14.
ABYSS, ANIMALS OF THE, by Anton F. Bruun, 1957 Nov. 50.
ABYSS, THE CIRCULATION OF THE, by Henry Stommel, 1958 July 85
ACCELERATION, THE PHYSIOLOGICAL EFFECTS OF, by Terence A. Rogers, 1962 Feb. 60.
ACCELERATOR, A 100-BILLION-VOLT, by Ernest D. [illegible] 1953 May 40.
AGORA, THE, by Homer A. Thompson, 1950 Aug. 46.
AGRICOLAE, GEORGII, DE RE METALLICA, 1951 Feb. 46
AGRICULTURAL REVOLUTION, THE, by Robert J Braidwood, 1960 Sept. 130.
AGRICULTURE, CHEMICAL, by Francis Joseph Weiss, 1952 Aug. 15.
AGRICULTURE, CLIMATE AND, by Frits W. Went, 1957 June 82
AIRBORNE MAGNETOMETER, THE, by Homer Jensen, 1961 June 151
AIR-CONDITIONED TERMITE NESTS, by Martin Luscher, 1961 July 138.
AIRCRAFT, VERTICAL-TAKEOFF, by John P. Camp- [illegible] Aug. 41.
1949 June 44.
AMOEBOID MOVEMENT, by Robert D. Allen, 1962 Feb. 112.
AMPLIFIERS, JUNCTION-DIODE, by Arthur Uhlir, Jr., 1959 June 118
ANALYSIS BY INFRARED, CHEMICAL, by Bryce Crawford, Jr., 1953 Oct. 42.
ANALYSIS OF BRAIN WAVES, THE, by Mary A. B. Brazier, 1962 June 142
ANALYSIS OF TELEVISION PROGRAMS, AN, by Dallas W. Smythe, 1951 June 15.
ANATOMY OF THE ATLANTIC, THE, by Henry Stommel, 1955 Jan. 30.
ANCESTORS OF MAMMALS, THE, by Edwin H Colbert, 1949 Mar 40.
ANCIENT FLUIDS IN CRYSTALS, by Edwin Roedder,

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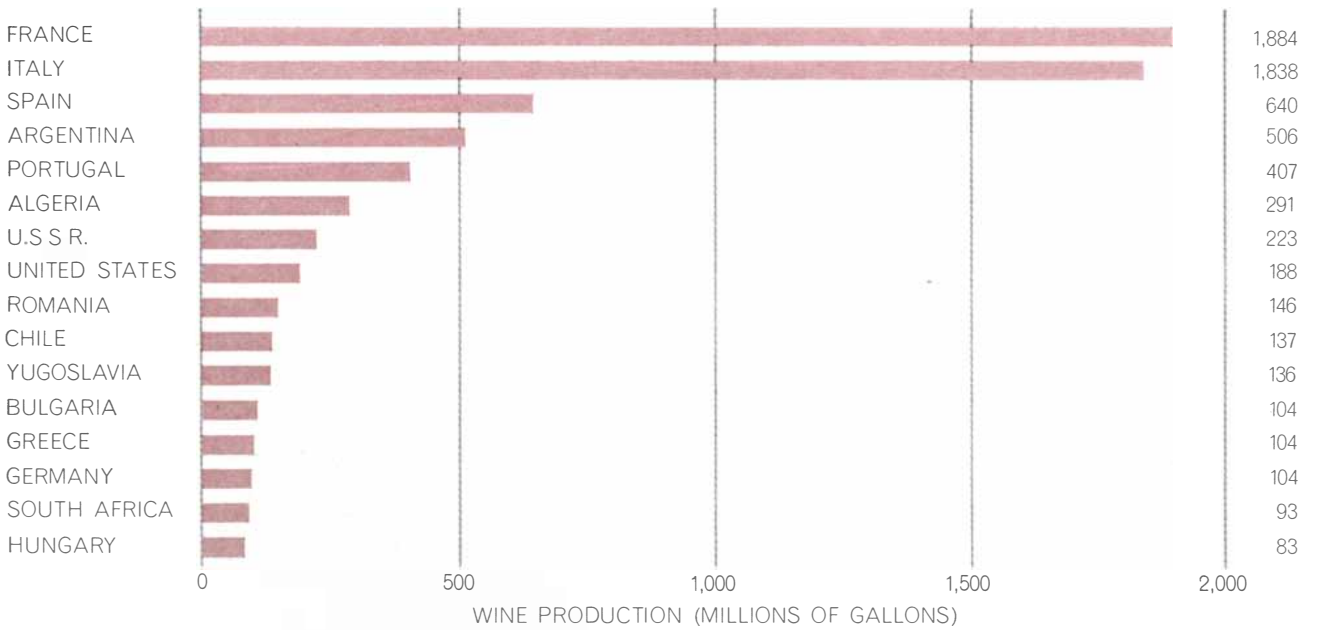
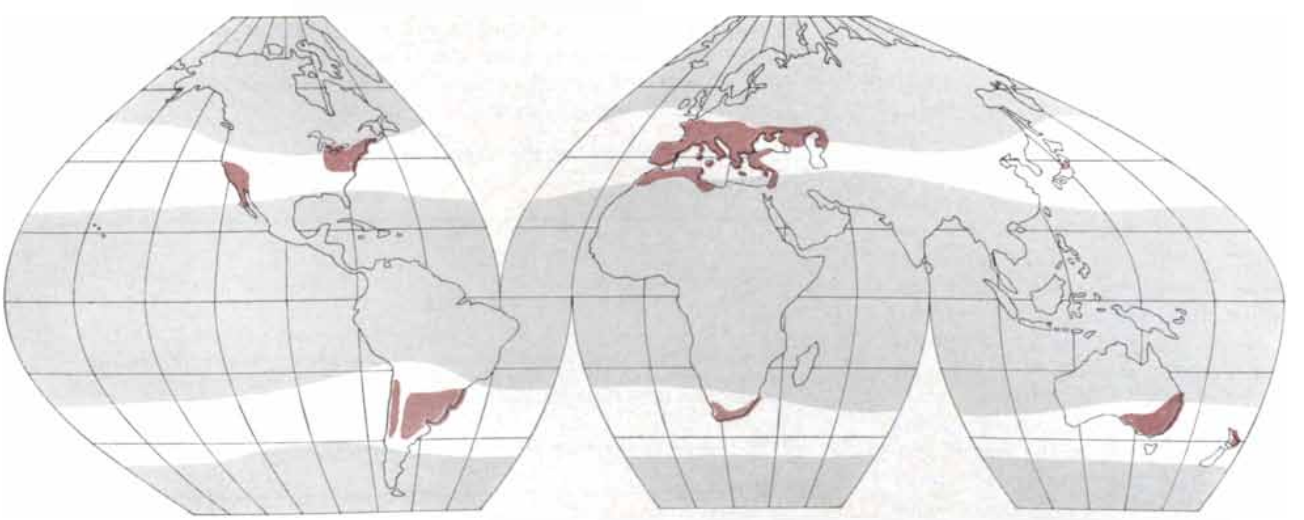
tural rather than epicurean considerations.

The use of wine as medicine is another and much more interesting story. The medical historian Salvatore P. Lucia, of the University of California Medical School in San Francisco, asserts in his *A History of Wine as Therapy* that it is "the oldest of medicines." Salves made with wine were used in Sumer as early as the third millennium B.C., according to a clay tablet found in the ruins of Nippur. Virtually every culture has employed wine for medicinal purposes, either directly or as a solvent. It used to be listed in the U.S. *Pharmacopeia,* but it was dropped during prohibition (which all but killed the appreciation of wine in the U.S.) and has not been reinstated since. Many physicians, however, have resumed prescribing it for various ailments.

Wine is considered a specific for certain disorders because its alcohol is absorbed from the digestive tract into the bloodstream slowly (as opposed to the rapid absorption of pure ethyl alcohol) and because some of its ingredients may be metabolically helpful to the body. The physicians who believe in its therapeutic powers recommend it variously as an analgesic for minor pain, as a tranquilizer or sedative, as a vasodilator for hypertensive patients, as a diuretic, as a nutritional supplement for diabetics and as an aid to the absorption of fat by the intestines after an operation for ulcers or stomach cancer. The noted medical teacher William Dock, professor of medicine at the Downstate Medical Center of the State University of New York, has remarked: "It is useful to think what would happen if alcohol should be discovered all over again.... The sales for all other sedatives and tranquilizers would go down; there would be four-page spreads with color in all the medical journals... and the stock of the patent licensees would go right through the ceiling on Wall Street. The lucky discoverers would get every possible honor, as did the men who discovered insulin."



LEADING PRODUCERS of wine are listed according to 1962 output in millions of gallons. The figures for Algeria, the U.S.S.R. and Chile are estimates. No statistics are available for China. France and Italy together produced about half of the world supply.



WINE-GROWING REGIONS of the world lie within belts where average annual temperature is between 50 and 68 degrees Fahrenheit. The hot summer of the southwestern U.S. and the humidity in the Southeast preclude the cultivation of *Vitis vinifera* grapes.

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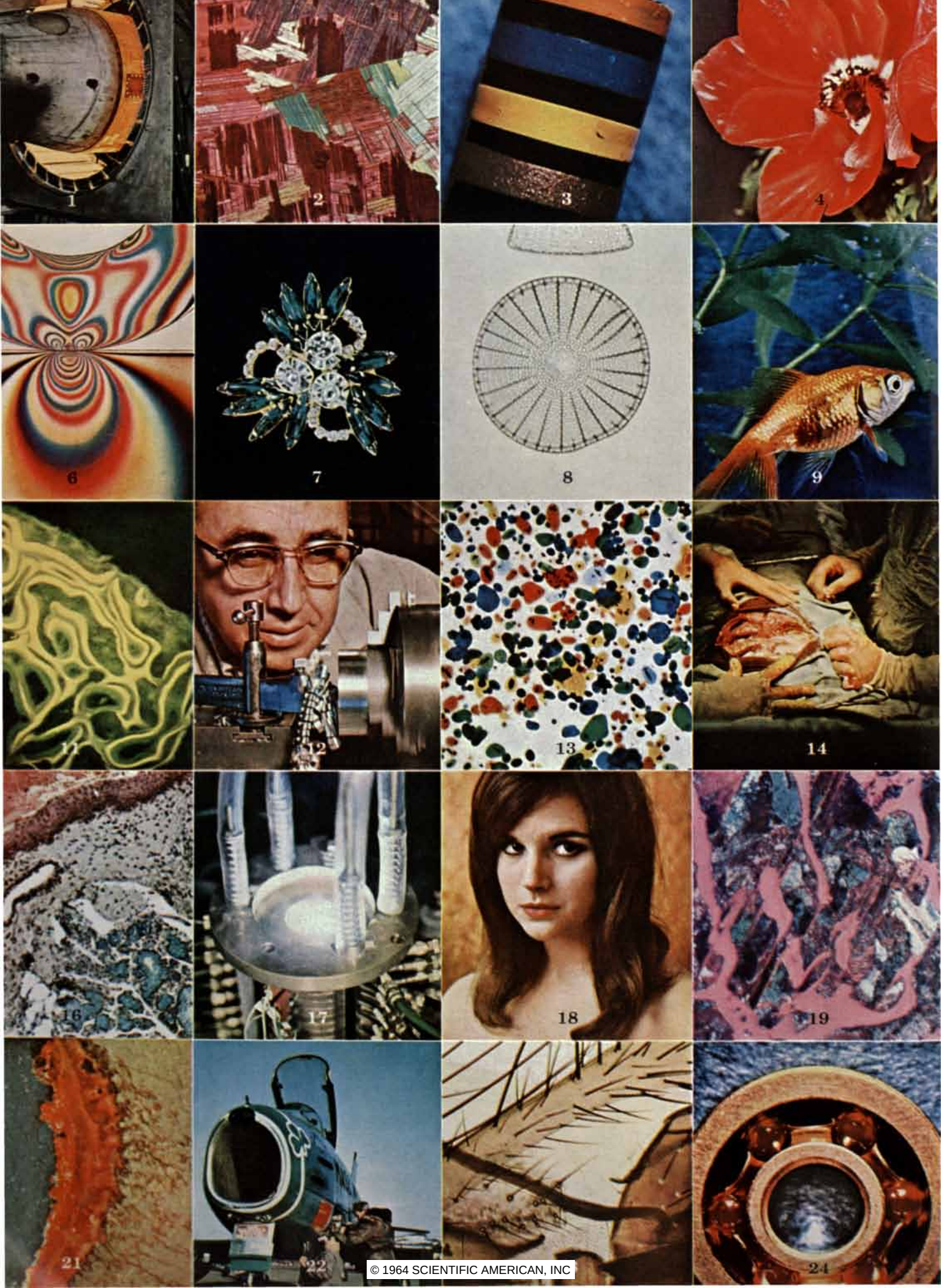

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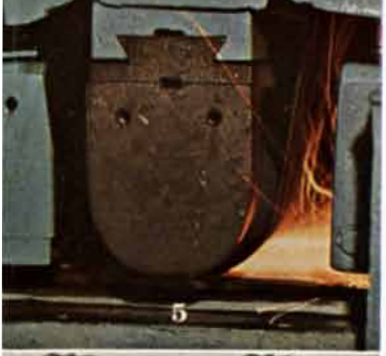

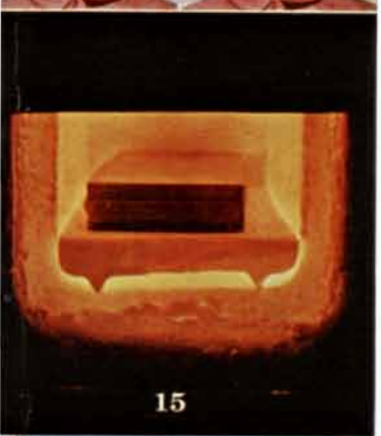

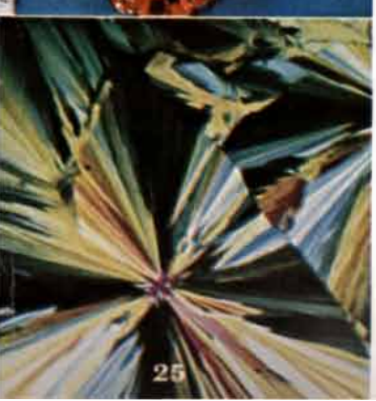

1. Static test of a jet engine at AVCO's Research and Advanced Development Division.
2. Titanium dioxide magnified 200X under polarized light.
3. 10X macrophotograph (of a resistor) used in quality-control tests.
4. Illustration of an anemone for a garden catalog.
5. Automatic butt welder joining bimetallic strips into a continuous length.
6. Stress-analysis picture of plastic models under 80 psi pressure photographed in polarized light.
7. Illustration for a costume jewelry advertisement.
8. A diatom from Oamaru, New Zealand, magnified 100X.
9. *Carassius auratus*.
10. Employee identification picture (one exposure) made with an Avant QUAD Camera.
11. Fluorescence photomicrograph of a cross section of canine tibia, showing the site of active bone growth (69X).
12. Hardinge Super-Precision high-speed lathe.
13. Photomicrograph (100X) of differential staining of starch grains with vegetable dyes.
14. Pectus excavatum operation performed at Andrews Air Force Base Hospital.
15. Preliminary bonding of ingots in the forming of bimetallic strips at Metals and Controls Division of Texas Instruments.
16. Human larynx section (Trichrome stain) at 100X by Leo Goodman, Mallory Institute of Pathology.
17. Plasma-jet experiment used in high-temperature research.
18. Magazine illustration by advertising photographer, Wingate Paine.
19. White iron photographed at 400X under polarized light.
20. Gross specimen of a human gall bladder photographed at the Free Hospital for Women, Boston.
21. Research photomicrograph of a corrosion pit in cast bronze (50X).
22. Pre-flight check on an F-86 Sabrejet, Massachusetts ANG, 102nd Tactical Fighter Wing.
23. Proboscis of a *Calliphora* blowfly at a magnification of 100X.
24. Frictionless ruby bearing (with a gold-plated race) for a missile, 10X macrophotograph by New Hampshire Ball Bearing Co.
25. Beta bromopropionic acid crystals viewed between crossed polarizers (70X).

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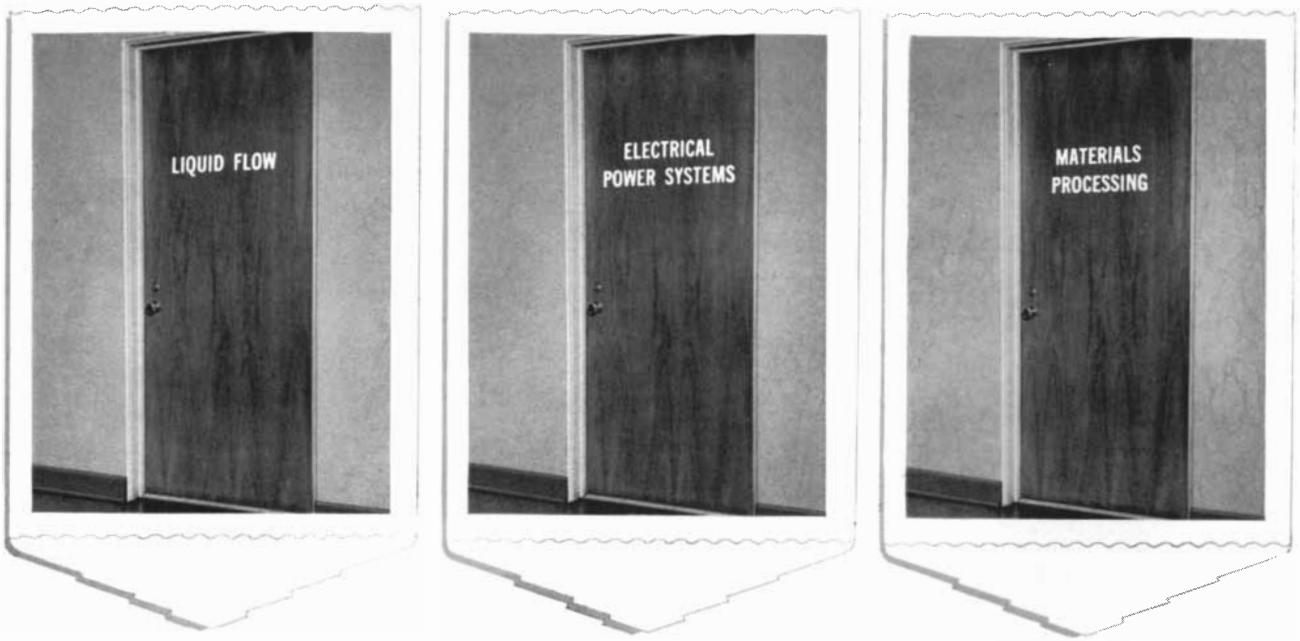

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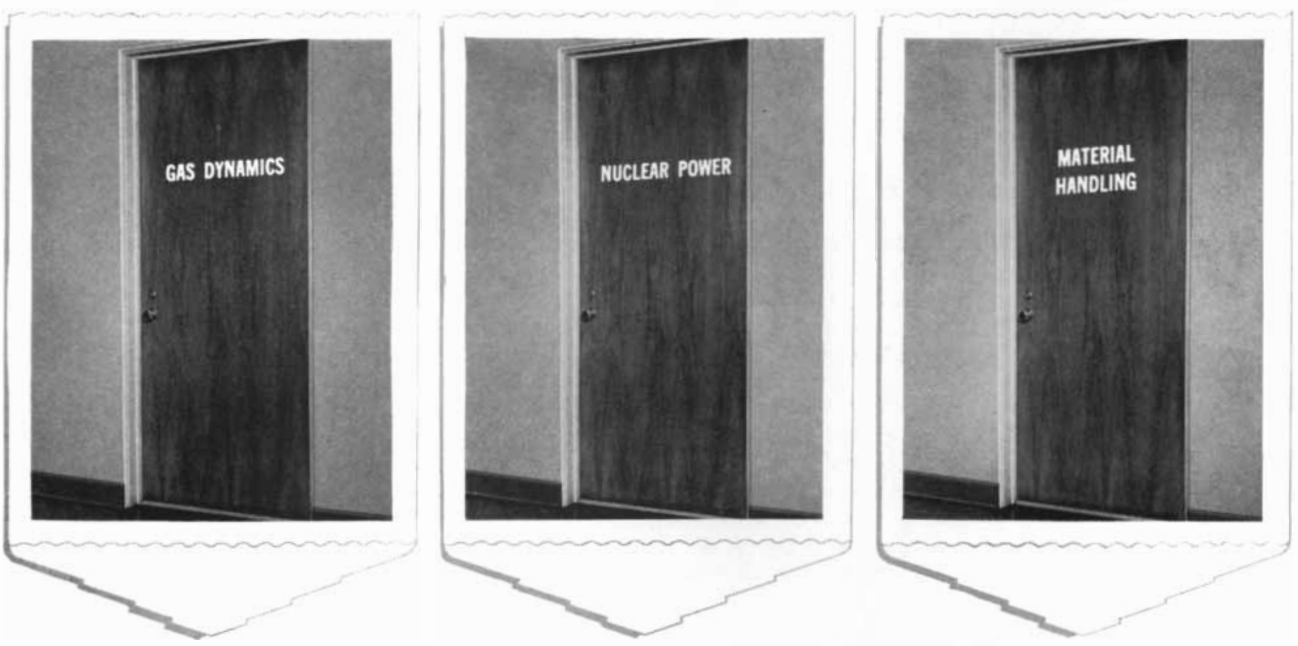

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The Embryological Origin of Muscle

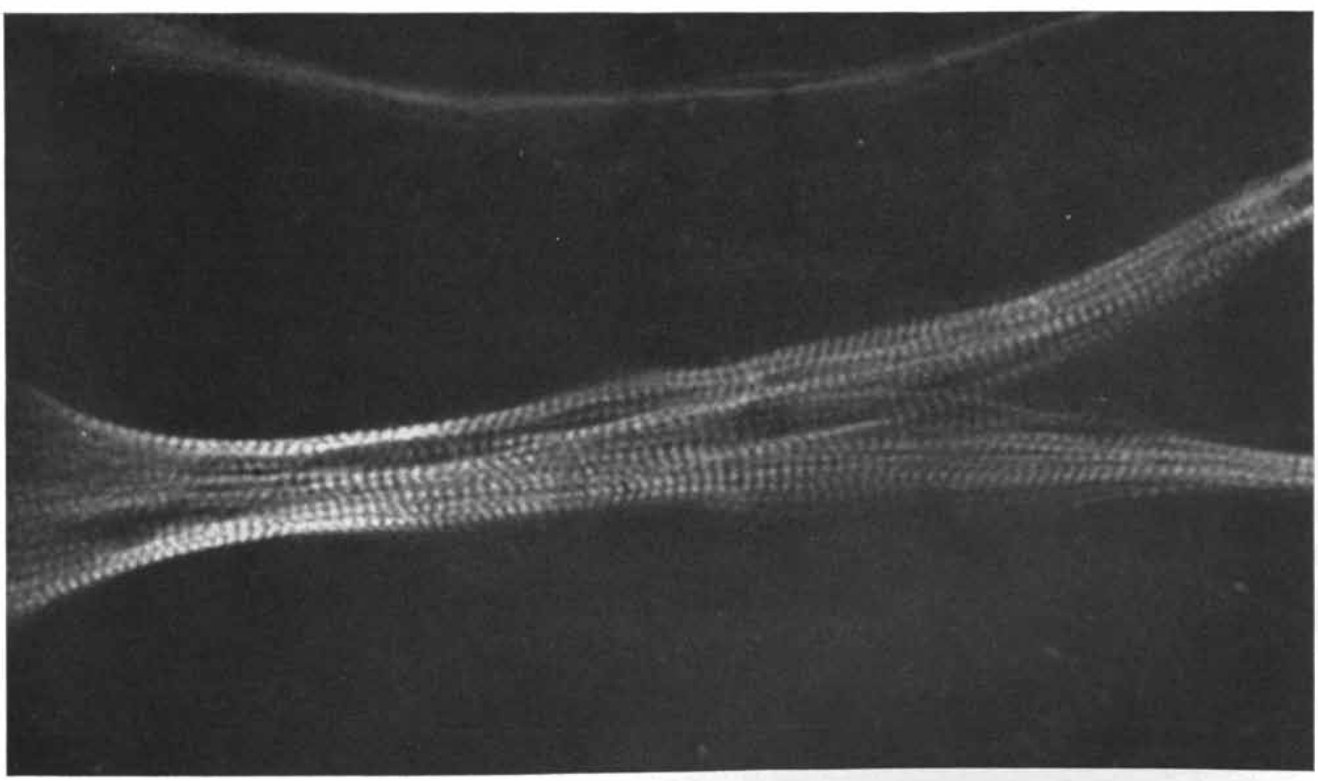
How does the fertilized egg differentiate into specialized tissues? This traditional question of biology is now being investigated by growing differentiated muscle colonies from single embryonic cells

by Irwin R. Konigsberg

In recent years large strides have been made toward an understanding of how living organisms transmit their characteristics from one generation to the next. Much of this knowledge has emerged from experiments with bacteria, which, being single-celled organisms, convey identical genetic instructions to all their descendants (except for an occasional mutant). It is now quite clear that the functions of all cells, from bacteria to the cells of man, are governed by the hereditary blueprint embodied in the molecules of deoxyribonucleic acid (DNA). It is also generally assumed that in a many-celled organism such as man the DNA present in the fertilized egg is reproduced in exactly the same form in all the cells descended from the egg. Yet these cells, unlike bacteria, differentiate into many kinds of cells, namely the cells of such specialized tissues as skin, nerve and muscle. This raises the question: If all the cells have the same blueprint, how can they differentiate? Or, to put the question another way: How is the same blueprint translated differently in all the cells descended from the fertilized egg?

These questions introduce a complication into the study of the mechanism of heredity, and it was to avoid this complication that geneticists chose bacteria for their experiments. Such experiments, however, have provided uncomplicated models of cell behavior that can now be tested with the cells of multicellular organisms. They have also given other biologists an appreciation for the advantages of working with pure populations of a single type of cell.

In the earliest stages of embryonic development all the cells of the embryo exhibit certain synchronous changes. In later stages the cells progressively di-



DIFFERENTIATED MUSCLE was grown in culture from a single chick-embryo cell isolated 13 days earlier. Magnification of 500 diameters in polarization microscope reveals characteristic striated pattern of skeletal muscle in the colony of which this is a small part. The experiment demonstrates that single embryonic cells will multiply and differentiate in culture under appropriate conditions.

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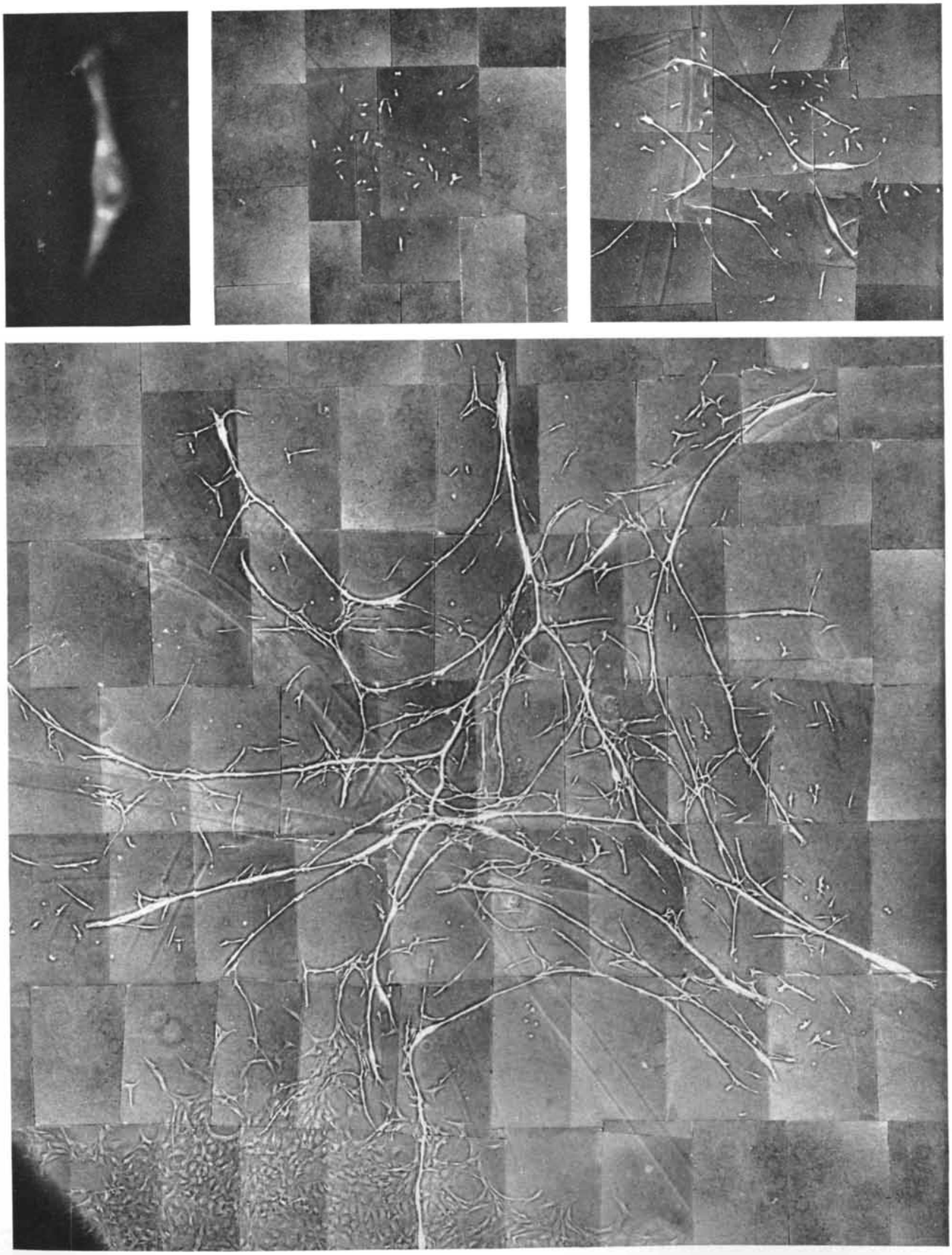

DEVELOPMENT OF MUSCLE COLONY from a single cell proceeds rapidly. The single cell, magnified some 850 diameters, is at top left. Three days later a number of cells have appeared (*top center*). By the sixth day several long, multinuclear cells have formed, presumably by cell fusion (*top right*). Scattered mononuclear cells are also seen. The large mosaic is made of photomicrographs taken on 13th day. Magnification is about 45 diameters. An invading colony of cells of unidentified type is at bottom edge.

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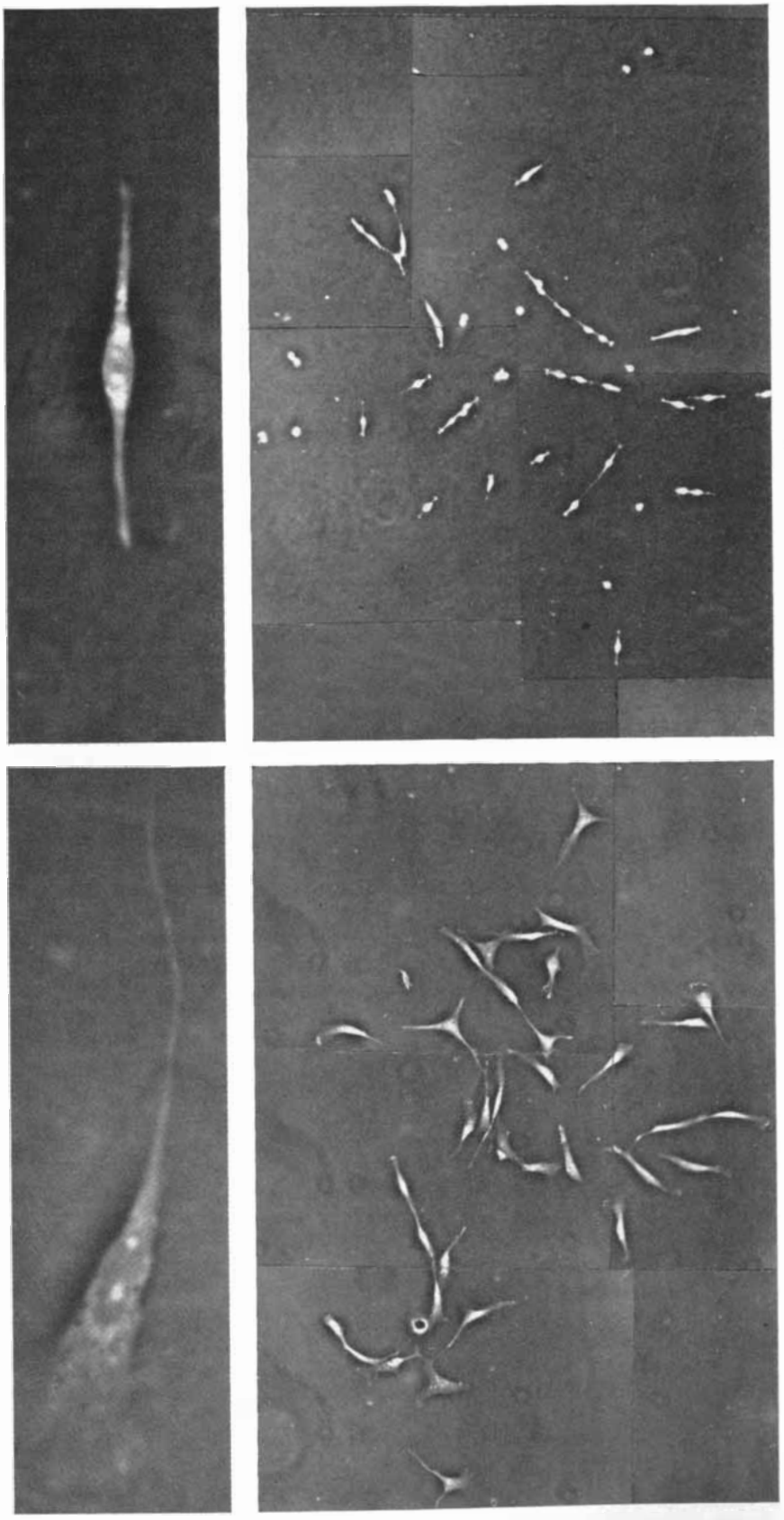
verge in their characteristics. At this point the student of differentiation must focus his attention on specific types of cells, but until recently he has had to compromise by studying particular areas of the embryo. Now he can isolate a single embryonic cell and grow a pure population of cells descended from it.

The technique of culturing animal cells from a single progenitor, called cloning, was developed largely by the efforts of the late Wilton R. Earle of the National Institutes of Health and Theodore T. Puck of the University of Colorado School of Medicine and their respective associates. The cells usually grown in such cultures, although originally isolated from animal tissues, have become adapted to the culture environment and have lost those properties that characterized them in the original tissue. Accordingly they are not suited to studies of normal differentiation. For the purpose of such studies it seemed reasonable to apply the cloning technique to newly isolated embryonic cells, and at the Department of Embryology of the Carnegie Institution of Washington we undertook to do this.

It was first necessary to determine if the methods we would have to use would allow differentiation to occur at all. Cells can be liberated from living animal tissue by controlled digestion with an enzyme; moreover, the enzyme treatment does not in itself prevent differentiation, provided that the cells are allowed or encouraged to re-form a compact mass. Our first question was: Would cells freed by such procedures be capable of differentiating when they were grown not in a compact mass but dispersed on a glass surface?

In undertaking to answer the question we used cells of skeletal muscle (muscle of the type that is involved in voluntary movement); the specialized features of such cells can be easily identified both microscopically and biochemically. Cell suspensions were prepared from developing leg muscle dissected from a 12-day-old chick embryo. Equal numbers of cells were pipetted into each of a series of Petri dishes containing a liquid nutrient medium. The cells settled separately on the bottom of the dish and attached themselves to the glass. Incubated at body temperature, they multiplied and in three to four days yielded a population so dense that it formed a continuous layer, one cell thick, completely covering the bottom of the dish.

As the sheet of cells became continu-



CELL DIFFERENCES are readily apparent as soon as single cells attach to bottom of Petri dish and flatten out. Embryonic muscle cell (*top left*) is distinguished by its spindle shape. "Fibroblastic" cell (*bottom left*) is more irregular. Colonies of living cells, photographed on the fourth day (*right*), show same differences. Magnification is some 740 diameters in photomicrographs at left and approximately 95 diameters in those at right.

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ous, large numbers of long, ribbon-like cells appeared. This new type of cell was identified as a muscle cell on the basis of three criteria. First, each cell contained many nuclei. (A considerable body of evidence has accumulated in recent years that indicates that muscle cells form by the successive fusion of individual cells.) Second, such cells were observed to undergo a series of rapid contractions spontaneously. Third and most conclusive was the presence of the cross-striated pattern typical of skeletal and heart muscle. This pattern, which reflects the ordered periodic arrangement of the muscle proteins actin and myosin, is not present in any other type of cell.

Such experiments demonstrated that embryonic muscle cells, even though cultured as randomly distributed individuals, were able to continue their differentiation. We were closer to our goal of studying differentiation in pure populations of a single cell type, but we were still dealing with heterogeneous mixtures of cells. Embryonic muscle tissue is composed primarily of two specialized cell types: (1) fibroblasts, which lay down the connective-tissue framework of the muscle, and (2) myoblasts, which become the contractile muscle cells themselves. Our dispersed cultures contained both cell types in intimate association. Could one type multiply and differentiate in the absence of the other?

An approach to this question was provided by the elegant technique developed by Puck and his associates for growing colonies from single animal cells. Following these procedures, we prepared cell suspensions from embryonic muscle tissue as before, but now we pipetted into each Petri dish a relatively small number of cells (200 to 400). Dispersed over the surface of the dish, the cells were isolated from one another by virtue of the large distances that separated them. In the course of a week each viable cell multiplied into a colony large enough to be seen with the naked eye.

These initial trials, however, were disappointing. We could not detect any indication of muscle differentiation in any of the colonies. Later we extended the culture period to 10 to 13 days instead of terminating the experiment after a week. It then became apparent that one deficiency in the design of the earlier experiments had been patience. After the longer culture interval we could detect in some of the colonies (about one in 10) the familiar long, multinucleated cells with the characteristic pattern of cross striations.

The fact that only one in 10 colonies exhibited these characteristics was puzzling. Did this ratio indicate that only one cell in 10 was a future muscle cell, or myoblast, or did it indicate that the progeny of only certain myoblasts could differentiate under the particular culture conditions we used? We began to test modifications of our culture conditions that might be effective in increasing the yield of muscle colonies.

Our earlier experiments, in which muscle cells had differentiated after forming a continuous sheet, had suggested that a relation might exist between the degree of crowding and the initiation of the process of cell fusion, by which the multinucleated muscle cells are formed. This relation might indicate simply that the intimate contact between cells imposed by crowding was a prerequisite for fusion. But certain other experiments, while not entirely excluding the effect of physical crowding, focused our attention on the possibility that the steadily increasing population of cells was changing the culture medium in which they were growing. Simply by reusing the nutrient medium removed from older cultures to initiate new cultures we obtained differentiation 24 hours sooner than in freshly prepared medium. Apparently the composition of the medium had been changed by the metabolic activities of the first population of cells cultured in it, making it more effective in supporting the differentiation of the second population.

When such "conditioned" medium was used in cloning small numbers of cells, we found that it not only supported a luxuriant growth of colonies but also increased fourfold the proportion of differentiated colonies. In essence, when small numbers of cells are pipetted into conditioned medium, the net effect is to simulate the presence of a larger mass of cells. Similar tricks have been used before to promote the growth of single cells. Our results indicate that this one is an effective means of promoting not only growth but also differentiation.

As to exactly what changes have occurred in the medium during the first period of conditioning, we can at present only speculate. Actively metabolizing cells would remove some substances from the medium and contribute others. Harry Eagle and his associates at the Albert Einstein College of Medicine have recently described an interesting example of the relation of the cultured

ISOLATION OF CELLS begins with removal of chick embryo from the egg (*1*). Muscle tissue is dissected from bone (*2*) and minced (*3*). The minced muscle, suspended in a dilute solution of the enzyme trypsin, is transferred in pipette to a small flask (*4*),

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cell to its environment. In examining the nutritional requirements of several strains of animal cells they found that some of the "essential" constituents of the medium required for cell growth could in fact be synthesized by the same cells. These substances had to be added to the medium, Eagle found, simply because the cells were leaky: they lost the substances to the medium faster than they could replace them by synthesis. When the substances were included in the medium at a high enough level, the cells could maintain an internal concentration of them at the level required for growth.

The same principle may apply to the differentiation of cells. For many years embryologists have recognized that in culture, differentiation was favored by maintaining the cells in a compact mass. Such conditions would tend to minimize the loss of substances from the cells and thus compensate for any leakiness.

Having developed a procedure for obtaining a relatively high yield of muscle colonies, we could turn our attention to a more critical and detailed examination of the pattern of growth and differentiation in the colonies. To obtain this information we used the simplest of experimental designs: we looked. Eighteen hours after inoculating a Petri dish we scanned the bottom of the dish with a phase-contrast microscope. When we located single cells that had not yet divided, we circled their position on the underside of the dish. Then at regular intervals we examined and photographed each of the colonies that developed.

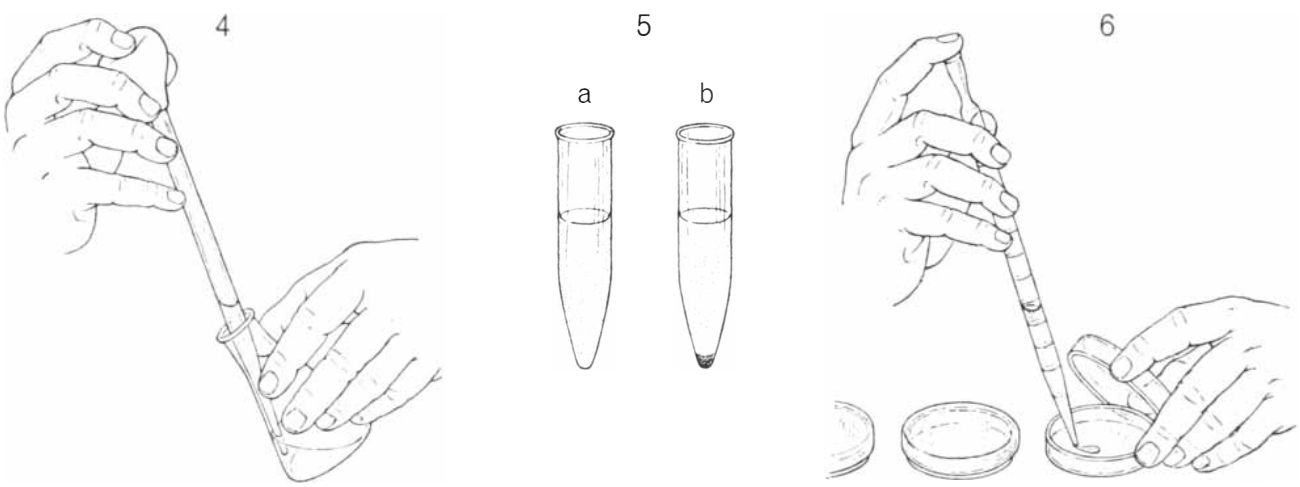
These single cells multiplied at a remarkably rapid rate—at least during the first four days, when it was still feasible to count their descendants. From the photographic records we calculated that the cells must have divided every 12 to 18 hours. By the end of the fourth day the colonies usually consisted of 50 to 60 individual cells. At some time during the fifth or sixth day short multinuclear cells formed. These were the first muscle fibers. By the end of the second week the colonies measured several millimeters in diameter and consisted of a delicate tracery of interlaced fibers. When they were appropriately stained, they could be distinguished from the disk-shaped colonies of fibroblast cells even with the unaided eye [*see upper illustration on next page*].

These studies of the sequence of growth and differentiation in colonies helped to settle a troublesome question. It was of considerable importance to establish rigorously whether or not a colony of muscle cells could actually develop from a single cell. We had not been able to exclude the possibility that our muscle colonies had arisen from small groups of cells; cell suspensions commonly contain a few clumps of from two to six cells. Our sequential observations indicated, however, that a solitary cell could indeed give rise to a muscle colony. As a further check on this point we ran several series of experiments in which the single cell under observation was not only separate from other cells but also physically isolated from them. This was accomplished by placing a small glass cylinder over the cell and sealing the cylinder to the Petri dish with silicone grease. Within the confines of the glass cylinder single cells again multiplied and formed colonies of differentiated muscle.

It often happens that an experiment devised to answer a specific question also provides information of a totally unexpected kind. The sequential studies of colony formation led us to the realization that the parent cell of the muscle colony—the myoblast—had certain distinguishing features that made it possible to identify it with a high degree of accuracy. Such cells had a rounded body with two slender, symmetrically arranged processes extending from it [*see illustration on page 63*]. The myoblasts were readily distinguishable from the highly flattened cells, irregular in outline, that gave rise to "fibroblastic" colonies. (Whether or not any of these colonies represent true fibroblasts has yet to be determined.)

We were surprised at how reliably myoblasts could be identified because so many factors can alter the shape of a cell in culture. For this reason shape alone is generally considered to be a poor criterion of cell type. Since we had established that a particular cell gave rise to a muscle colony, however, it was not surprising that the cell happened to have a bipolar shape. In the embryo, at a particular time in its development, the future muscle cell similarly assumes a bipolar shape. Does the change in shape also mark the stage at which the cell acquires the capacity for giving rise to a muscle colony in isolation? This question remains to be investigated by the culture of single cells that have been taken from the embryo at earlier stages.

The fact that the isolated myoblast retains its characteristic morphology is



where the cells separate during a brief incubation. Solution is placed in a tube (*5a*) and centrifuged, which packs cells into a pellet at tip of tube (*5b*). After resuspension in liquid medium the cells are counted and then inoculated into Petri dishes (*6*).

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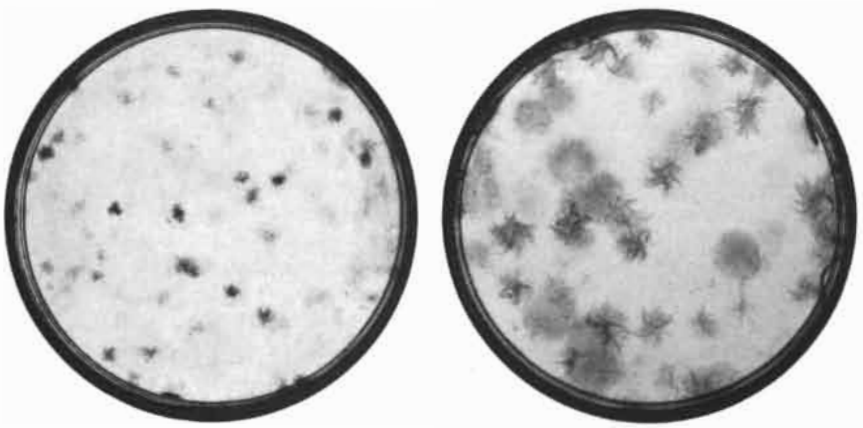
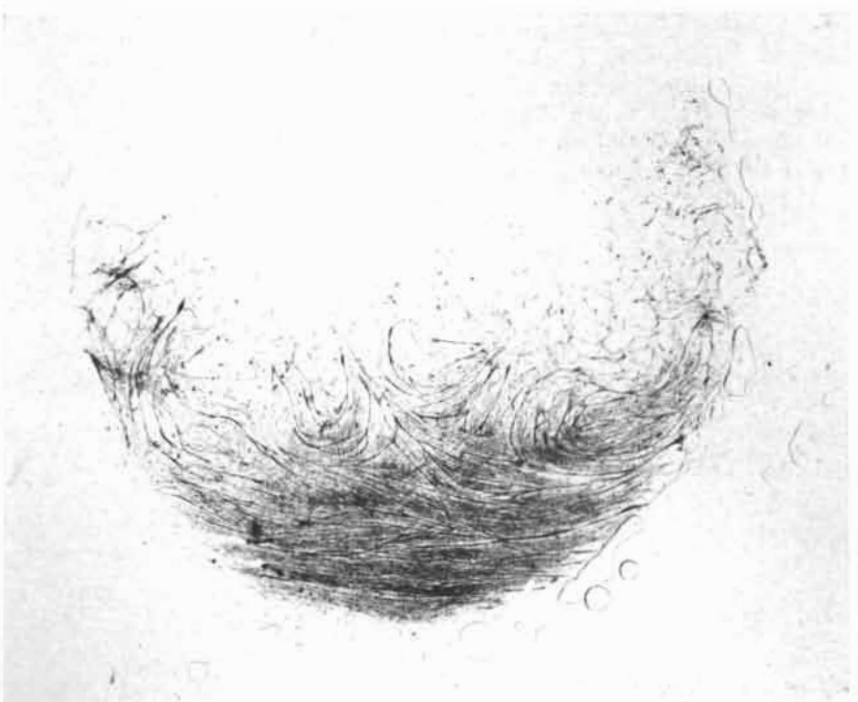
more than just an interesting observation. It provides a marker with which we can predict the developmental fate of a *living* cell. Ordinarily the identification of embryonic cell types necessitates techniques that kill the cell. This situation was somewhat analogous to the uncertainty principle of the physical sciences. We could say only that a particular cell *was* a myoblast. Cloning makes it possible for us to say that a cell *is* a myoblast because it allows us to test our prediction.

The cloning of embryonic cells is potentially a powerful tool because it permits such predictions to be made. Being able to deal with a homogeneous population of cells whose developmental fate is predictable, we can now ask what factors permit that fate to be realized. Can it be interrupted? Can the course of one type of differentiation be reversed and the cells channeled into another type of differentiation? This last question has long remained unresolved simply because it has not been possible to start with uniform populations of cells of a predictable normal fate. That obstacle, we know now, is not insurmountable.



TWO CULTURES, shown actual size, were each inoculated with 200 cells. The culture at left was fixed and stained after seven days, that at right after 13 days. Colonies at right that appear to be interlaced threads are differentiated muscle grown from single cells.



ONE COLONY, magnified 17 diameters, developed in 13 days. It grew from a single cell that had been isolated from neighboring cells in culture by walling it off with a tiny greased glass ring. This colony is like those in the Petri dish at right in the top illustration.

RAVE REVIEW ON SONY 600

Radio-Electronics Magazine

June, 1964 says:

"This recorder has some very good specifications and, although its price is above the 'cheap' range, one does not readily believe such excellent specs for a 4-track machine until they prove out. This machine fulfilled its promise. With it, you can tape your stereo discs and play them back without being able to detect any difference, which is saying something. The physical design of this unit is good, for either permanent installation or the most complete portability.

"The footage indicator *is* a footage indicator, not merely a place spotter, and it keeps its count with all normal tape movements. Independent control of left and right channels, so one can be operated in record, while the other is in playback, enables the unit to be used for an endless variety of 'special' effects.

"Playback and record functions are completely separate, so that a recorded program can be monitored immediately. Microphone and auxiliary inputs can be mixed for combination and re-record effects. First stage amplification uses transistors, while the main amplification uses tubes—a good marriage in this particular design.

"The mikes are very good, compared with most of the 'inexpensive' types used with home recorders. Extremely good realism is possible for home recordings. I had my family 'act natural' in front of the two-mike combination and the playback was unbelievably real.

"The Sony 600 will naturally take a little playing around to find out how to do various 'extra' things you may want. But when you get to know it, you'll find it a very versatile instrument. It's a recorder with which familiarity brings confidence."

Norman H. Crowhurst

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Population Control in Animals

Unlike man, most animals maintain fairly constant population levels. A new hypothesis suggests that they do so by forms of social behavior that limit reproduction to avoid overexploitation of food resources

by V. C. Wynne-Edwards

In population growth the human species is conspicuously out of line with the rest of the animal kingdom. Man is almost alone in showing a long-term upward trend in numbers; most other animals maintain their population size at a fairly constant level. To be sure, many of them fluctuate in number from season to season, from year to year or from decade to decade; notable examples are arctic lemmings, migratory locusts living in the subtropical dry belt, many northern game birds and certain fur-bearing animals. Such fluctuations, however, tend to swing erratically around a constant average value. More commonly animal populations maintain a steady state year after year and even century after century. If and when the population does rise or fall permanently, because of some change in the environment, it generally stabilizes again at a new level.

This well-established fact of population dynamics deserves to be studied with close attention, because the growth of human populations has become in recent years a matter of increasing concern. What sort of mechanism is responsible for such strict control of the size of populations? Each animal population, apart from man's, seems to be regulated in a homeostatic manner by some system that tends to keep it within not too wide limits of a set average density. Ecologists have been seeking to discover the nature of this system for many years. I shall outline here a new hypothesis that I set forth in full detail in a recently published book, *Animal Dispersion in Relation to Social Behaviour.*

The prevailing hypothesis has been that population is regulated by a set of negative natural controls. It is assumed that animals will produce young as fast as they efficiently can, and that the main factors that keep population density within fixed limits are predators, starvation, accidents and parasites causing disease. On the face of it this assumption seems entirely reasonable; overcrowding should increase the death toll from most of these factors and thus act to cut back the population when it rises to a high density. On close examination, however, these ideas do not stand up.

The notions that predators or disease are essential controllers of population density can be dismissed at once. There are animals that effectively have no predators and are not readily subject to disease and yet are limited to a stable level of population; among notable examples are the lion, the eagle and the skua [see "The Antarctic Skua," by Carl R. Eklund; SCIENTIFIC AMERICAN, February]. Disease per se does not act on a large scale to control population growth in the animal world. This leaves starvation as the possible control. The question of whether starvation itself acts directly to remove a population surplus calls for careful analysis.

Even a casual examination makes it clear that in most animal communities starvation is rare. Normally all the individuals in the habitat get enough food to survive. Occasionally a period of drought or severe cold may starve out a population, but that is an accident of weather—a disaster that does not arise from the density of population. We must therefore conclude that death from hunger is not an important density-dependent factor in controlling population size except in certain unusual cases.

Yet the density of population in the majority of habitats does depend directly on the size of the food supply; the close relation of one to the other is clear in representative situations where both variables have been measured [*see illustration on page 71*]. We have, then, the situation that no individual starves but the population does not outgrow the food supply available in its habitat under normal conditions.

For many of the higher animals one can see therefore that neither predators, disease nor starvation can account for the regulation of numbers. There is of course accidental mortality, but it strikes in unpredictable and haphazard ways, independently of population density, and so must be ruled out as a stabilizer of population. All these considerations point to the possibility that the animals themselves must exercise the necessary restraint!

Man's own history provides some vivid examples of what is entailed here. By overgrazing he has converted once rich pastures into deserts; by overhunting he has exterminated the passenger pigeon and all but eliminated animals such as the right whale, the southern fur seal and, in many of their former breeding places, sea turtles; he is now threatening to exterminate all five species of rhinoceros inhabiting tropical Africa and Asia because the horns of those animals are valued for their alleged aphrodisiac powers. Exploiting the riches of today can exhaust and destroy the resources of tomorrow. The point is that animals face precisely this danger with respect to their food supply, and they generally handle it more prudently than man does.

Birds feeding on seeds and berries in the fall or chickadees living on hibernating insects in winter are in such a situation. The stock of food to begin with is so abundant that it could feed an enormous population. Then, however, it would be gone in hours or days, and the birds must depend on this food supply for weeks or months. To make it

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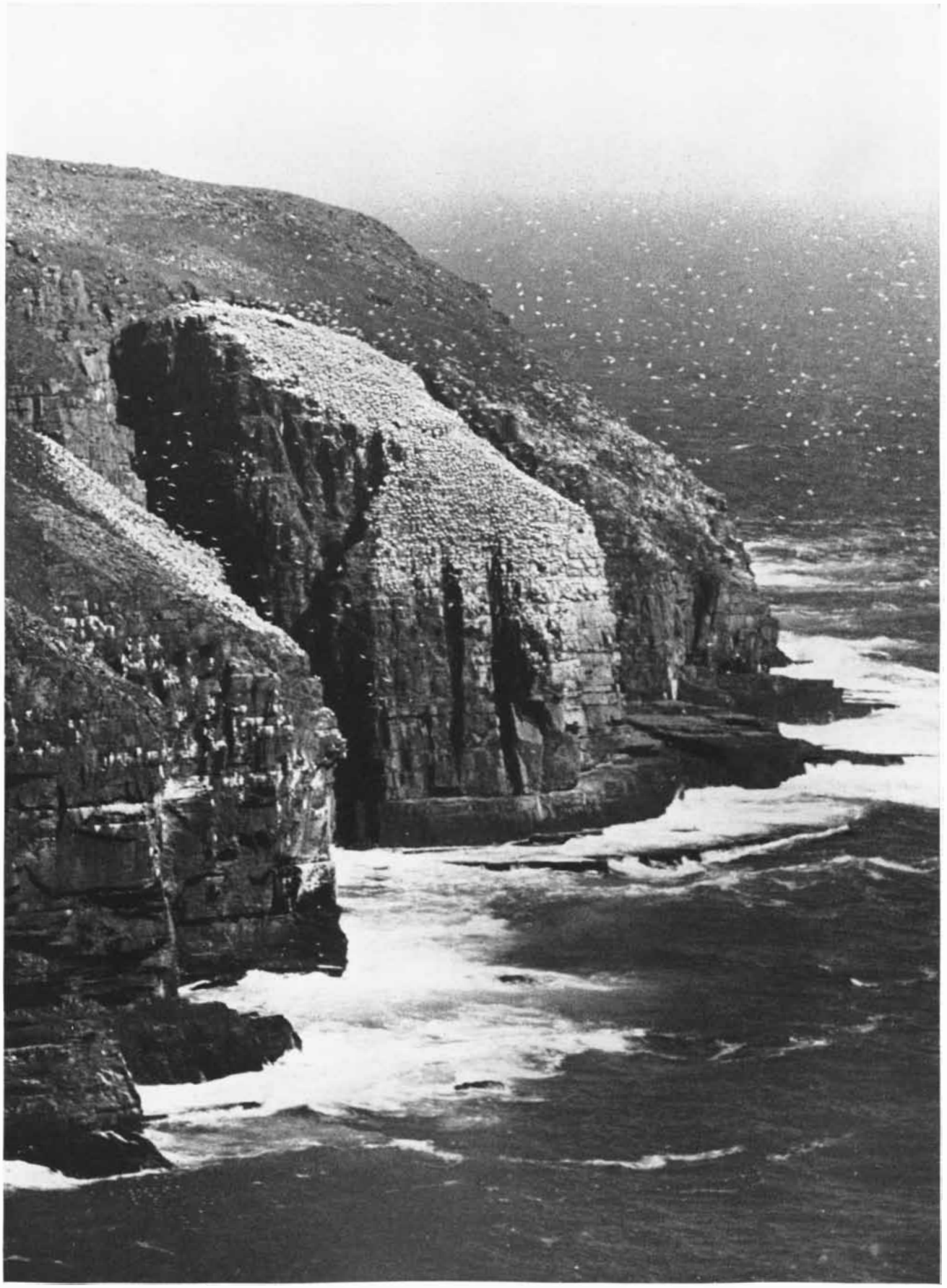

UNEMPLOYED BIRDS are visible at a gannetry on Cape St. Mary in Newfoundland. They are the ones on the slope at left; the main colony is on the large adjacent slope. The unemployed gannets are excluded from breeding, apparently as part of the colony's automatic mechanisms for controlling the population level. These birds do, however, constitute a reserve for raising the population level.

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MASSED MANEUVERS by starling flocks occur frequently on fine evenings, particularly in the fall. The maneuvers are an example of communal activity that appears to have the purpose of providing the flock with an indication of population density. If the density is too high or too low in relation to the food supply, the flock automatically increases the activities that will improve the balance.

last through the season the birds must restrict the size of their population in advance. The same necessity holds in situations where unlimited feeding would wipe out the sources that replenish the food supply. Thus the threat of starvation tomorrow, not hunger itself today, seems to be the factor that decides what the density of a population ought to be. Long before starvation would otherwise occur, the population must limit its growth in order to avoid disastrous overexploitation of its food resources.

All this implies that animals restrict their population density by some artificial device that is closely correlated with the food supply. What is required is some sort of automatic restrictive mechanism analogous to the deliberate conventions or agreements by which nations limit the exploitation of fishing grounds.

One does not need to look far to realize that animals do indeed possess conventions of this kind. The best-known is the territorial system of birds. The practice of staking out a territory for nesting and rearing a family is common among many species of birds. In the breeding season each male lays claim to an area of not less than a certain minimum size and keeps out all other males of the species; in this way a group of males will parcel out the available ground as individual territories and put a limit on crowding. It is a perfect example of an artificial mechanism geared to adjusting the density of population to the food resources. Instead of competing directly for the food itself the members compete furiously for pieces of ground, each of which then becomes the exclusive food preserve of its owner. If the standard territory is large enough to feed a family, the entire group is safe from the danger of overtaxing the food supply.

The territorial convention is just one example of a convention that takes many other forms, some of them much more sophisticated or abstract. Seabirds, for instance, being unable to stake out a territory or nest on the sea itself,

PLACE IN HIERARCHY is at stake in this contest between male black bucks in India. Many mammal and bird groups have a hierarchical system or a system of defended territories. Successful individuals acquire food and breeding rights; the others leave, or perhaps stay as a reserve available for breeding if needed. By such means the group correlates its population with food resources.

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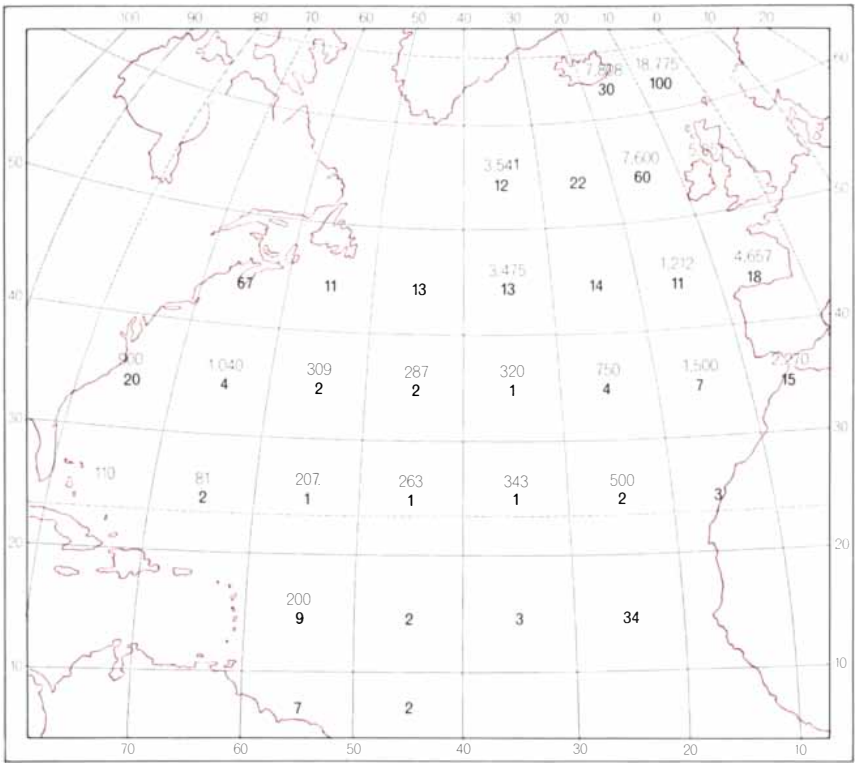
adopt instead a token nesting place on the shore that represents their fishing rights. Each nesting site occupies only a few square feet, but the birds' behavior also limits the overall size of their colony, thereby restricting the number that will fish in the vicinity. Any adults that have not succeeded in winning a site within the perimeter of the colony are usually inhibited from nesting or starting another colony nearby.

Other restrictive conventions practiced by animals are still more abstract. Often the animals compete not for actual property, such as a nesting site, but merely for membership in the group, and only a certain number are accepted. In all cases the effect is to limit the density of the group living in the given habitat and unload any surplus population to a safe distance.

Not the least interesting fact is that the competition itself tends to take an abstract or conventional form. In their contest for a territory birds seldom actually draw blood or kill each other. Instead they merely threaten with aggressive postures, vigorous singing or displays of plumage. The forms of intimidation of rivals by birds range all the way from the naked display of weapons to the triumph of splendor revealed in the peacock's train.



POPULATION AND FOOD SUPPLY show a correlation in the North Atlantic Ocean. The figures in light type give the average volume of plankton found per cubic centimeter of water; the darker figures show the average daily count of ocean birds that feed on plankton.

This hypothesis about the mechanism of population control in animals leads to a generalization of broader scope, namely that this was the origin or root of all social behavior in animals, including man. Surprisingly there has been no generally acceptable theory of how the first social organizations arose. One can now argue logically, however, that the kind of competition under conventional rules that is typified by the territorial system of birds was the earliest form of social organization. Indeed, a society can be defined as a group of individuals competing for conventional prizes by conventional methods. To put it another way, it is a brotherhood tempered by rivalry. One does not need to ponder very deeply to see how closely this cap fits even human societies.

A group of birds occupying an area divided into individual territories is plainly a social organization, and it exhibits a considerable range of characteristically social behavior. This is well illustrated by the red grouse of Scotland—a bird that is being studied intensively in a long-term research project near Aberdeen.

The grouse population on a heather moor consists of individuals known to one another and differing among themselves in social standing. The dominant males hold territories almost all year round, the most aggressive claiming on the average the largest territories. Their individual domains cover the moor like a mosaic [*see top illustration on page 73*]. The community admits as members some socially subordinate males and unmated hens that have no territories of their own, but with the onset of winter, or with a decline in the food supply for some other reason, these supernumeraries at the bottom of the social ladder get squeezed out. Only as many as can be supported by the lowered food level are allowed to stay. Thus the social hierarchy of the red grouse works as a safety valve or overflow mechanism, getting rid of any excess that would overtax the food resources. The existence of the peck-order system among birds has been known for some time, but its functional reason for being has been unclear; it now appears that the lowest members of the order serve as a dispensable reserve that can fill in as replacements for casualties among the established members or be dropped as circumstances require.

Certain definite rules mark the competition of the red grouse males for territory and status. One is that, at least in the fall, they crow and threaten only on fine mornings between first light and two or three hours later. So aggressive is this struggle that the stress forces some of the losers to make a break away from the moor; on unfamiliar ground and without their usual food they soon weaken and are killed by predators or disease. Once the early-morning contest is over, however, those birds that remain in the habitat flock together amicably and feed side by side for the rest of the day.

The convention of competing at dawn or at dusk and leaving the rest of the day free for feeding and other peaceable activities is exceedingly common among animals of various kinds. The changes of light at dawn and dusk are, of course, the most conspicuous recurrent events of the day, and this no doubt explains why they serve so often as a signal for joint or communal activities. There are many familiar manifestations of this timing: the dawn chorus of songbirds and crowing cocks, the flight of ducks at dusk, the massed maneuvers of starlings and blackbirds at their roosts as darkness falls; the evening choruses of almost innumerable other birds, various tropical bats, frogs, cicadas and fishes such as the croaker, and the morning concerts of howler monkeys.

All these synchronized outbursts give an indication of the numbers present

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in the respective populations. They provide an index of the population density in the habitat from day to day, and so feed to the group information that causes it, not deliberately but automatically, to step up those activities that may be necessary to restore the balance between the density and the food supply.

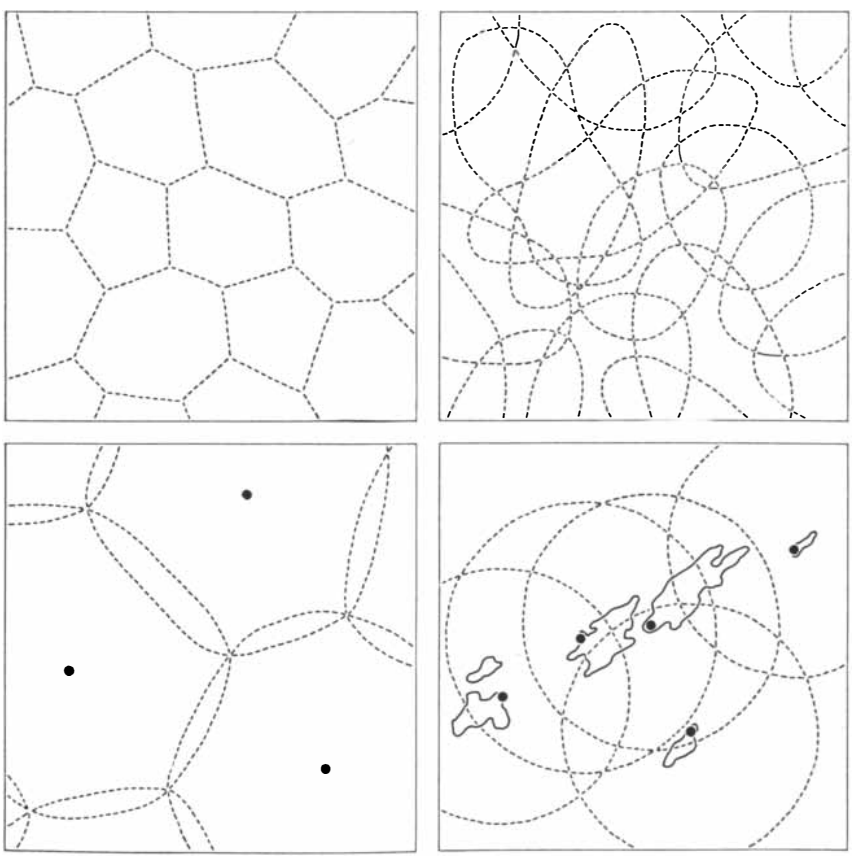
The daily community display puts a changing pressure on the members taking part. If the stress is great enough, a reduction in the population can be triggered off; if it is felt lightly or not at all, there is room for new recruits. Overcrowding will lead to expulsion of the population surplus, as in the case of the red grouse. In the breeding season the density index, in the form of the daily display, can influence the proportion of adults that mate and breed; likewise the number of young can be restricted in a variety of other ways to the quota that the habitat will allow.

In the light of this hypothesis one would expect these "epideictic" displays (that is, population-pressure demonstrations) to be particularly prominent at the outset of the breeding season. That is actually the case. In birds the demonstrators are usually the males; they can be called the epideictic sex. They may swarm and dance in the air (as many flying insects do) or engage in ritual tournaments, gymnastics or parades (characteristic of sage grouse, prairie chickens, tropical hummingbirds, manakins and birds-of-paradise). The intensity of these activities depends on the density of the population: the more males there are, the keener the competition. The new hypothesis suggests that this will result in greater stress among the males and sharper restriction of the size of the population.

In many animals the males have vocal abilities the females lack; this is true of songbirds, cicadas, most crickets and katydids, frogs, drumfishes, howler monkeys and others. Contrary to what was once thought, these males use their voices primarily not to woo females but in the contest with their fellow males for real estate and status. The same applies to many of the males' adornments and scent glands, as well as to their weapons. This newly recognized fact calls for some rethinking of the whole vexed subject of sexual selection.

Epideictic displays rise to a height not only as a prelude to the breeding season but also at the time of animal migrations. They show the scale of the impending change in the population density of the habitat and, during the migration, give an indication of the size of the flocks that have gathered at the stopping places, thereby enabling the migrants to avoid dangerous congestion at any one place. Locusts build up for a great flight with spectacular massed maneuvers, and comparable excitement marks the nightly roosting of migratory chimney swifts and other big gatherings of birds, fruit bats and insects.

Altogether the hypothesis that animal populations regulate themselves through the agency of social conventions of this kind seems to answer satisfactorily several of the major questions that have concerned ecologists. Basically the average population level is set by the long-term food resources of the habitat. A system of behavioral conventions acts as homeostatic machinery that prevents the growth of the population from departing too far from the optimal density. Fluctuations from this average can be explained as being due partly to temporary accidents (such as climatic extremes) and partly to the working of the homeostatic machinery itself, which allows the population density to build up when the food yields are good and thins it down when the yields fall below average. At any particular time the availability of food in relation to the number of mouths to be fed—in other words, the standard of living at the moment—determines the response of the regulating mechanism. The mechanism acts by controlling the rate of recruitment, by creating a pressure to emigrate or sometimes by producing stresses that result in large-scale mortality.



POPULATION-CONTROL DEVICES include the territory, of which the four basic types are depicted. Birds or mammals with territories have an established right to the available food; they also are the ones that breed. The others are in effect squeezed out. At top are two types of territory occupied by single males and their mates. At bottom are the types occupied by animals that live in colonies. One is virtually exclusive. The other is overlapping; shown here are islands from which five seabird colonies fan out within a maximum radius.

It has been particularly gratifying to find that the hypothesis offers explanations of several social enigmas on which there has been no good theory, such as the biological origin of social behavior; the function of the social hierarchy, or peck-order system, among birds; the chorus of birds and similar social events synchronized at dawn and dusk.

The theory has wide ramifications, which I have discussed at length in my book. The one that interests us most,

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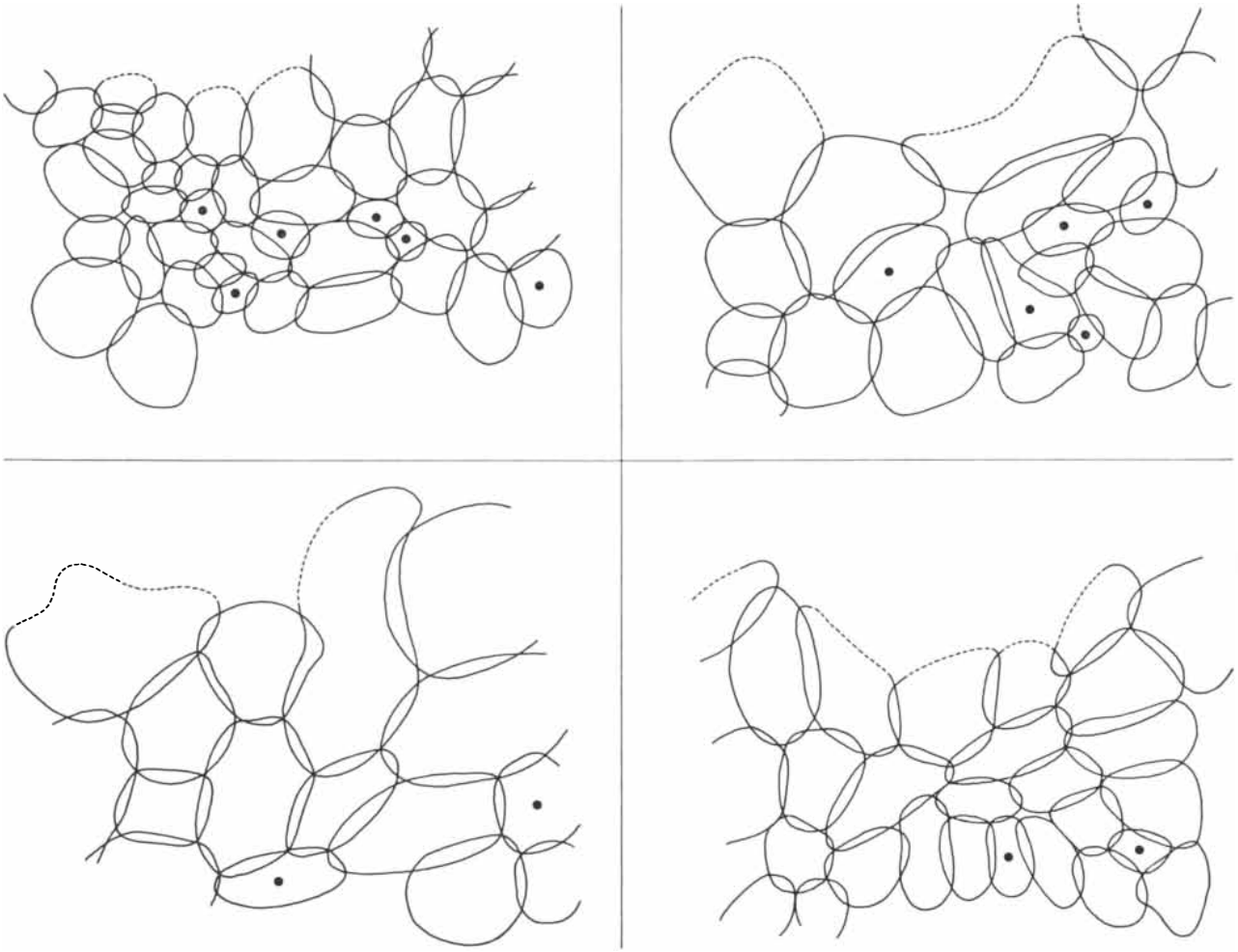
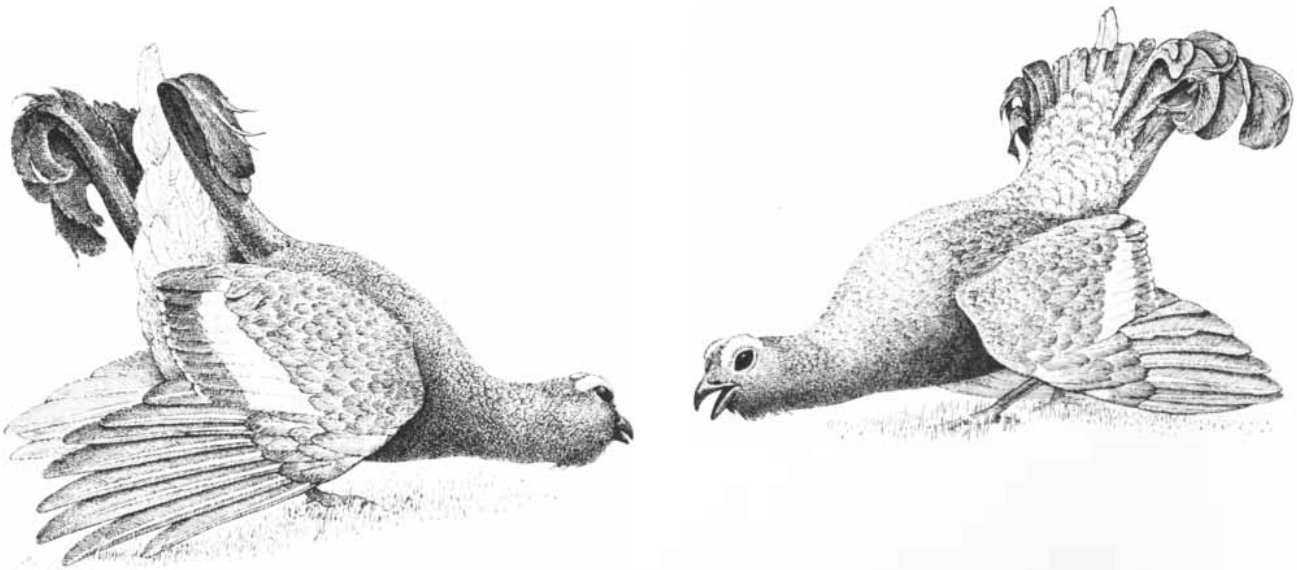


TERRITORIAL VARIATIONS of Scottish red grouse males reflect a form of population control. The drawings show the territorial holdings of individual cocks in four successive springs (1958–1961) on the same 140 acres of moorland. Some of the smaller territories, marked by dots, were held by males who remained unmated. Average territory size varies from year to year, thus affecting the density of breeding; in these four years the number of territories ranged between 40 in 1958 (*top left*) and 16 in 1960 (*bottom left*). The density of breeding is correlated with the food supply, which is to say with the quantity and quality of the heather.



BLACK GROUSE MALES are depicted in an "epideictic display," or ceremonial demonstration, that appears to be a form of population control. It evidently provides a measure of the population density within the area, because many males participate simultaneously on a communal strutting ground. It also serves as a means of excluding some less prominent males, who seldom display and often are chased away by the dominant birds. Epideictic displays also occur among many other bird and mammal species.

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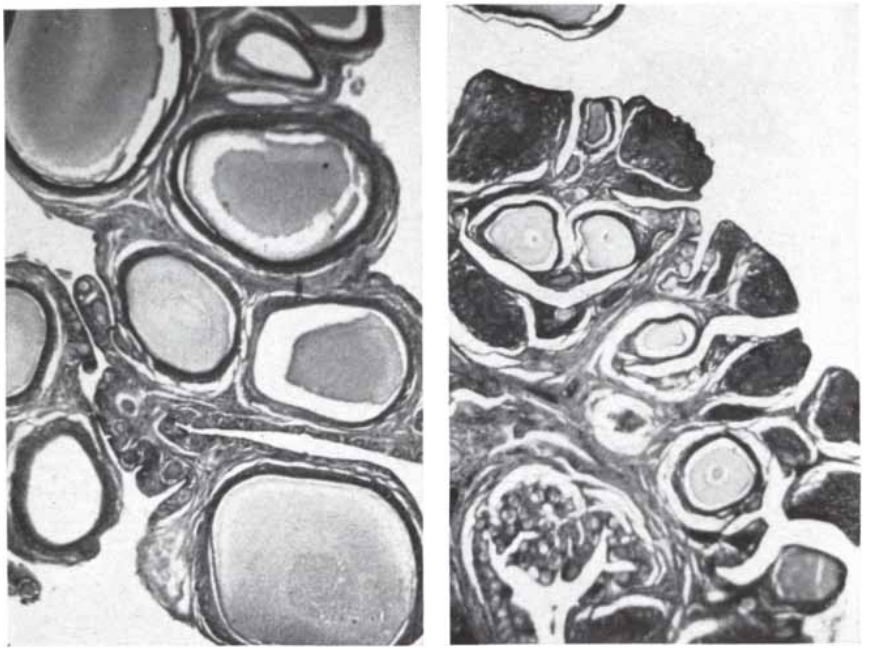
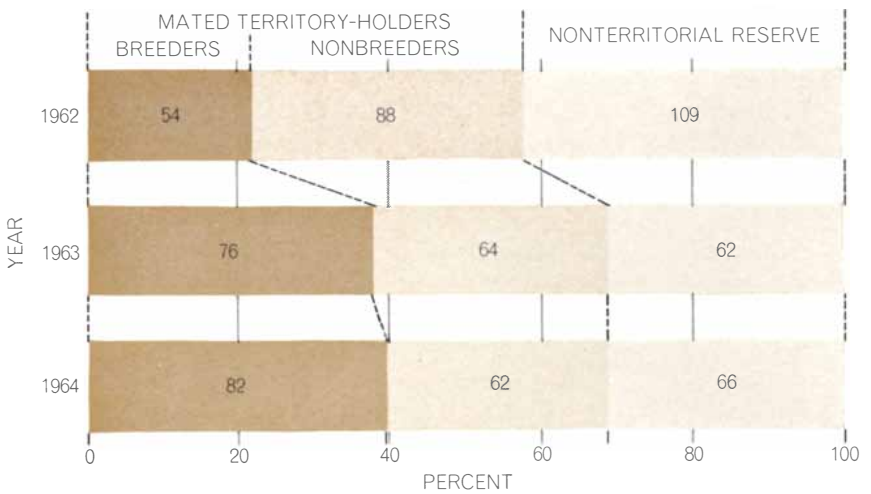
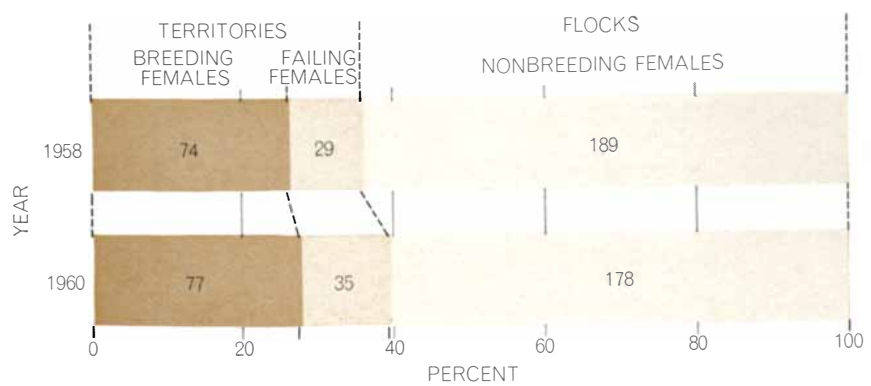


OVARY SECTIONS of nonbreeding fulmars indicate that population pressure may force a female to stop breeding. Section at left is from a young bird; that at right, from an older one as shown by dark resorbed ova. Older bird had bred as recently as the previous season.



POPULATION RESERVE exists among Scottish shelducks, as shown in data obtained by C. M. Young of the University of Aberdeen. The mated territory-holders all could have bred but many did not. The nonterritorial birds were denied even the opportunity to breed.



SIMILAR DATA for the Australian magpie also show a breeding reserve. Females in flocks had no opportunity to breed; females in territories could have bred but many did not. The birds were studied over several years by Robert Carrick of the Australian government.

of course, is its bearing on the problem of the unchecked growth of the human population. The hypothesis opens up to clearer view the differences between man's demographic history and that of other animals.

There are two outstanding differences. In the first place, the homeostatic control of animal populations is strictly automatic: even the social conventions of behavior are innate rather than deliberately arrived at. In part the density-dependent control in many animals, including some of the mammals, is exercised by means of a biological reaction—either reduction of the rate of ovulation through a change in the output of hormones, or resorption of the embryos in the uterus as a result of stress (as occurs in rabbits, foxes and deer). Man's fertility and population growth, on the other hand, are subject only to his conscious and deliberate behavior. The second important difference is that modern man has progressively and enormously increased the food productivity of his habitat.

Primitive man, limited to the food he could get by hunting, had evolved a system for restricting his numbers by tribal traditions and taboos, such as prohibiting sexual intercourse for mothers while they were still nursing a baby, practicing compulsory abortion and infanticide, offering human sacrifices, conducting headhunting expeditions against rival tribes and so forth. These customs, consciously or not, kept the population density nicely balanced against the feeding capacity of the hunting range. Then, some 8,000 to 10,000 years ago, the agricultural revolution removed that limitation. There was no longer any reason to hold down the size of the tribe; on the contrary, power and wealth accrued to those tribes that allowed their populations to multiply, to develop farms, villages and even towns. The old checks on population growth were gradually discarded and forgotten. The rate of reproduction became a matter of individual choice rather than of tribal or community control. It has remained so ever since.

Given opportunity for procreation and a low death rate, the human population, whether well fed or hungry, now shows a tendency to expand without limit. Lacking the built-in homeostatic system that regulates the density of animal populations, man cannot look to any natural process to restrain his rapid growth. If the growth is to be slowed down, it must be by his own deliberate and socially applied efforts.

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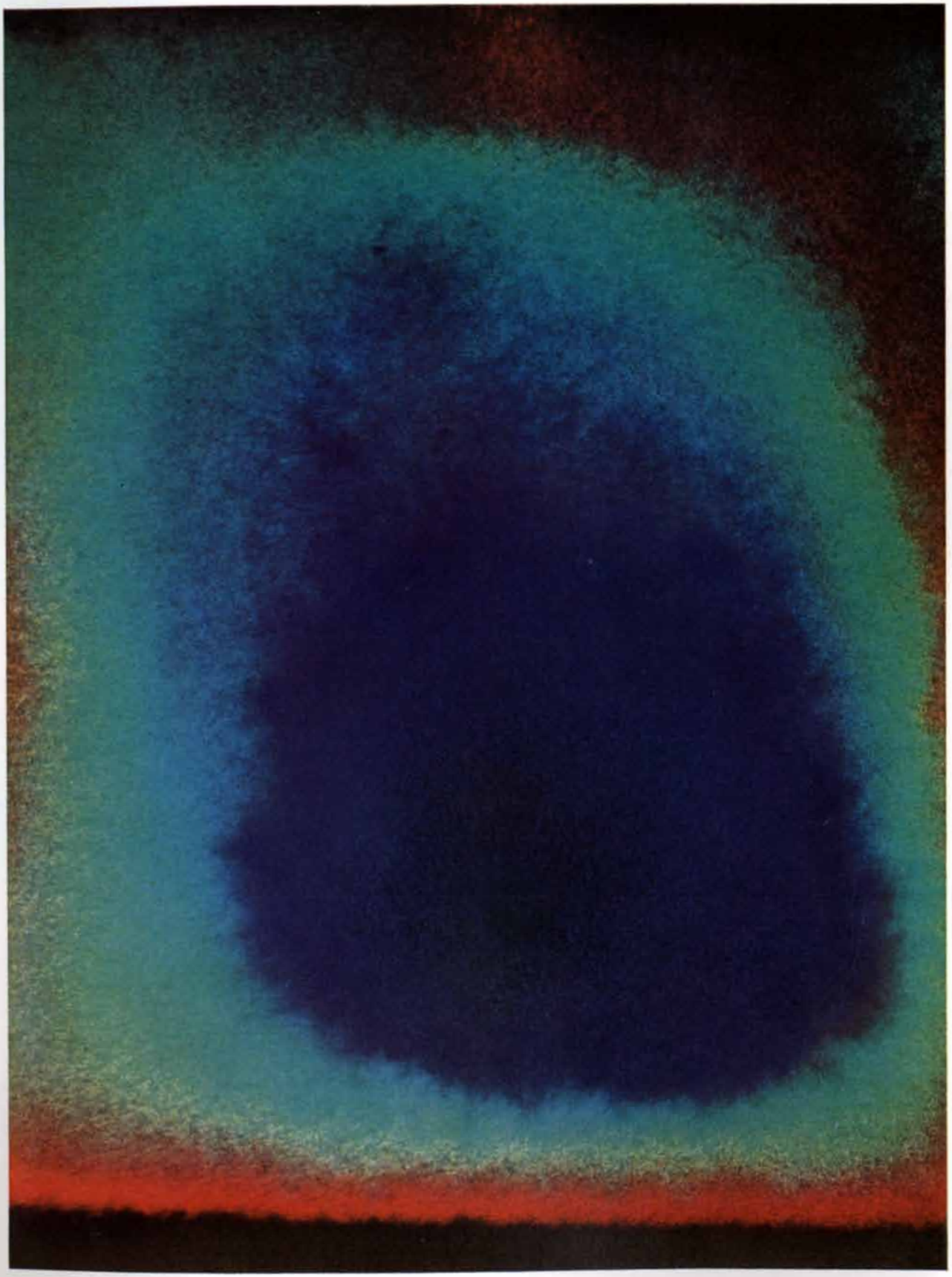

LIQUID CRYSTALS react to minute fluctuations in temperature by changing their color. The liquid-crystal substance shown here is a mixture of three different compounds that contain cholesterol. A thin layer of the mixture was spread on a four-inch-square black surface and covered with a transparent Mylar film. A beam of light was then directed at the center, creating a slight temperature gradient outward from the center. The total temperature range was from about 26 degrees centigrade (*red area*) to 30 degrees (*blue area*).

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LIQUID CRYSTALS

Substances that behave mechanically as liquids yet exhibit many of the optical properties of crystals have been known for more than 70 years. Their technological possibilities are just beginning to be explored

by James L. Fergason

The title of this article appears to be self-contradictory. A substance is called liquid if it flows and takes the shape of its container; a crystal is generally thought of as being a rigid solid. In more specific terms, the molecules in a liquid, although not as randomly distributed as those in a gas, are not arranged in any order that extends over a distance greater than a few molecules across. The molecules in a crystal, on the other hand, are fixed in a regular, three-dimensional array. In almost every way a crystal would seem to be the very opposite of a liquid.

Yet liquid crystals—substances that share some of the properties of both liquids and crystals—do exist. What is more, they cannot be considered rare, since they account for at least one of every 200 new organic compounds synthesized in the laboratory. Mechanically these substances resemble liquids, with viscosities ranging from runny glue to "solid" glass. Optically they exhibit many of the properties of crystals; for example, a typical liquid-crystal substance scatters light in symmetrical patterns and reflects different colors depending on the angle from which it is viewed. It is sometimes helpful to think of the liquid-crystal phase of matter as consisting of one- or two-dimensional crystals.

Although their existence has been known for more than 70 years, substances that exhibit the liquid-crystal phase have until recently been regarded more as laboratory curiosities than as potentially useful or theoretically important objects of study. In the past few years, however, several investigators in this country and abroad have undertaken to reexamine the liquid-crystal phase. The first results of these new studies have helped to clarify the unusual molecular architecture of liquid crystals. They also point to a number of possible applications that arise from the remarkable ability of liquid-crystal substances to register minute fluctuations in temperature, mechanical stress, electromagnetic radiation and chemical environment by changing their color.

Liquid crystals were first observed in 1888 by the Austrian botanist Friedrich Reinitzer, who noted that the compound cholesteryl benzoate appeared to have two distinct melting points. At 145 degrees centigrade the solid turned to a cloudy liquid and at 179 degrees the liquid became clear. Shortly thereafter the German physicist O. Lehmann showed that the cloudy intermediate phase contained areas that seemed to have a crystal-like molecular structure. He suggested the name "liquid crystal" for this phase and, in spite of many subsequent arguments about nomenclature, the name has stuck.

Liquid-crystal research reached a peak during the early 1930's. In addition to dozens of experimenters, who turned up many new liquid-crystal substances, the field had attracted such eminent theoreticians as W. H. Bragg, Louis de Broglie and Max Born. In spite of this flurry of activity, interest soon waned and for the next 30 years virtually no important work was done on the liquid-crystal phase. Several factors contributed to this period of quiescence. One was apparently the general feeling among physicists that all the important problems in the field were solved and only minor difficulties remained. Another was the tendency of almost all writers of general texts on physics and chemistry to ignore the liquid-crystal phase altogether; as a result many modern workers are only vaguely aware that an ambiguous melting point can be attributed to something other than impurities in the substance being tested. Perhaps the most important reason for the waning of interest in liquid-crystal research, however, was the apparent lack of practical applications. The importance of this factor can be appreciated if one considers that the spectacular development of solid-state physics in the past two decades has been stimulated largely by the promise of prompt technological dividends.

In 1958 my colleagues and I at the Westinghouse Research Laboratories began a research project aimed at learning more about the molecular structure, optical properties and technological possibilities of liquid-crystal substances. Several other investigators in this country, notably Glenn H. Brown at Kent State University, have also begun work on liquid crystals. In the U.S.S.R. a group headed by I. G. Chistyakov has recently undertaken a comprehensive study of the liquid-crystal phase. These efforts have already produced some very interesting findings, and it seems likely that as our knowledge of liquid crystals broadens, still more insights and applications will ensue.

Liquid crystals are conventionally divided into three classes, based on a system proposed by G. Friedel in 1922. In the first class, which is named "smectic" from the Greek word for soap, the roughly cigar-shaped molecules are arranged side by side in a series of layers [*see top illustrations on next page*]. In some smectic substances the molecules are further ordered by being arranged in rows within the individual layers, whereas in others the molecules are randomly distributed in the layers. In either case the long axes of all the molecules in a given layer are parallel to one another and perpendicular to the

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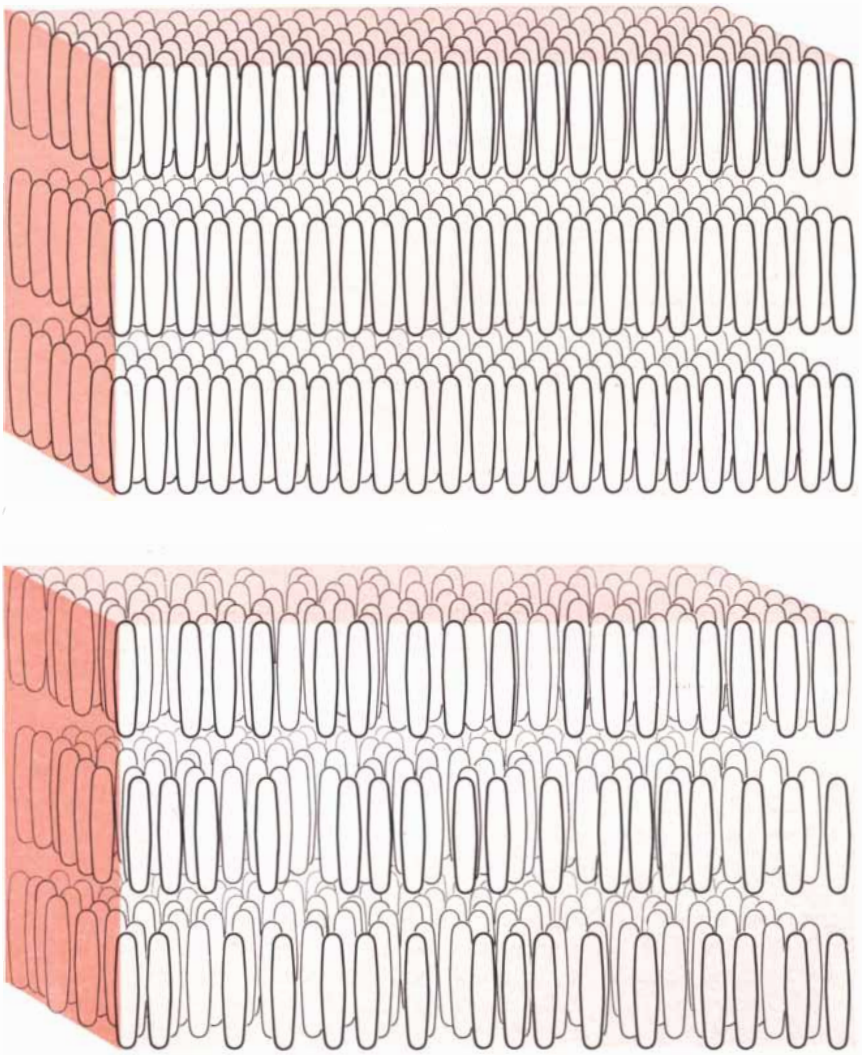
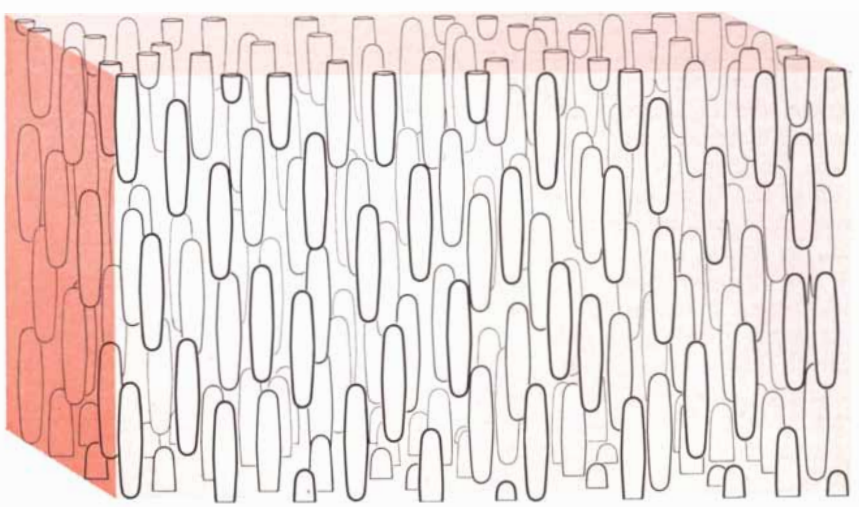


SMECTIC LIQUID CRYSTALS consist of a series of layers in which the molecules are arranged either in rows (*top*) or at random (*bottom*). The long axes of the molecules in each layer are perpendicular to the plane of the layer. The layers are free to slide over one another, giving the substance the mechanical properties of a two-dimensional fluid.



NEMATIC LIQUID CRYSTALS are less highly ordered than smectic substances. The molecules are arranged with all their long axes parallel, but they are not separated into layers. Both nematic and smectic liquid crystals exhibit many of the optical properties of solid crystals, including phenomenon of birefringence (*see upper illustration on page 82*).

plane of the layer, which is one molecule thick. The resulting configurations are analogous to two fields of corn, one planted in rows and the other sown at random.

A common example of a smectic liquid-crystal substance is a soap bubble [*see top illustration on opposite page*]. Smectic layers form both the inner and the outer surfaces of the bubble, with water filling the space between the layers. The side-to-side attraction of the soap molecules in the surface layers gives the bubble its necessary surface cohesion. If the bubble grows larger, free molecules of soap in the interstitial liquid slip into place in the layers, increasing the area of the film. As the bubble contracts, soap molecules drop out of the layers and go back into solution in the interstitial liquid.

In a typical smectic material, such as p-azoxybenzoate, the layers of molecules are quite flexible. If a single sheet could be suspended in space, free from gravity, it would take the form of a perfectly flat surface, since the side-to-side attraction of the molecules in the sheet would be the strongest force acting on it. If such a sheet were bent, it would eventually return to a flat configuration.

Imagine a number of such smectic sheets laid on top of one another like the leaves of a book. They would now tend to adjust themselves still further, so that the ends of the molecules in one sheet would fit in some characteristic way to the ends of the molecules in the adjacent sheets. Thus a solid crystal would be formed, in which there would be order and repetition in every direction in space. In the smectic phase the temperature is just high enough to ease the bonds between sheets but not high enough to break up the sheets themselves. In some cases the crystalline structure within a given sheet may even break down, with the result that the sheet will act as a sort of two-dimensional fluid. Such a sheet would slide without hindrance over similar neighboring sheets.

With the aid of a microscope that admits only polarized light it can be shown that a smectic liquid-crystal substance behaves optically like a three-dimensional crystal such as quartz. Hence the velocity of light transmitted perpendicularly to the layers is less than that transmitted parallel to the layers. In other words, light travels at a lower velocity along the long axes of the molecules than it does across these axes. Crystal structures of this type are said to be optically positive.

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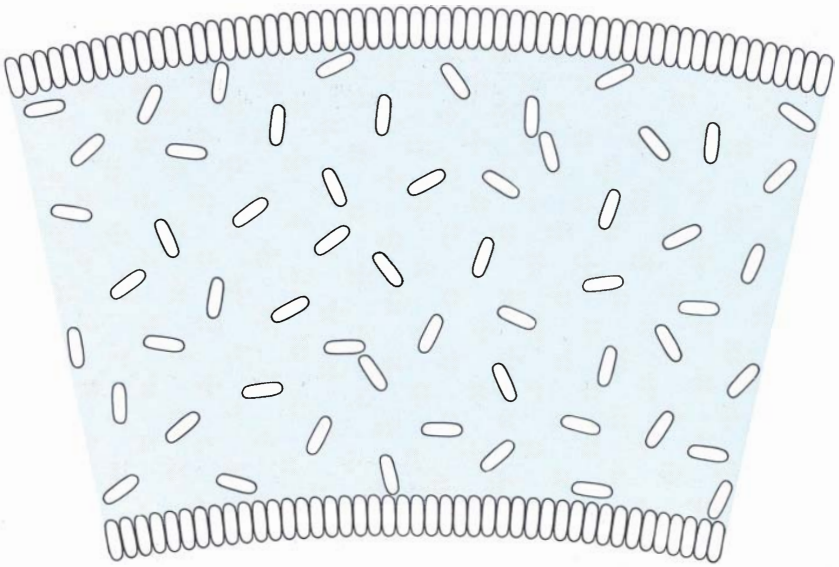
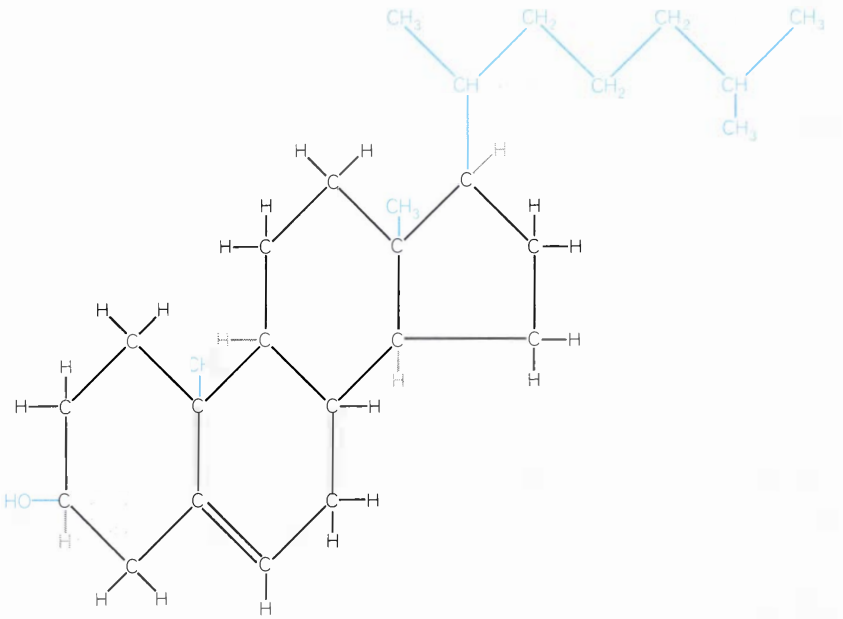
The second major class of liquid-crystal substances is called "nematic," from the Greek word for thread. Friedel chose the name because these substances contain microscopic threadlike structures, either floating free or attached to the surface of the container. Nematic liquid crystals are not so highly ordered as smectic substances. Although the molecules in the nematic phase are arranged with their long axes parallel, they are not separated into layers [*see bottom illustration on opposite page*]. A helpful analogy here would be a long box of short toothpicks, which are all free to roll around and slide back and forth but which remain parallel to the long axis of the box. Like smectic liquid crystals, nematic crystals are optically positive.

The overall molecular structure of nematic substances has been a source of controversy since the early 1930's. At that time the German physicists L. S. Ornstein and W. Kast maintained that the molecules in nematic substances were arranged in parallel groups, or "swarms," only in local areas and not throughout the material as a whole. They based their contention on the behavior of various nematic substances in an electromagnetic field. The molecules of a typical nematic substance respond to electric and magnetic stimuli in much the same way iron filings do: they line up with their long axes parallel in response to a very weak field. For instance, it is possible to affect the viscosity of a nematic material, such as p-azoxyanisole, simply by applying a weak magnetic field perpendicularly to the direction of flow. From experiments of this type Ornstein and Kast obtained evidence for the existence of local swarms of parallel molecules, containing roughly a million molecules each. More recently C. W. Oseen of the University of Uppsala has argued that the molecules in a nematic material are homogeneous and parallel throughout. His argument is based on observations of the mechanical and thermal properties of several nematic substances. At present the fate of the theory of swarms would seem to be in doubt.



CROSS SECTION OF SOAP BUBBLE shows the smectic liquid-crystal layers that form both the inner and the outer surfaces of the bubble. The side-to-side attraction of the soap molecules (*oblong objects*) in the surface layers gives the bubble its necessary surface cohesion. If the bubble is stretched laterally, free molecules of soap in the interstitial liquid (*colored area*) will slip into place in the layers, thereby increasing the area of the film. The soap molecules are not shown to scale; in actuality they would be considerably smaller.



MOLECULE OF CHOLESTEROL is essentially flat, with a side chain of methyl (CH_3) groups (*top right*) projecting upward from the plane of the molecule. Parts of the molecule that extend above the plane are in color; parts that extend below the plane are in light gray. Although cholesterol by itself does not exhibit a liquid-crystal phase, many compounds that contain cholesterol do; compounds in this category are called cholesteric.

Friedel named the third class of liquid crystals "cholesteric," since their molecular structure is characteristic of a large number of compounds that contain cholesterol. (Cholesterol by itself does not have a liquid-crystal phase.) In many ways the properties of the cholesteric phase resemble those of the smectic and nematic phases, but Friedel noted a somewhat closer resemblance between the cholesteric phase and the nematic phase. No substances were found exhibiting both phases, whereas each commonly occurred in association with the smectic phase.

As in smectic liquid crystals, the molecules in cholesteric liquid crystals are arranged in layers; within each layer, however, the parallel alignment of molecules is more reminiscent of the nematic phase [*see illustration on next page*]. The molecular layers in a cholesteric substance are very thin, with the long axes of the molecules parallel to the plane of the layers. The individual molecules are essentially flat, with a

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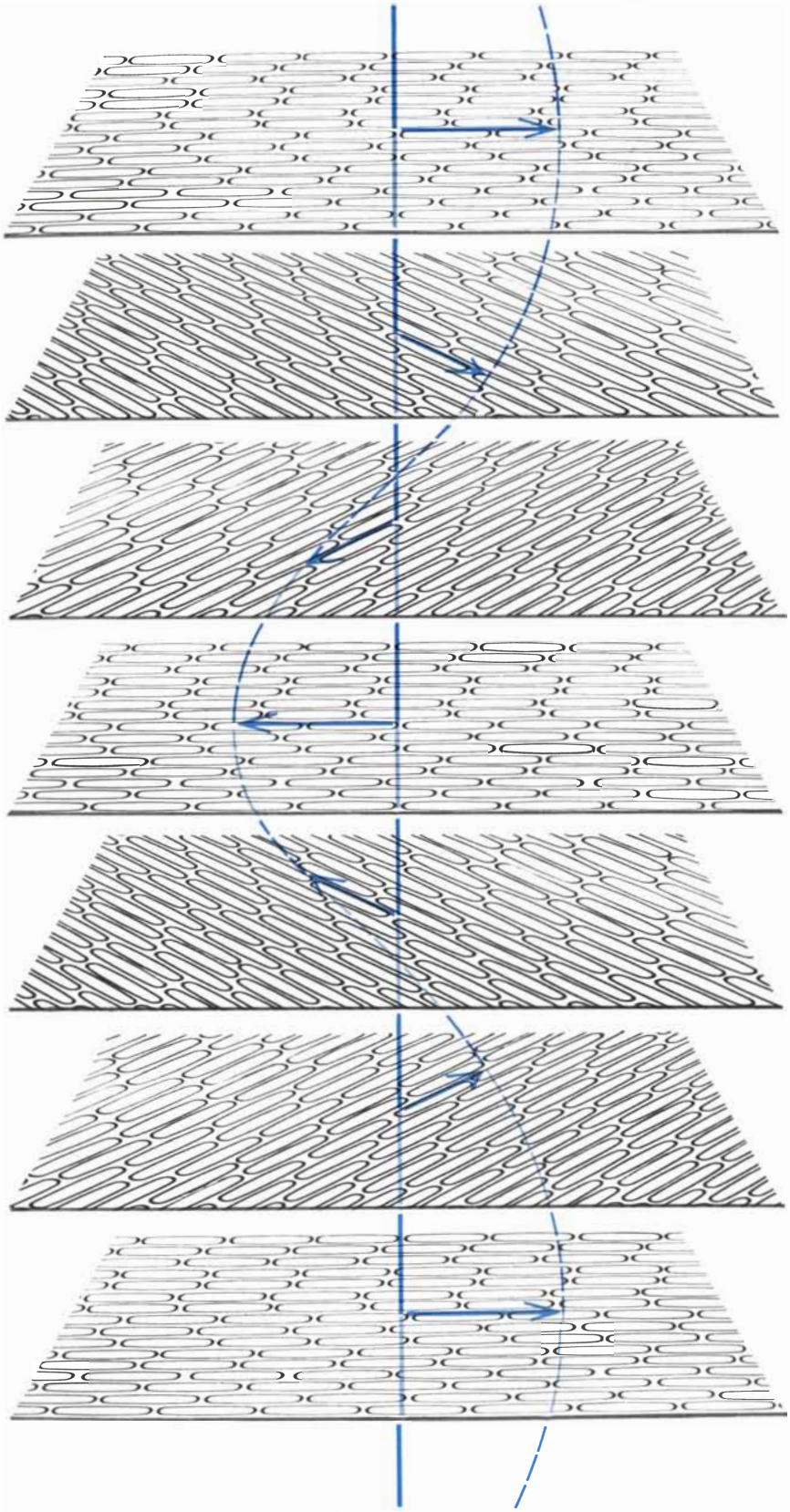

CHOLESTERIC LIQUID CRYSTALS resemble smectic liquid crystals in that the molecules are arranged in layers; within each layer, however, the parallel alignment of molecules is more reminiscent of the nematic phase. The molecular layers are very thin, with the long axes of the molecules parallel to the plane of the layers. Because of the peculiar shape of the cholesterol molecules (*see bottom illustration on preceding page*), the direction of the long axes of the molecules in each layer (*colored arrows*) is displaced slightly from the corresponding direction in the adjacent layers; the overall displacement traces out a helical path (*broken colored line*). Roughly every 300th layer is depicted.

side chain of methyl groups (CH_3) projecting upward from the plane of each molecule [*see lower illustration on preceding page*]. This unusual configuration causes the direction of the long axes of the molecules in each layer to be displaced slightly from the corresponding direction in adjacent layers. This displacement, which averages about 15 minutes of arc per layer, is cumulative through successive layers, so that the overall displacement traces out a helical path.

The unique molecular architecture of cholesteric liquid crystals gives rise to a number of peculiar optical properties. For example, if linearly polarized light is transmitted perpendicularly to the molecular layers, the direction of the electric vector of the light will be rotated progressively to the left along a helical path. Thus the plane of polarization, which is determined by the electric vector and the direction of propagation, will also be rotated to the left, through an angle that will be proportional to the thickness of the transmitting material. Crystalline substances that rotate the plane of polarization of light in this manner are called optically active. Certain types of quartz, for instance, rotate the plane of polarization about 20 degrees per millimeter and are considered very active. An optically active cholesteric substance, on the other hand, rotates the plane of polarization through an angle of as much as 18,000 degrees, or 50 rotations, per millimeter. Liquid crystals of this type are by far the most optically active substances known.

Another strictly crystalline optical property exhibited by cholesteric liquids is circular dichroism [*see lower illustration on page 82*]. When ordinary white light is directed at a cholesteric material, the light is separated into two components, one with the electric vector rotating clockwise and the other with the electric vector rotating counterclockwise. Depending on the material, one of these components is transmitted and the other is reflected. It is this property that gives the cholesteric phase its characteristic iridescent color when it is illuminated by white light. The particular combination of colors depends on the material, the temperature and the angle of the incident beam.

Unlike smectic and nematic substances, cholesteric liquid crystals are optically negative; that is, light entering perpendicularly to the molecular layers has a maximum velocity. An optical property shared by all three classes of

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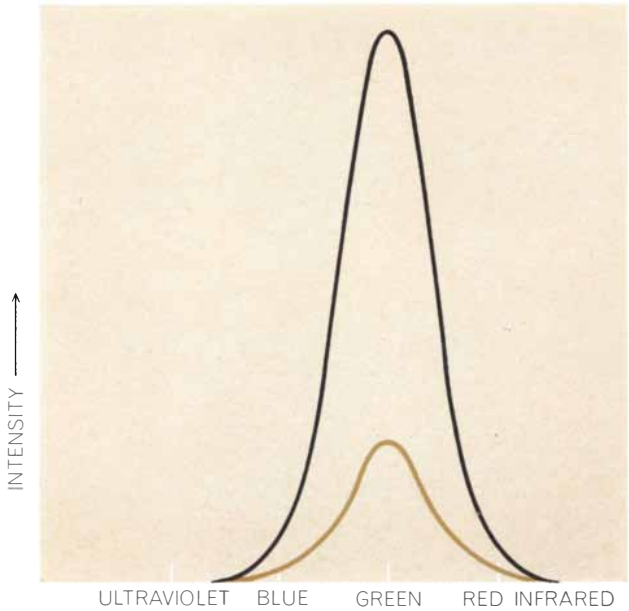
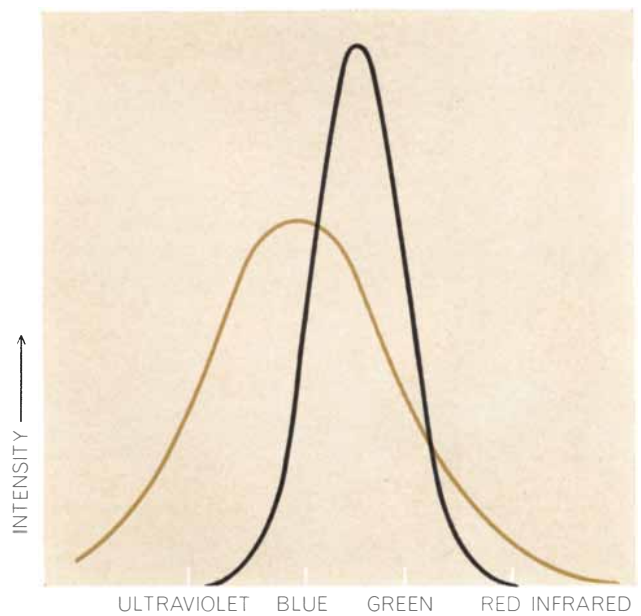
TEMPERATURE has a pronounced effect on the color of a cholesteric liquid-crystal substance. In this case the substance was predominantly red at a lower temperature (*black curve*) but shifted to blue when heated to a higher temperature (*colored curve*).



PREVIOUS HISTORY of heating and cooling also affects the color of a cholesteric substance. In this case the liquid crystals were an intense green color before heating (*black curve*); they subsequently changed to a drabber green when they were cooled (*colored curve*).



MECHANICAL STRESS is another factor in determining the color of a cholesteric substance. In the absence of any stress, this substance was an intense blue-green (*black curve*). Placed under a stress, the color shifted to a less intense blue (*colored curve*).

CHEMICAL ENVIRONMENT also has a pronounced effect on the color of a cholesteric substance. The black and gray curves represent the colors produced by the addition of minute amounts of two different chemical vapors to the basic mixture (*colored curve*).

liquid-crystal substances is the phenomenon of birefringence, or double refraction [*see upper illustration on next page*]. A beam of white light normally consists of transverse vibrations in every direction perpendicular to the direction of propagation of the beam. When such a beam strikes the surface of a birefringent material, the beam is split into two polarized components, which vibrate at right angles to each other. The two components travel at different velocities through the birefringent material and so are refracted at slightly different angles. They emerge from the material as parallel beams of mutually perpendicular polarized light. One of the most convenient ways to identify a liquid-crystal substance is to test it for birefringence.

The molecular structure of a cholesteric liquid-crystal substance is very delicately balanced and can be easily upset. Thus any small disturbance that interferes with the weak forces between the molecules can produce marked changes in such optical properties as reflection, transmission, birefringence, circular dichroism, optical activity and color.

Perhaps the most striking optical transformation that occurs in a cholesteric substance in response to subtle

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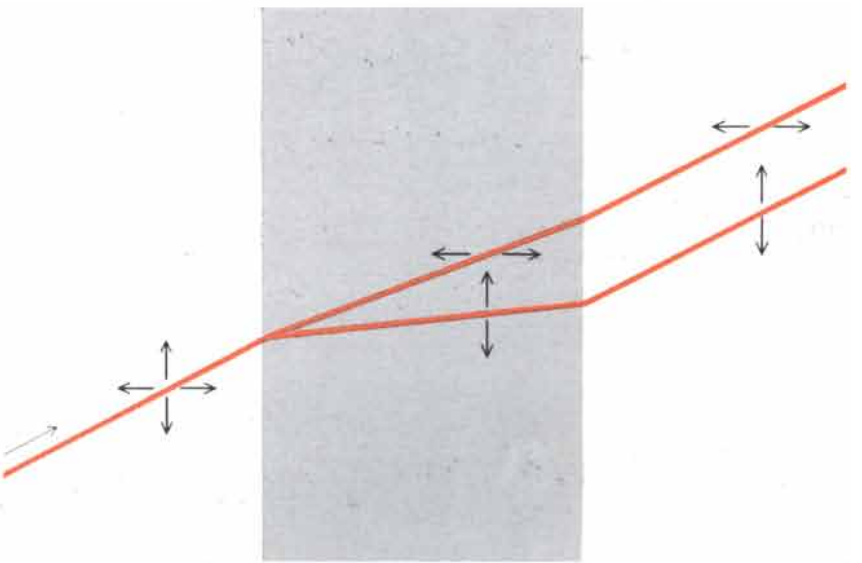
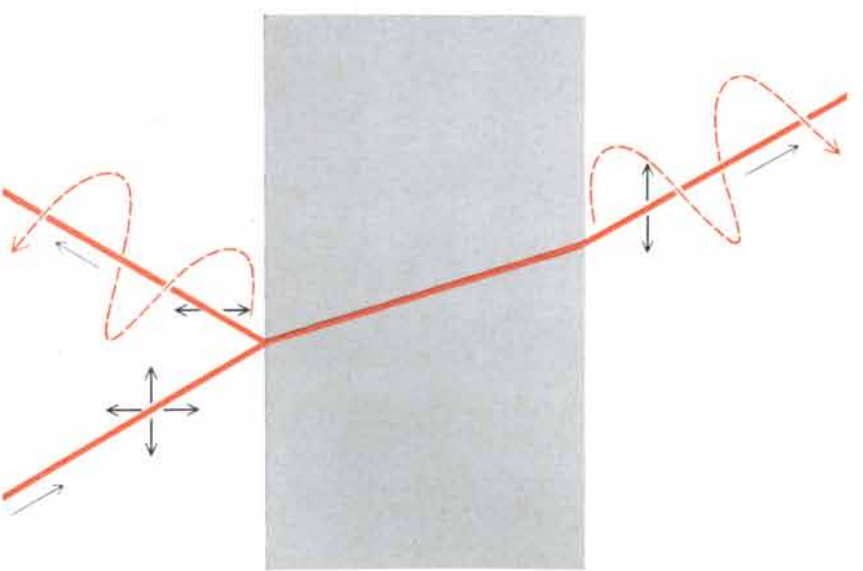
changes in its environment is the variation of color with temperature [*see illustration on page 76*]. Although most cholesteric substances are colorless as liquids, they pass through a series of bright colors when they are cooled through their liquid-crystal phase. In this phase they may first appear to be violet, then blue, then green, then yellow, then red and finally colorless again as the reflection maximum enters the infrared region. Further cooling brings these substances into the smectic phase, which is also colorless.

All cholesteric liquid crystals do not respond in the same way to fluctuations in temperature. For example, some change only from red to green on cooling; others change from red to green to blue or from red to green and back to red. Some substances are initially blue and change to green and then to red when they are cooled; still others show no reaction at all to changes in tempera-



BIREFRINGENCE, or double refraction, is an optical phenomenon characteristic of solid crystals and most liquid-crystal substances. When a beam of unpolarized light encounters a birefringent substance (*left*), it is split into two polarized components whose transverse vibrations are at right angles to each other. The two components are refracted at different angles through the substance and emerge as parallel beams of polarized light (*right*).



CIRCULAR DICHROISM is another typically crystalline optical property exhibited by cholesteric liquid crystals. When unpolarized light is directed at a cholesteric substance, the light is broken into two components, one with the electric vector rotating clockwise and the other with the electric vector rotating counterclockwise; one of these components is transmitted and the other is reflected. It is this property that gives the cholesteric phase its characteristic iridescent color when it is illuminated by white light.

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

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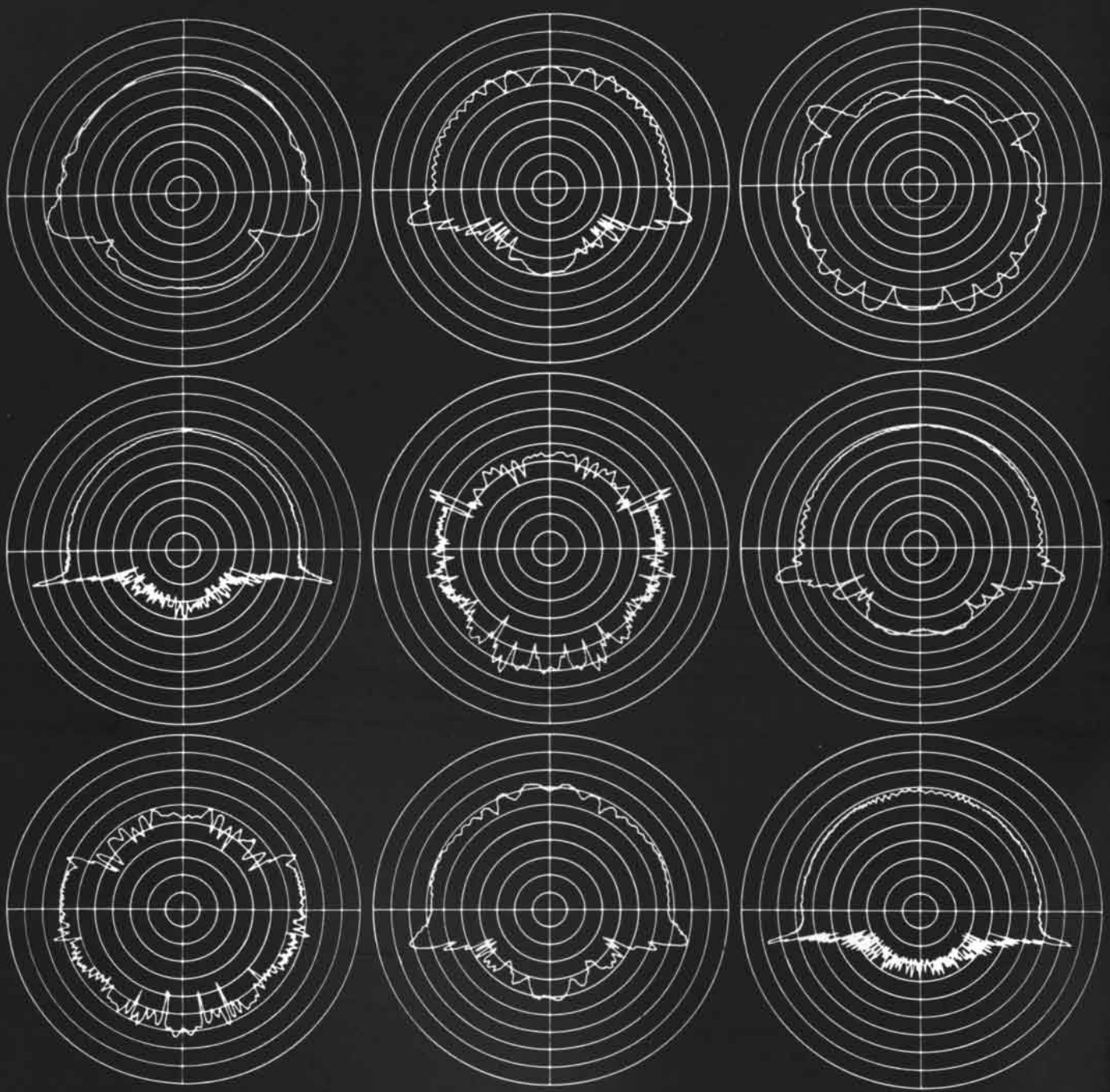
Backscatter Patterns



The Lincoln Laboratory of the Massachusetts Institute of Technology conducts a program of general research in advanced electronics with applications to urgent problems of national defense and space exploration. Research in the area of *Ballistic Missile Defense* is concerned with radar techniques for detection and surveillance, as well as re-entry physics studies aimed at achieving improved target identification and decoy discrimination. All qualified applicants will receive consideration for employment without regard to race, creed, color or national origin. Lincoln Laboratory, Massachusetts Institute of Technology, Box 18, Lexington 73, Massachusetts.

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ture. The important point, in any case, is that at a certain temperature a given material or combination of materials will always exhibit the same color. Moreover, the rate of change from color to color as well as the exact temperature at which specific color changes occur are invariable. Therefore by mixing cholesteric substances in various proportions any desired temperature-color combination can be obtained. (The intensity of the color at any temperature is dependent on several other factors, including the previous history of heating and cooling within the liquid-crystal phase and the surface on which the substance is deposited.)

Cholesteric liquid crystals are just beginning to be used for measuring temperature fluctuations in the laboratory. So far several different combinations of cholesteric substances have been used to measure temperatures ranging from minus 20 degrees C. to plus 250 degrees. These substances have been fabricated into flexible films or tapes that can be applied to surfaces to record temperature gradients in several directions. This technique can be extended to the inspection of opaque materials for certain structural flaws that would conduct heat unevenly and so produce different patterns of color in a cholesteric substance applied to the surface. Most of this kind of inspection work is now done with X-ray techniques. In medicine cholesteric liquid-crystal substances could similarly be applied to the surface of the skin to locate veins, arteries or other internal structures that would conduct heat at a different rate from that in the surrounding tissue. A variety of temperature-sensitive warning devices could also be made with cholesteric liquid-crystal materials.

The color response of cholesteric liquid crystals to chemical vapors resembles the color response to temperature, although the two effects are usually unrelated. The addition of extremely small amounts of certain chemical vapors can change the basic molecular structure of the liquid crystals and thereby affect their reflecting properties. If the liquid crystals merely serve as a solvent for the vapor, this color change will be reversible. If the vapor reacts chemically with the liquid crystals or serves as a catalyst for some other reaction, the color change will be permanent. In either of the last two cases the reacted liquid-crystal molecules are able to diffuse through the substance very rapidly, so that the addition of only a few parts per million of the vapor will produce an almost immediate change in color throughout the substance. The use of liquid crystals in the laboratory to detect traces of chemical vapors seems as promising as their use as temperature indicators. As in temperature indication, different mixtures of cholesteric substances could produce any desired vapor-color combination [*see illustration below*].

The molecular structure, and hence the color-reflecting properties, of cholesteric liquid crystals can also be altered by mechanical stress. Since the intermolecular binding forces in these substances are so weak, mechanical distortion has a much greater effect on liquid crystals than it does on rigid, three-dimensional crystals. The color response to mechanical stress, however, is much less pronounced than it is in the case of temperature or chemical vapor changes. Electromagnetic radiation can also induce chemical changes in cholesteric substances that in turn affect color and other optical properties.

The possible function of liquid crystals in living organisms is largely unexplored territory. The fact that all the liquid-crystal materials that exhibit a color sensitivity to chemical vapors occur naturally or can be prepared from naturally occurring substances suggests that liquid crystals may be involved in sensing certain vapors, perhaps in relation to the sense of smell. Furthermore, cholesterol is found in the bodies of all vertebrate animals; there is about a third of a pound in an adult human, although only in the case of certain diseases is it in the form of crystals. So far liquid-crystal substances containing cholesterol have not been found in a living animal, but the evidence strongly indicates that such a discovery is in the offing.

ORIGINAL MIXTURE	PERCENT	ORIGINAL COLOR	SOLVENT ADDED	FINAL COLOR
CHOLESTERYL CHLORIDE CHOLESTERYL NONANOATE CHOLESTERYL OLEATE	15 80 5	RED	ACETONE BENZENE CHLOROFORM TRICHLOROETHYLENE METHYLENE CHLORIDE PETROLEUM ETHER	BLUE BLUE BLUE BLUE BLUE BLUE
CHOLESTERYL CHLORIDE CHOLESTERYL NONANOATE	20 80	GREEN	BENZENE CHLOROFORM TRICHLOROETHYLENE METHYLENE CHLORIDE PETROLEUM ETHER	BLUE RED NO CHANGE RED BLUE
CHOLESTERYL CHLORIDE CHOLESTERYL NONANOATE	25 75	YELLOW-RED	BENZENE CHLOROFORM TRICHLOROETHYLENE METHYLENE CHLORIDE PETROLEUM ETHER	DEEPER RED RED DEEPER RED RED BLUE
CHOLESTERYL CHLORIDE CHOLESTERYL NONANOATE	30 20	RED	CHLOROFORM METHYLENE CHLORIDE PETROLEUM ETHER	DEEPER RED DEEPER RED BLUE

TRACES OF CHEMICAL VAPORS can be detected by observing the changes in color undergone by various mixtures of compounds that contain cholesteric liquid crystals. In this case the vapors act as a solvent for the cholesteric substances and the change in color is reversible. By varying the proportions of the liquid-crystal compounds any desired solvent-color combination can be obtained.

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THE SOLUTREAN CULTURE

A vigorous hunting culture with a unique tool kit appeared in western Europe 21,000 years ago. Once deemed invaders, the practitioners of Solutrean techniques instead seem to have had their roots in France

by Philip E. L. Smith

During the last advances and the final retreat of the Pleistocene ice sheets in Europe, between 32,000 and 10,000 years ago, the most vigorous cultures of the Old Stone Age flourished. The hunting peoples of this Upper Paleolithic period enjoyed an abundance of cold-climate game: migrating reindeer by the thousands, herds of horses and wild cattle, and such giants of the subarctic zone as the mammoth and the woolly rhinoceros. The well-fed hunters made these same animals the subjects of sculpture, in the round or in relief, of fine-line engraving on bone, antler and ivory, and of richly colored cave paintings such as those found at Altamira in Spain and Lascaux in France.

Prehistorians generally divide the Upper Paleolithic culture of western Europe into four major components. The two earliest of these, called the Perigordian and the Aurignacian, were roughly contemporary; the distinction between them is based primarily on differences in their assemblages of stone tools and weapons. In western Europe both of these cultural traditions were succeeded some 21,000 years ago by a new array of distinctive stone implements that are assigned to the Solutrean culture. About 17,000 years ago, in turn, the last phase of the Solutrean gave way to the Magdalenian culture, whose members produced many of the most notable examples of Upper Paleolithic art. Finally, as the ice sheets began their last retreat, Magdalenian artifacts disappeared and in southwestern France a comparatively impoverished successor culture, the Azilian, marked the end of an era [*see illustration on page 89*].

These cultural successions have been interpreted in a number of ways. Thinking in terms of the many waves of migration and conquest that have passed over Europe during historical times, some students argue that each distinctive assemblage of Upper Paleolithic artifacts represents a fresh influx of people from Asia or Africa. Other students point to the enormous time span of the Upper Paleolithic: roughly five times longer than all recorded history. These scholars do not discount the possibility that ideas were imported into western Europe, but they prefer to attribute most of the cultural changes in the region to cultural evolution within a relatively stable population.

It might be less difficult to determine which, if either, of these hypotheses is best supported by the evidence if the history of archaeological research in Europe had been different. For much of its 100-year history the collection of archaeological evidence in some countries has been in the hands not only of scholars but also of amateur antiquarians and professional looters. One result is that few Upper Paleolithic sites have been excavated under controlled conditions. This means that the stratigraphic positions, and thus the age and associations, of many of the period's most significant artifacts have been lost forever.

France is western Europe's greatest Upper Paleolithic treasure-house and the department of Dordogne, in southwestern France, is the country's richest single depository. Thanks to stringent government regulations, looters can no longer mine the limestone caves and shelters in the valleys of the Dordogne and Vézère rivers. During the years since World War II a number of promising sites have been scientifically excavated. Some are still in the process of long-term excavation; an example is the Pataud rock-shelter near the village of Les Eyzies, where a group from Harvard University has been working for eight years. In the 1950's another rock-shelter at Les Eyzies was reinvestigated by François Bordes of the University of Bordeaux. Known as Laugerie-Haute, it had been shown to be rich in Upper Paleolithic artifacts by the noted French prehistorian Denis Peyrony in the 1920's. More than half of the site was still untouched in the 1950's; the strata containing Upper Paleolithic remains were 10 meters thick in some places, with Solutrean layers occupying more than a meter of this depth.

I worked at Laugerie-Haute with Bordes in 1957. In 1959 he asked me to investigate the site's Solutrean levels to see if some of the problems concerning this comparatively short-lived but remarkable culture could be cleared up by recovering new samples of Solutrean artifacts from a precisely calibrated stratigraphic sequence.

Peyrony's studies of the 1920's were not the first conducted at Laugerie-Haute. A century ago, in 1863, two pioneer prehistorians began a series of now classic investigations at a number of sites in the vicinity of Les Eyzies. One was Édouard Lartet, a French paleontologist whose interests had turned to the new field of archaeology; the other was a British businessman, Henry Christy. Before they were done at such sites as La Madeleine (from which the Magdalenian culture takes its name), the Gorge d'Enfer and Laugerie-Haute the two investigators had discovered the first evidence of prehistoric art—the figure of a mammoth engraved on bone—and had given the name "Reindeer Age" to what we rec-

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PAIR OF WILD CATTLE, attributed to a Solutrean sculptor, was rendered in bas-relief on the surface of a limestone outcropping on the Dronne River in southwestern France. This Upper Paleolithic work of art was found at a site called Fourneau du Diable.

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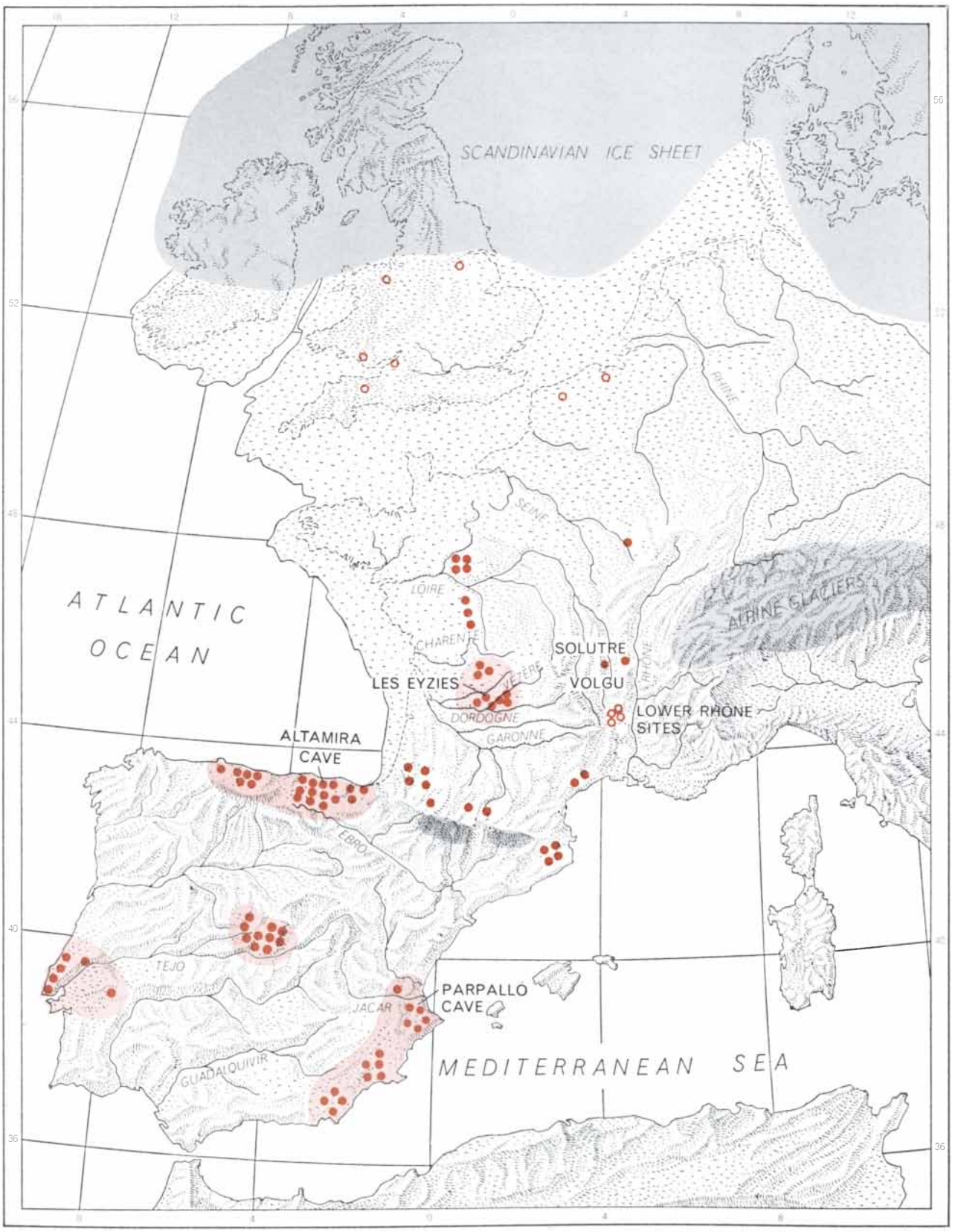

WESTERN EUROPE some 20,000 years ago had approximately today's Mediterranean coastline, but neither the English Channel nor the North Sea existed. Glaciers were extensive in the Alps and the Pyrenees, and the great Scandinavian ice sheet covered most of Ireland and all of Scotland and the Baltic. The third advance of the Würm glaciation was just ending and the weather was cold. Solid dots locate sites where Solutrean materials have been discovered. The five major areas (*light color*) are the classic Solutrean region of the Dordogne in southwestern France and four outlying Iberian regions. The open dots in the lower Rhône valley identify sites from which the earliest Solutrean techniques seem to have dispersed. The other open dots locate sites of less certain affinity.

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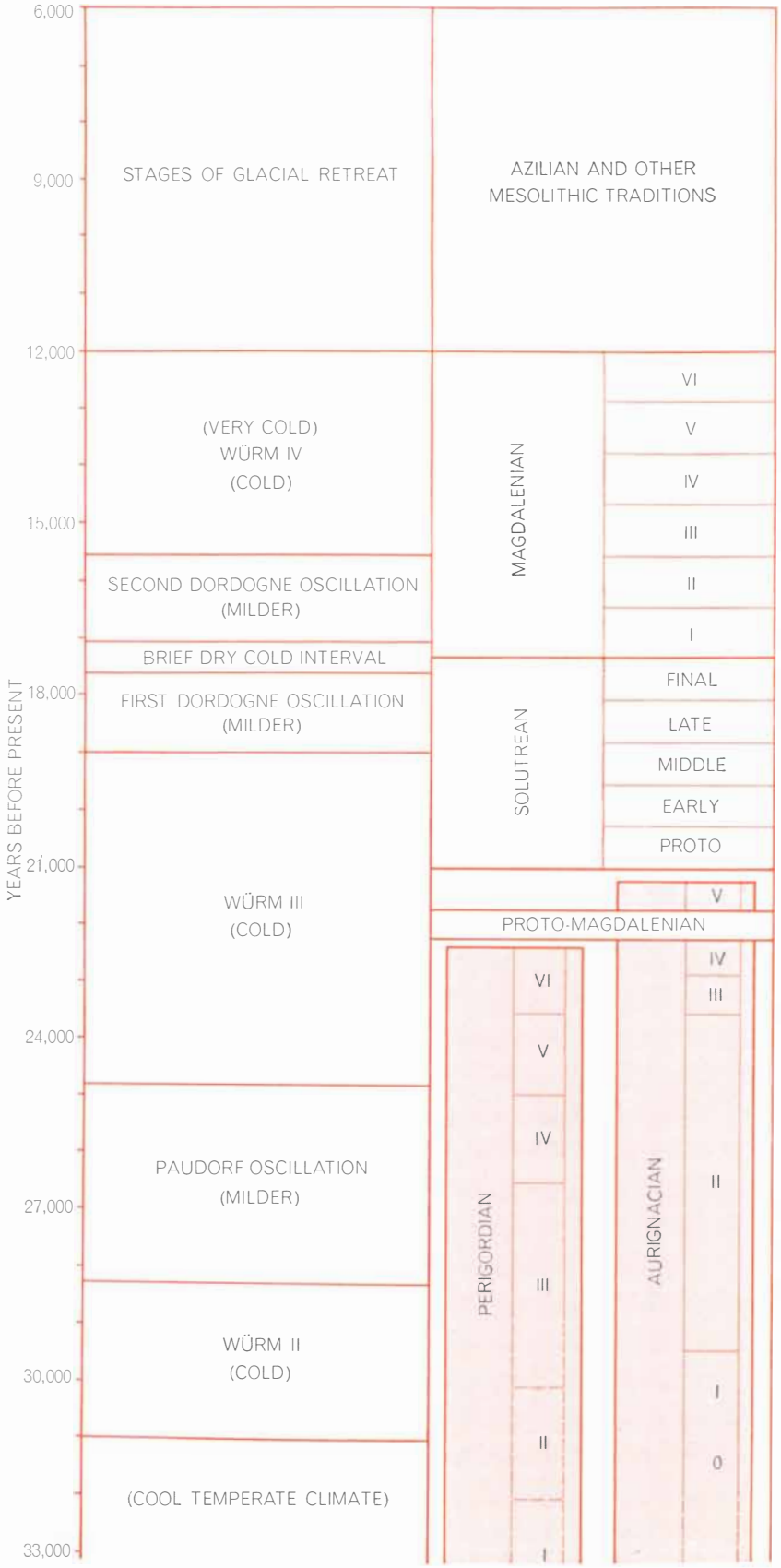
ognize today as the whole of the Upper Paleolithic. In addition, at Laugerie-Haute they excavated examples of three distinctive Solutrean flint tools: the laurel-leaf blade, the willow-leaf blade and the shouldered point [*see illustration on page 91*].

Lartet and Christy recognized that the exquisite flat flaking of these artifacts was unique, and they christened them the "industry of Laugerie-Haute." This might be the name of the Solutrean culture today except for the fact that other important Upper Paleolithic finds were made at nearby Laugerie-Basse. To avoid confusion prehistorians named the Laugerie-Haute industry after Solutré, a site in eastern France where the same distinctive stone tools were found a few years later.

There were several questions that new excavations at Laugerie-Haute could help to answer. One was that even after 100 years there is little real agreement among prehistorians as to what the Solutrean industry really represents. Some believe, as they do of other Upper Paleolithic cultures, that the Solutrean is merely the grafting of a few foreign ideas onto already existing traditions. Others visualize an invasion of western Europe by groups armed with superior weapons who absorbed or eliminated the earlier inhabitants until they in turn were absorbed or eliminated by the people of the later Magdalenian culture. Finally, still other prehistorians deny both of these hypotheses and assert that the Solutrean culture evolved indigenously in western Europe from one or another of the immediately preceding traditions.

In the past there has been a tendency to overemphasize the exotic and spectacular among Solutrean artifacts, particularly the leaf-shaped blades and the elegantly made projectile points, and to ignore the rest of the Solutrean tool kit: ordinary implements such as burins for engraving and incising, scrapers, perforators and other such tools. Whether special tools were made locally or were introduced from outside is the kind of question that can be answered only by statistical analysis. For this, it is not enough merely to distinguish the major "periods" of a culture. For example, the period named *Solutréen inférieur* in France (and here called early Solutrean) shows five distinct strata at Laugerie-Haute. Careful dissection of these microlayers—each of which may correspond to a separate human occupation of the site—is a prerequisite for sound statistical conclusions.

I began my work in April, 1959, with



UPPER PALEOLITHIC PERIOD had its inception in western Europe some 32,000 years ago, at a time of retreating ice. The first Solutrean-style tools appeared 11,000 years later, near the end of a cold period. During the next 4,000 years Solutrean culture dominated southwestern France and offshoots appeared in the Iberian Peninsula. It was succeeded some 17,000 years ago by the final Upper Paleolithic culture: the art-rich Magdalenian.

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the following questions in mind. Is the Solutrean a continuum with each phase evolving indigenously into the next, or does each phase reflect new stimuli from elsewhere? What clues do the earliest Solutrean levels provide to even earlier ancestral periods? And what was happening at the end of Solutrean times just before the Solutrean culture was replaced by the Magdalenian?

The Laugerie-Haute rock-shelter stretches for about 50 meters under the limestone cliffs bordering the Vézère River. Today the house of the curator of the Museum of Prehistory at Les Eyzies is built directly over the middle of the site, so that excavating is restricted to the east and west ends. The shelter was inhabited for several thousand years before Solutrean times by people using Perigordian, proto-Magdalenian and Aurignacian tools. After the final Aurignacian occupation there was a short interval during a period of very cold climate when the site and perhaps the whole region was deserted.

LAUREL-LEAF BLADE is an example of the remarkable capacity for working in stone that characterizes Solutrean culture.

This hiatus at Laugerie-Haute is marked by a thick layer of limestone fragments that had fallen from the roof and sides of the shelter. The layer contains no trace of human occupation. Lying directly on this sterile rubble in one small area of the site is a stratum that can be considered proto-Solutrean. The artifacts possess many of the characteristics of later Solutrean assemblages but in a rudimentary form. Very fine, flat flaking is evident on certain flint tools, and a large number of flint blades show the secondary flaking that is called retouching.

Of particular importance are the tools known as unifacial points. These are blades of flint with one surface fully or partially retouched by flat flaking and with the base often chipped to a narrower width as if for mounting on a shaft or handle. The exact use to which these unifacial points were put is unknown. The important thing is that in this proto-Solutrean stratum they are already present but in a form that is heavier and thicker than that in later levels.

There is no doubt that this bottom layer is the earliest evidence of the Solutrean industry in the Les Eyzies region. It probably dates back to somewhere between 21,000 and 22,000 years ago. The proto-Solutrean occupation at Laugerie-Haute seems to have been no more than a brief encampment by a visiting group. The only other site in southwestern France that has yielded a similar assemblage of tools is some 30 kilometers away at Badegoule.

Above this lowest Solutrean stratum there is another short hiatus and then a sequence of five levels, all of which can be classed as early Solutrean. Charcoal from one of these levels gave a radiocarbon date of 18,700 B.C. The discovery of these five strata has allowed a finer subdivision of the early Solutrean than was hitherto possible. The period proves to have evolved by stages from a rather archaic assemblage not much different from proto-Solutrean at the bottom to an uppermost level that is on the point of transforming itself into middle Solutrean. The characteristic unifacial points become finer and more carefully retouched until, in the final early Solutrean level, the more archaic types disappear and the retouching invades much of the opposite face of the blade. The statistical distribution of other tool types similarly approaches the values typical of the middle Solutrean.

The next strata at Laugerie-Haute belong to the middle Solutrean and consist of at least four layers. In the earliest of these the only real difference from the final early Solutrean lies in the timid appearance of a very few laurel-leaf blades. These elegant implements make up scarcely 3 percent of the total flint inventory, but their appearance may be said to have been heralded by the increasing popularity of bifacial workmanship on the unifacial points in the immediately preceding strata.

In the next three middle-Solutrean levels these laurel leaves increase in numbers and variety and the unifacial points decline proportionately. Flat retouching now becomes an extremely popular flintworking technique. In succeeding strata the Solutrean craftsmen show an amazing flair for experimenting with the forms of the laurel leaves. Some are tiny and delicate; others are long and thick. Many are long and slender, and the retouching consists of fine parallel flaking. Some have such thin cross sections that it is difficult to imagine how they could have served any utilitarian purpose. Indeed, they may have been showpieces and luxury items. This same extravagance is reflected in many bizarre bifacial tools that exhibit notches, stems and asymmetrical shapes [*see illustration on page 93*].

A count of the laurel-leaf blades found in successive Solutrean levels at Laugerie-Haute shows them to have been scarce at the lowest levels of the middle Solutrean, then increasingly abundant and finally constituting a fourth of all stone tools by the end of that period [*see illustration on opposite page*]. It has already been noted that a lengthy evolution of bifacial retouching techniques preceded the first appearance of the laurel leaves. Both facts favor the conclusion that these seemingly exotic tools are the result of local evolution rather than an explosive invasion of either new peoples or new ideas.

It is not known exactly how long the middle Solutrean lasted—probably not more than 1,000 years at the most—but

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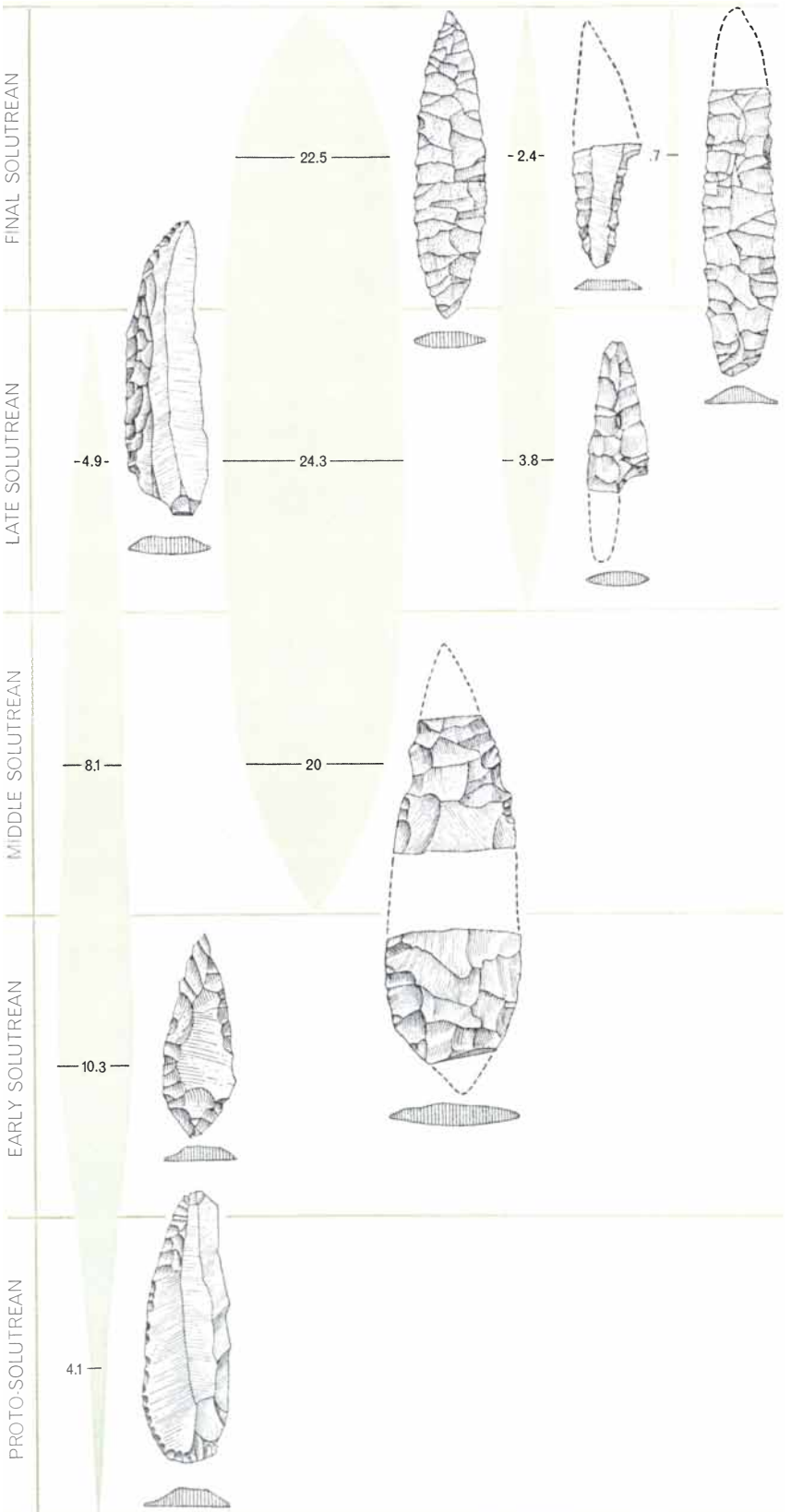
in its uppermost strata there is evidence that new ideas were being introduced or pioneered. Very small flint blades appear, their backs blunted by retouching, perhaps to make them fit into slots in wooden or bone shafts. Equally tiny scrapers are found. Another introduction or invention at the end of this period is the "single-shouldered" point [*see illustration at right*]. Thus, much as in the transition from the early to the middle Solutrean, the top levels of the middle Solutrean grade almost imperceptibly into the next division, the late Solutrean.

At Laugerie-Haute there are four strata that can be assigned to the late Solutrean. One key artifact that marks these layers is an increasingly sophisticated version of the single-shouldered point, which grows longer and shows more elaborate bifacial retouching from layer to layer. In contrast, the unifacial point of the proto-Solutrean and early Solutrean levels has now almost disappeared. The laurel leaves continue, and although they diminish in number and size they exhibit increasingly fine workmanship. Meanwhile a new kind of blade—the willow leaf, with rounded ends and delicate retouching on one face only—is found.

In the middle strata of the late Solutrean at Laugerie-Haute a very practical invention makes its first known appearance: the eyed needle made of bone. This seems to have been a Solutrean innovation; although bone needles are common in the Magdalenian strata that follow, none have been found in earlier Upper Paleolithic levels. The needle eyes are sometimes quite small, and it is a safe supposition that these implements were used for fine stitching or to produce fitted clothing.

Toward the end of the Solutrean period a curious change is evident. In contrast with the thick and rich deposits of earlier age, the sites of human occupation both at Laugerie-Haute and elsewhere in France become thin, restricted in area and impoverished in tools. There seems good reason to suppose that by this time the population of the Dordogne was composed of much smaller or more nomadic bands than before. These bands may even have been single families. Certainly they remained at each site for a shorter time. This phenomenon may be related to the unusually mild climate in the late Solutrean, which may have made the game animals scarcer.

A recent analysis of the strata at Laugerie-Haute has shown that at the



FOUR KEY STONE TOOLS appeared during successive Solutrean periods. Unifacial points (flaked on one surface only) are found at Laugerie-Haute from proto-Solutrean through late Solutrean times. They total 10.3 percent of all tools found in the early Solutrean period. Next to appear are laurel-leaf blades, which account for a fourth of all late Solutrean tools found at Laugerie-Haute. The shouldered point is unknown before the late Solutrean. Last of all to appear at Laugerie-Haute are the exquisitely flaked willow-leaf blades. These number less than 1 percent of the tool inventory in the final Solutrean period.

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very end of the Solutrean a cold, dry spell struck southern France. This climatic change was brief: it lasted only into the earliest Magdalenian times. It is not yet possible to say whether the preceding mild period, the cold snap or a combination of both was responsible for the disappearance of the Solutrean culture from the Dordogne. In other regions the Solutrean may have lasted longer, but at Laugerie-Haute it was suddenly succeeded by an early Magdalenian industry.

There are as yet no radiocarbon dates for the end of the Solutrean at Laugerie-Haute, but somewhere around 17,000 years ago is probably not far off. Elsewhere, perhaps, there were contacts of some kind between the final Solutrean and the early Magdalenian; the Magdalenian industry not only possesses eyed needles but also shares with the Solutrean the production of carved stone bas-reliefs. There was no such contact at Laugerie-Haute, however. The rock-shelter had already been deserted before the 5,000 years of Magdalenian occupation began.

During the middle and late Solutrean the population of southwestern France was expanding into surrounding areas. A factor in these migrations may have been the mild climate of the period. To judge by widespread finds, some groups equipped with Solutrean techniques not only occupied sites near the Pyrenees but also spilled over into Spain. The Spanish Solutrean is in some ways distinct from the French, marked by characteristic versions of bifacial blades and stemmed and barbed points.

The expansion was not exclusively to the south; middle Solutrean industries are also found in central France, north of the Loire and almost into Brittany. The Solutrean of this period apparently never reached the Paris basin or the open lands of Belgium and Britain, which was then attached to the Continent. One thriving colony far to the east, however, was the site of Solutré itself in the Rhône valley not far from Lyons. The curious thing about this open-air site, which was discovered in 1866, is that it is the only scene of Solutrean occupation in all that region; if other occupation sites exist, they have yet to be found. In 1873 an isolated cache of 17 very large laurel-leaf blades was found by canal diggers at Volgu, about 50 kilometers west of Solutré, but this hoard was not associated with an occupation site.

After nearly a century of digging at Solutré, there is still no clear knowledge of the length of time the site was occupied or how it ties in chronologically with the Solutrean of other regions. Yet it is clear that Solutré was by no means the scene of a brief encampment far from some home base. It is a large occupation area that shows two thick and quite separate levels: a middle Solutrean (which corresponds roughly to the middle Solutrean of the Dordogne region) and a later stage. These later strata do not contain the shouldered points, willow-leaf blades or eyed needles typical of the Dordogne; instead they show a local specialization in laurel-leaf blades. Certainly this famous site deserves further investigation.

Combining the specific knowledge gained at Laugerie-Haute with more general information about the Solutrean obtained elsewhere, what can be said in summary about this short-lived Upper Paleolithic culture? First and most important is the fact that the Solutrean does not differ fundamentally from other hunting cultures of western Europe. Almost all Upper Paleolithic peoples were skilled hunters adapted to a rigorous cold environment and living in rock shelters, caves and open-air settlements. They had many kinds of stone implements in common, some of them "secondary" tools intended for fashioning other artifacts in bone, antler, ivory and wood. The ordinary Solutrean tool kit—stone, bone and antler—was not particularly different from that of other hunters. The Solutrean

SITE OF SOLUTRÉ, near Lyons in eastern France, gave the distinctive Upper Paleolithic culture its name. Most Solutrean sites are located in rock-shelters. Solutré, however, was an open-air encampment below a steep precipice. It contains two distinct levels. The earliest one resembles the middle Solutrean of the Dordogne, but the later level shows a local specialization in big blade tools.

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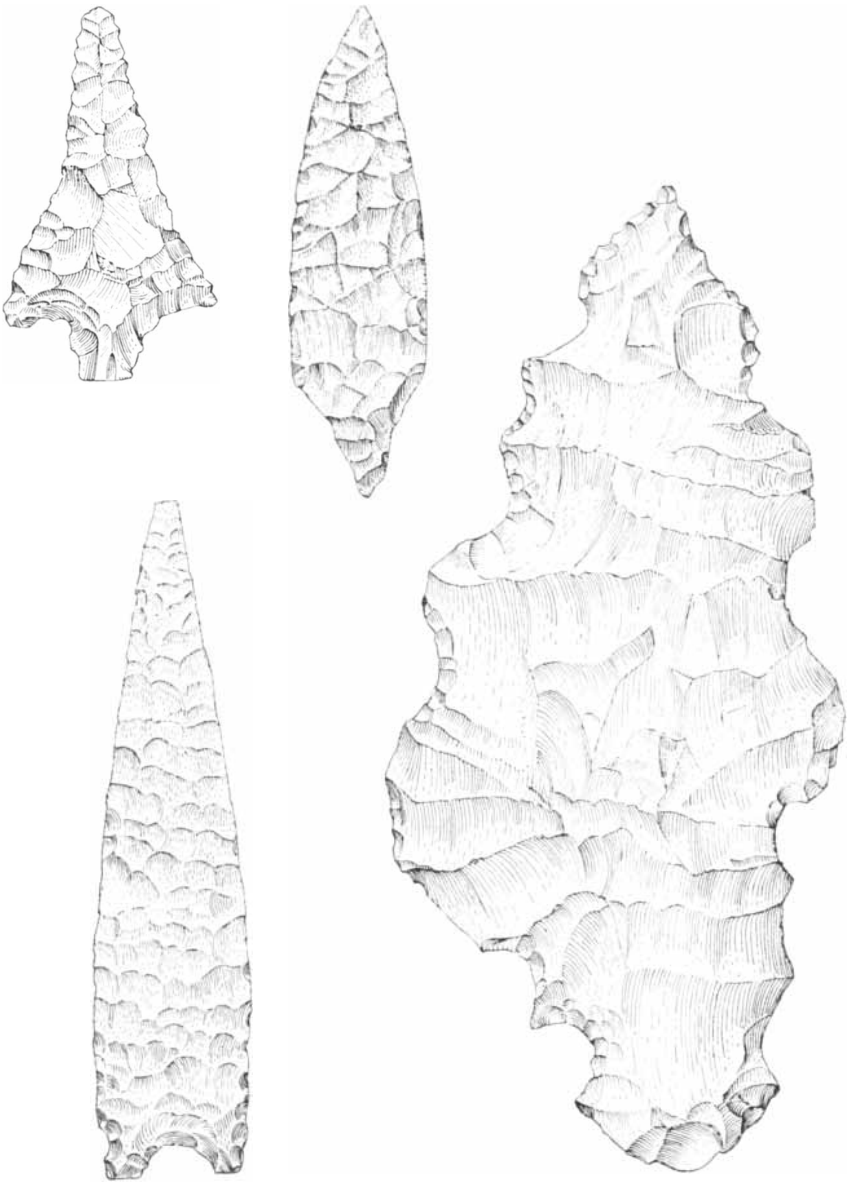
subsistence pattern was founded, as was that of the other cultures, on the hunting of large game animals. At Laugerie-Haute more than 90 percent of the animal bones in Solutrean strata belong to reindeer, but horses, wild cattle, ibex and occasionally mammoth and musk-ox were also prey. The bones of salmon and other fishes are sometimes found; at one Solutrean site in Spain hares were the principal game.

Like most other Upper Paleolithic cultures, the Solutrean left an abundance of personal decorations. There are bone and ivory pendants, beads and bracelets: long bone pins with notches may possibly have been used in hair arrangement. Red, yellow and black pigments, found in some sites, could indicate the custom of body or face painting.

For many years it was thought that the Solutrean culture was unlike other Upper Paleolithic cultures of western Europe because it was almost without art. In due course Solutrean decorative work in bone and antler was recognized, but the experts still denied the culture either paintings or sculpture. Then the discovery of Solutrean stone friezes and bas-reliefs added sculpture to the cultural repertoire [*see illustration on page* 87]. Finally, in the 1930's the discovery of paintings on plaques of stone buried in Solutrean strata at the cave of Parpalló in eastern Spain filled the final gap in the artistic inventory. Moreover, associated with early Solutrean remains in the lower valley of the Rhône are paintings and engravings on cave walls that show mammoths, bears and horses in a distinctive style. A case might also be made for viewing the remarkable Solutrean work in flint as a product of some basic Upper Paleolithic artistic drive. In some Solutrean sites, particularly the later ones, the number of such specialized decorative artifacts as laurel leaves and willow leaves reaches amazing proportions—sometimes approaching 50 percent of all stone implements.



VIRTUOSO FLAKING characterizes four unusual Solutrean tools (*reproduced full-size*). The large bifacial blade (*lower left*) has its base chipped into a neat semicircle. The point (*upper left*) shows two such basal semicircles. At center a small laurel-leaf blade has been given a stemmed base. What use the asymmetrical form (*right*) served is conjectural.

How, then, does the Solutrean differ from the other Upper Paleolithic traditions in western Europe? In the first place, its geographical range is surprisingly limited compared with such cultures as the Aurignacian that preceded it or the Magdalenian that followed it. This fact may be related to the culture's relatively short lifetime—a matter of little more than 4,000 years. Negative evidence is perhaps less persuasive, yet the absence of the "Venuses"—female figurines—that are characteristic of other Upper Paleolithic traditions may indicate a distinctive set of Solutrean beliefs or values. The lack of deliberate burials may point in the same direction.

But it is in flintworking techniques that the Solutrean is unique. The passion for fine, flat retouching extended beyond specialized blades and points to many commonplace tools. Moreover, the Solutrean abounds in artifacts not only of flint but also of fine-grained and brightly colored quartzes, jaspers and other fancy stones. Finally, wherever the Solutrean is found there are, in spite of variations due to time or place, quantitative and morphological consistencies in these stone tools. The proportion of the specialized blades and points is high; the proportion of burins and ordinary blades is low; the proportion of scrapers and perforators is in between. It is this statistical consistency, together with an emphasis on fine retouching and imaginative forms, that gives the Solutrean its distinctive "personality."

Where did the Solutrean culture originate? One school of prehistorians believed it was born in Hungary, where large bifacial flints resembling the laurel-leaf blades have been found, and then expanded across Central Europe to develop into the classic Solutrean of France and Spain. Another school has suggested that its origins lie in a North

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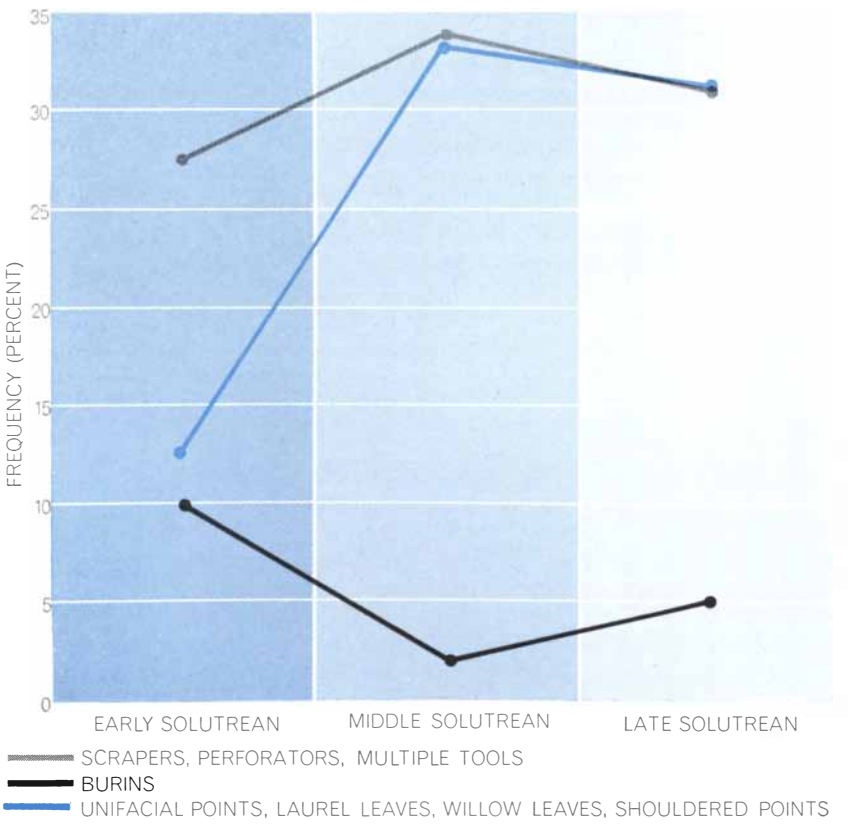
African stone-tool industry: the Aterian, which possesses not only bifacial blades but also tanged points that resemble those of the late Solutrean in eastern Spain. The same flaw mars both arguments; each implies that when the Solutrean culture first reached France, it already possessed laurel-leaf blades. The two earliest Solutrean periods in France have no laurel leaves and yet they are fully set in the Solutrean tradition. Therefore few prehistorians any longer believe that there are links between the Solutrean and cultures of eastern Europe or North Africa.

What about the possibility of an indigenous evolution of Solutrean culture from some preceding tradition in western Europe itself? Spain can be ruled out as a birthplace; the earliest levels known there contain an already well-developed middle Solutrean apparently derived from France. As for France itself, some interesting suggestions have come out of the ground in recent years.

The proto-Solutrean at Laugerie-Haute and at two other French sites is the earliest Solutrean identified so far. Any postulated ancestral Solutrean should therefore show certain affinities with proto-Solutrean. In the past decade some curious industries have been found in the lower valley of the Rhône, which is in eastern France. They are earlier in date than the Solutrean of the Dordogne. There are unifacially retouched blades and flakes very reminiscent of the proto-Solutrean; many of the other implements could fit well enough into an early Solutrean tool kit. Ancestral Solutrean may therefore have crystallized in the lower Rhône valley and then branched out, in the form of the proto-Solutrean culture, not only to southwestern France but also to the north. There the site of Le Trilobite in the Yonne valley has yielded suggestions of proto-Solutrean culture. Other possible traces of proto-Solutrean remains are found in northern France, in Belgium and even in Britain.

Why it was that the main Solutrean development took place only in southwestern France remains an unanswered question that only further fieldwork can solve. One fact, however, now seems established: It is no longer necessary to go outside western Europe or indeed outside France itself to locate the birthplace of the Solutrean culture.



CONSISTENCY of the Solutrean culture is evident in the quantities of different types of tool. During three successive periods the engraving and chiseling tools called burins never exceeded 10 percent of the stone-tool inventory at Laugerie-Haute. The number of scrapers, perforators and multiple tools at the site, in turn, remained consistently at a higher level. Only the four typically Solutrean blade tools showed a significant quantitative increase.

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LAURIE M. BROWN, in Physics Today, April 1964

Gonadotropins

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Proceedings of the Sixth Animal Reproduction Symposium, August 13, 1963, Oregon State University, Corvallis

Edited by H. H. Cole, *University of California, Davis*

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This recently published volume is the best single source of new information on gonadotropins, the group of hormones controlling the development and functioning of the gonads. Its publication is particularly timely in view of the growing use of natural and synthetic steroids to control reproductive activities, because these steroids work largely by influencing the secretion of gonadotropins. Workers in physiology, endocrinology, zoology, and biochemistry will find it a useful and up-to-date reference.

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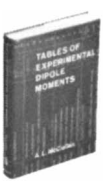

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MATHEMATICAL GAMES

Concerning several magic tricks based on mathematical principles

by Martin Gardner

Magic tricks that operate wholly or in part by mathematical principles fascinate a large segment of the conjuring fraternity. Dozens of such tricks are published every year in periodicals on magic or circulate from magician to magician, only occasionally finding their way into mathematical circles. Royal V. Heath's *Mathemagic* (1933) was the first book in this hybrid field. My own *Mathematics, Magic and Mystery* (1956) was the second. Last month Scribner's brought out a third: *Mathematical Magic*, by William Simon, who is president of a New Jersey firm that makes brake linings and also one of the country's most knowledgeable card experts.

Most of the items in Simon's fine collection will be unfamiliar to devotees of recreational mathematics. An example is a bewildering mind-reading trick discussed in the book's chapter on mental magic. Invented by Robert Hummer, a magician now living in Havre de Grace, Md., this trick is not only an entertaining parlor stunt but also such a puzzling exercise in logic that many magicians who regularly perform the trick are not sure themselves just why it works.

One of the best presentations is as follows. Three identical coffee cups are inverted in a row on a table. The positions (not the cups) are assumed to be one, two and three as seen by the spectators [*see illustration below*]. The magician, standing across the room with his back to the table, asks that a spectator conceal a small object, say a matchbook, under any one of the cups. The spectator now scrambles the positions of the cups by exchanging them in pairs, calling out each time the positions of the two cups involved. In making these exchanges the cups are slid across the table, so that if the cup covers the object, the object slides along with the cup. For example, suppose the matchbook is placed under the middle cup. If the spectator switches the end cups, he calls out, "One and three." If he next switches the two cups on his left, he calls out, "One and two." As these cups are slid the matchbook is carried along with its cup from position two to position one. The spectator continues to switch pairs of cups as long as he wishes. The magician then turns around and immediately lifts the cup covering the matchbook. The trick can be repeated many times. Since the performer is never told which cup the object was placed under initially, how does he guess correctly?

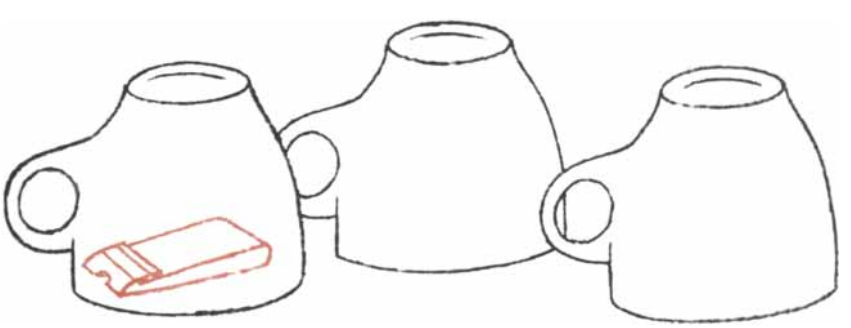
The method is simple and subtle. Although the three cups are alike, it is impossible for them to be *exactly* alike. Inspect any three cups carefully and you are sure to find some tiny distinguishing feature—a small chip, a discoloration, and so on—on one of them. Before you turn your back note the position of this marked cup. After the matchbook has been placed under a cup explain the switching procedure to the spectator, then ask him to make a practice switch by exchanging the two *empty* cups. Caution him not to tell you the two positions, since that would give away the location of the matchbook. This practice switch seems to have no bearing whatever on the trick; in fact, spectators usually forget it was even made. Actually it is the key to the trick, for a reason that I shall ask you to deduce.

As the spectator proceeds with his switching, calling out the positions of the cups involved in each switch, you must secretly keep track of one cup by using your left fingers as a computer. The first, second and third fingers represent positions one, two and three. Start with the tip of your left thumb pressed against the tip of the finger that indicates the initial position of the marked cup. You do not know, of course, if the marked cup is still in that position, but you assume that it is. Suppose that at the start this cup was in the middle. Your thumb is touching your second finger. If he calls one and two, move your thumb from the second to the first finger. If he next calls one and three, shift to the third finger. If he now calls one and two, you do not move your thumb because the position of the cup you are following is not involved in the exchange. When the spectator decides to stop, let us say your thumb is touching your third finger.

Turn around and inspect the cups. If the marked cup is at position three, where your thumb says it should be, you know that this cup covers the matchbook. If the marked cup is not at position three, the object will be under the *unmarked* cup that is *not* at position three. (Can you explain why?)

Some magicians carry an artificial eye in their pocket to use in this trick. The performer uses the eye as the object placed under one of the cups; he can then encourage the inference that the eye is somehow able to provide him with a clue to its own whereabouts. The eye also furnishes an excuse for amusing chatter. The magician can say: "Yes, I see the evil eye staring at me from inside *this* cup...."

Harry Lorayne, a New York City mnemonics expert (well known in entertainment circles for his sensational memory act), devised the following variation in which three objects are used



Hummer's three-cup trick

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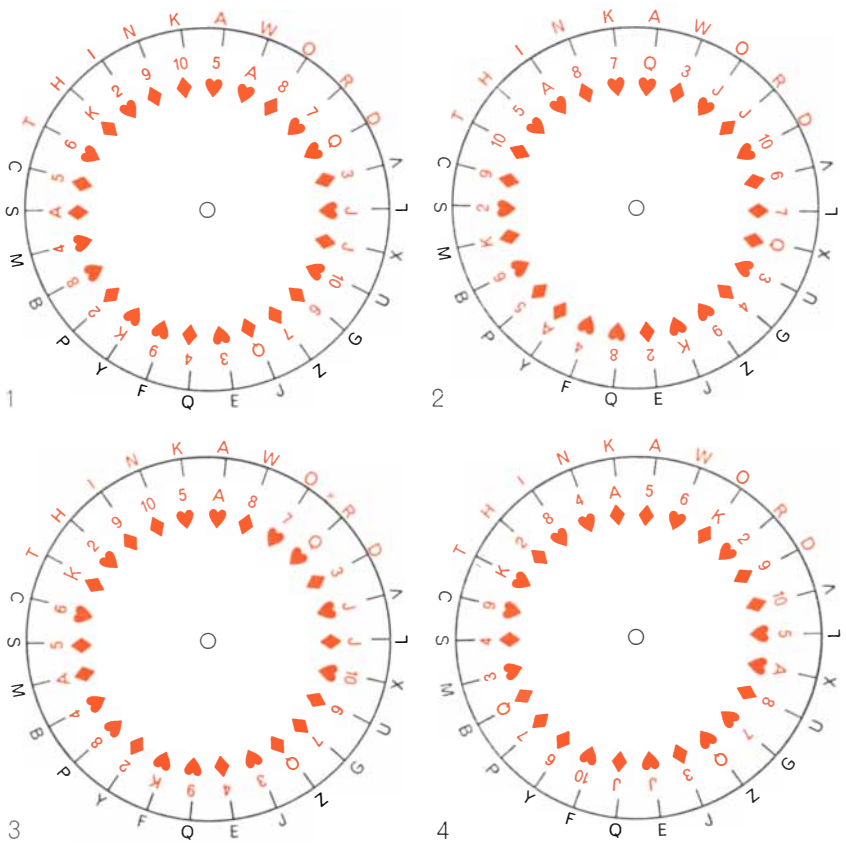
instead of cups, and the magician is able to name the thought-of object without turning around. Three different objects—say a coin, a matchbook and a finger ring—are placed in a row and someone is asked to think of one of them. He must also be able to recall the order of the objects, or else he should jot it down for future reference. The performer turns his back and calls for a practice switch with the two objects the spectator did *not* think of. In this instance the spectator does not say what switch he has made. The trick then continues as with the three cups, the spectator making exchanges and calling out positions. When he finishes, the performer asks if the objects are by any chance back in their original order. If not, the spectator makes the one or two additional switches needed to restore this order. These exchanges are called out as before. The performer seems to have no relevant information—the objects have merely been switched around and brought back to their initial state—yet he can name the thought-of object *without turning around.*

The method: Memorize the initial order. Pick any object and follow it with your thumb. You will not know, of course, whether or not that object remained in its original position after the practice exchange. Nonetheless, after the original order has been restored, if your thumb indicates that the object you are following is back in its former position, you know that it is the chosen object. Otherwise the selected object is the one at the position represented neither by where your thumb started nor where it ended. Again can you explain why?

Before writing this article I got in touch with Hummer and obtained his permission to describe another of his curious mind-reading tricks, here explained in print for the first time. The trick uses a cardboard circle attached to a sheet of cardboard by a paper fastener through the center. On the rim of the circle, in any order, are inscribed the values of the 26 red playing cards. Outside the circle, on the backing sheet, are the 26 letters of the alphabet. They too may be in any order, but Hummer arranges them as shown on this page so that the 10 letters at the top spell "Think a word."

A spectator is asked to think of any word, preferably a short word of four or five letters. He also thinks of any red card. While the magician turns his back, the spectator rotates the wheel until his chosen card indicates the first letter of his word. The magician turns around, glances quickly at the dial, then turns his back again while the spectator moves the wheel so that his card points to the second letter of his word. Again the magician glances at the dial. Obviously he does not know the spectator's card, so the dial would seem to give him no useful information. This procedure is repeated until the entire word is spelled. The magician, after appearing to concentrate for a moment, names both the word and the card.



The "Think a word" trick

A mathematician working with combinatorial mathematics, or a person skilled in cryptography, should have little difficulty devising a method for performing the wheel trick. For others I give it as a puzzle to be answered next month. The four positions of the dial in the illustration above are typical of what the performer may see during the spelling of a four-letter word. What word is being spelled there? It is not hard to find the word by the laborious procedure of testing each of the 26 red cards, but the problem is to devise a method that will enable the performer to name the word in a few seconds after seeing the dial's final position.

One of the best of many mathematical tricks invented by Jack Yates, a British magician, is his 12-penny trick, explained by Simon in a chapter on tricks with ordinary objects. The 12 pennies are arranged heads up in a circle to indicate the 12 hours on a clock. The penny at 12 o'clock is marked with a key as shown in the illustration on the next page. While the performer's back is turned someone is asked to turn over any six coins. The magician, keeping his back turned, now gives directions for six more reversals. These are likely to involve some of the pennies reversed by the spectator; that is, some pennies turned tails up by the first six reversals may get turned back to heads by the second six reversals.

"How many heads are now showing?" the magician asks.

Suppose he is told: "There are two heads." Obviously the performer has no way of knowing which coins are heads and which are tails. Yet he is able to give directions for dividing the coins into two sets of six coins each so that the number of heads (and tails) in each set is the same. In this case each set would have one head and five tails.

Surprisingly the performer does not

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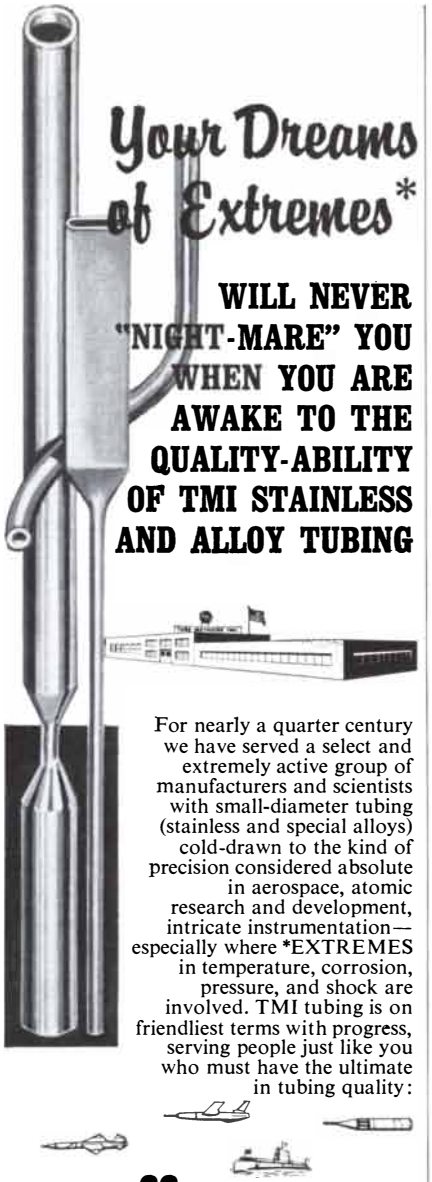


need to be told the number of heads showing, but his asking for the information throws spectators off the track of a solution of the trick. When he directs the reversal of six coins, he may pick any six he wishes, but he must remember their numbers. For example, he may ask for the reversal of coins one, four, five, eight, nine and 10. To divide the coins properly into the two final sets he asks that the following six coins be slid to one side: two, three, six, seven, 11 and 12. These are merely the six that are not in the previous set. (In set theory they are said to form the "complement" of the previous set.) To disguise the nature of this second set the performer directs their removal in pairs indicated by the hour of day. Instead of saying coins two and three, for instance, he says: "Please slide to one side the coins that mark ten minutes past three."

The principles of set theory exploited in this trick are the basis for numerous card tricks. The following, contributed by the British magician Norman MacCleod to a magic journal in 1955, is one of the best. While someone deals the deck into four bridge hands the performer writes on a slip of paper: "There will be 22 face-up cards." This prediction is folded and placed aside. A spectator takes two of the piles, the magician takes the other two.

"I have selected a number from one to ten," says the performer. "I shall turn that number of cards face up in each of my piles." He proceeds to turn some cards face up but without letting anyone see how many.

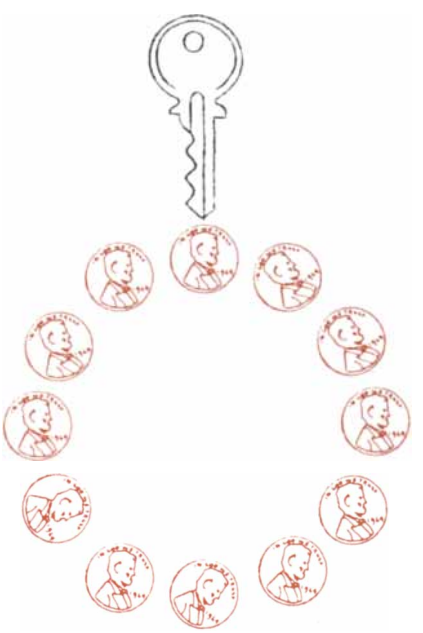
The spectator is asked to do the same with his two piles: choose a number from one to 10 and reverse that number of cards in each pile. The four piles are assembled, the deck spread and the face-up cards counted. There are 22. The prediction is unfolded and found to be correct.

To perform this trick you must cheat a bit. Any even number between 13 and 39 can be written in your prediction. This number, minus 13, tells you the total number of cards to leave *face down* in your two packets. In this case 22 minus 13 is nine, so you reverse, say, all but five cards in one pile and all but four in the other. Put your two piles together and one of the spectator's piles on top. Hold this large packet in your left hand and ask the spectator to cut his remaining pile into two parts. While attention is focused on the cutting casually turn over your left hand, thus secretly reversing all its cards. This large pile is sandwiched between the two halves of the cut pile.

All the cards are now together again and presumably no one knows how many of them are face up. Do you see why there must be 22? The procedure reverses 13 cards in the spectator's two piles for the same reason that Yates's coin trick works. The nine cards you left face down are now face up, making 22 in all. The trick can be repeated using other even numbers in the prediction. Odd numbers should be avoided because the procedure, if it is done legitimately, could not produce an odd number of face-up cards.

The magic linking and unlinking of rings can, if one stretches the term a bit, be regarded as topological effects. I have space for one quick trick, invented by William Bowman, a Seattle magician, and described in Simon's chapter on topological magic. Attach two paper clips to a $1 bill in the manner shown in the top illustration on the opposite page. If the bill is held at the ends and pulled flat, the clips pop off the bill *linked together*. (The linking is puzzling enough, but why do the clips hop from the bill with such force?) Simon has a story of young love to provide patter for all this, but I prefer to have the spectator hold the bill so that the clips point down. When the bill is pulled flat, the clips drop to the floor. Bet even money they will fall within one inch of each other. Of course you can't lose.

Another new book of great interest



Yates's 12-penny trick

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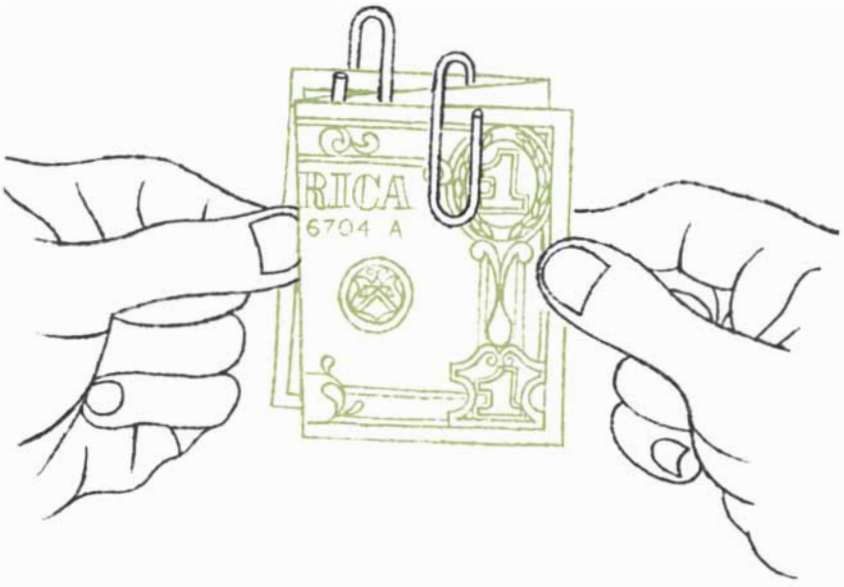
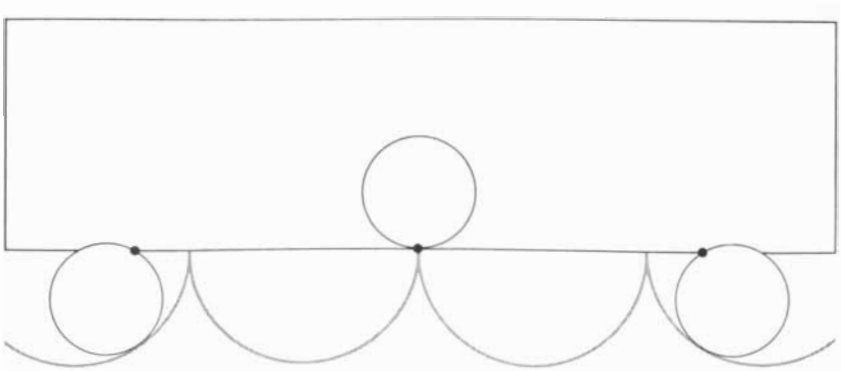


Bowman's bill trick

to recreational mathematicians is Harry Lindgren's *Geometric Dissections,* published by Van Nostrand in May. Readers may recall that this department in November, 1961, discussed the art of cutting a given polygon into a minimum number of pieces that could be rearranged to make another given polygon. Lindgren, who lives in Canberra, Australia, is the world's leading expert on this elegant branch of recreational geometry, and his book is the first to be devoted exclusively to the topic. It is a rich compendium of all that has been done so far in this field. Some of the author's recent achievements are almost unbelievable until you see them, and he has given an invaluable account of the ingenious methods by which he searches for minimum patterns.

I regretfully report that *Recreational Mathematics Magazine,* which concerned itself with puzzles and games, has ceased publication after 14 issues. *The Fibonacci Quarterly,* devoted to the study of Fibonacci numbers and other integers with special properties, is still flourishing after its seventh issue. Interested readers can obtain information from the editor, Brother U. Alfred, St. Mary's College of California, St. Mary's College, Calif.

Last month's problem concerned a train car with wheels attached to each axle at their circumference instead of their center. What kind of track will enable the car to travel without bobbing up and down? The illustration below supplies the surprising answer: a series of semicircles! If a circle is rolled inside a circular arc, points on its circumference generate what are called hypocycloids. When the radius of a semicircular track is twice that of the rolling circle, as it is here, the hypocycloid is a straight line.



Solution to last month's problem

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THE AMATEUR SCIENTIST

Extraction of growth-promoting substances from cantaloupe; tests with rolling balls

Conducted by C. L. Stong

Seven years ago Bernard O. Phinney and Charles A. West, respectively a botanist and a chemist at the University of California at Los Angeles, discovered that shoots of dwarf corn will grow to extraordinary heights if they are treated with extracts from the young seeds of beans, peas, lupine, wild cucumber and other plants. The effects of the extracts closely resemble those that are familiar to amateurs who apply commercial preparations of gibberellic acid (GA_3) to seedlings of various kinds. Chemical analysis has disclosed a close kinship between the seed extracts and gibberellic acid, one of the active ingredients of a disease-producing fungus that attacks rice plants. To date eight gibberellins in addition to gibberellic acid have been isolated and identified by British, Japanese and U.S. chemists. With the exception of gibberellic acid the new chemicals are not readily available for amateur experimentation, but they can be prepared in crude form at home. Richard C. Caggiano, a 14-year-old high school student of Mission Hills, Calif., recently made a series of experiments to learn if cantaloupes contain gibberellin-like substances. In addition to having a lot of fun, he walked off with first prize at several science fairs, acquired a supply of interesting chemicals directly from nature and simultaneously found that the cantaloupe does elaborate growth-promoting substances with gibberellin-like properties.

FRACTION (PERCENT)	ARITHMETIC MEAN	STANDARD ERROR
5	37.6	3.9
10	39.8	3.0
15	42.0	3.5
20	40.1	3.3
25	48.6	2.7
30	41.0	3.1
35	44.0	4.0
40	43.2	1.0
45	46.0	4.8
50	51.0	1.8
55	60.7	4.3
60	66.8	3.3
65	84.8	2.6
70	84.9	4.0
75	80.9	4.5
80	88.6	3.6
85	83.0	4.2
90	77.7	4.5
95	68.4	3.1
100 (FIRST)	65.8	3.0
100 (SECOND)	65.7	3.0
100 (THIRD)	63.0	2.9
CONTROL	55.8	3.2

Table of growth responses

"When you live in my part of California," writes Caggiano, "interest in the growth of plants comes easily. Nearly everything will grow here. Having hit on the idea of doing an experiment involving growth-promoting substances, I found that I could easily get lots of help and advice, particularly from Kenneth C. Jones of the Department of Botany and Plant Biochemistry at the University of California at Los Angeles.

"Since cantaloupe was available as a source of young seeds, I selected it for the experimental subject. Seeds were separated from enough melons to make about 200 grams, fresh weight. The seeds were chopped and then soaked for 24 hours in a 500-milliliter solution consisting of four parts of acetone and one part of water at a temperature of five degrees centigrade. The solution was poured from the seeds and the procedure was repeated twice. The three solutions were combined and the acetone was evaporated under vacuum at a temperature of 30 degrees C., leaving some 300 milliliters of water and the extracted materials from the seeds.

"This solution was then partitioned, a process involving the separation of acid, neutral and basic components. The *p*H, or acidity, was first measured by conventional techniques. The solution turned out to be somewhat acid. The *p*H was increased to 8 (slightly basic) by the addition of a few drops of weak potassium hydroxide solution. At this *p*H gibberellins are insoluble in ethyl acetate but soluble in water.

"The solution was then placed in a separatory funnel. Approximately 100 milliliters of ethyl acetate were added and the funnel was shaken for two minutes to mix the ingredients thoroughly. The water, being immiscible and denser than the ethyl acetate, settled to the bottom. The stopcock of the funnel was opened and the water was collected in a flask. The collected water was then similarly processed four more times. After each partitioning the ethyl acetate was discarded. The *p*H of the water solution was next decreased to 3 by the addition of sufficient hydrochloric acid. In this highly acid state the gibberellins are soluble in ethyl acetate. The acid solution was then partitioned with ethyl acetate. The water fraction was reextracted five times and the ethyl acetate fractions were combined to give a total of 500 milliliters of ethyl acetate solution. The solution was transferred to a beaker and evaporated overnight in a fume hood. A filmy residue of plant extract remained in the beaker.

"I then used a technique of elution chromatography to purify any possible gibberellins, or gibberellin-like substances, contained in the residue. The apparatus consists of a cylindrical glass funnel that has an inside diameter of 30 millimeters and is 45 millimeters high. The funnel plugs into a companion filtering flask below. The side arm of the filtering flask connects to a vacuum pump. The outlet of the funnel is closed with a plug material such as glass wool.

"I soaked four grams of a mixture of equal volumes of powdered carbon (Norit A, decolorizing carbon, neutral, prepared by the Fisher Scientific Company of Fair Lawn, N.J.) and Celite, an inert diatomaceous silica (prepared by Johns-Manville), for three and a half hours in a solution of one part of hydrochloric acid to 25 parts of distilled water (by volume).

"The carbon-Celite slurry was then poured into the chromatographic col-

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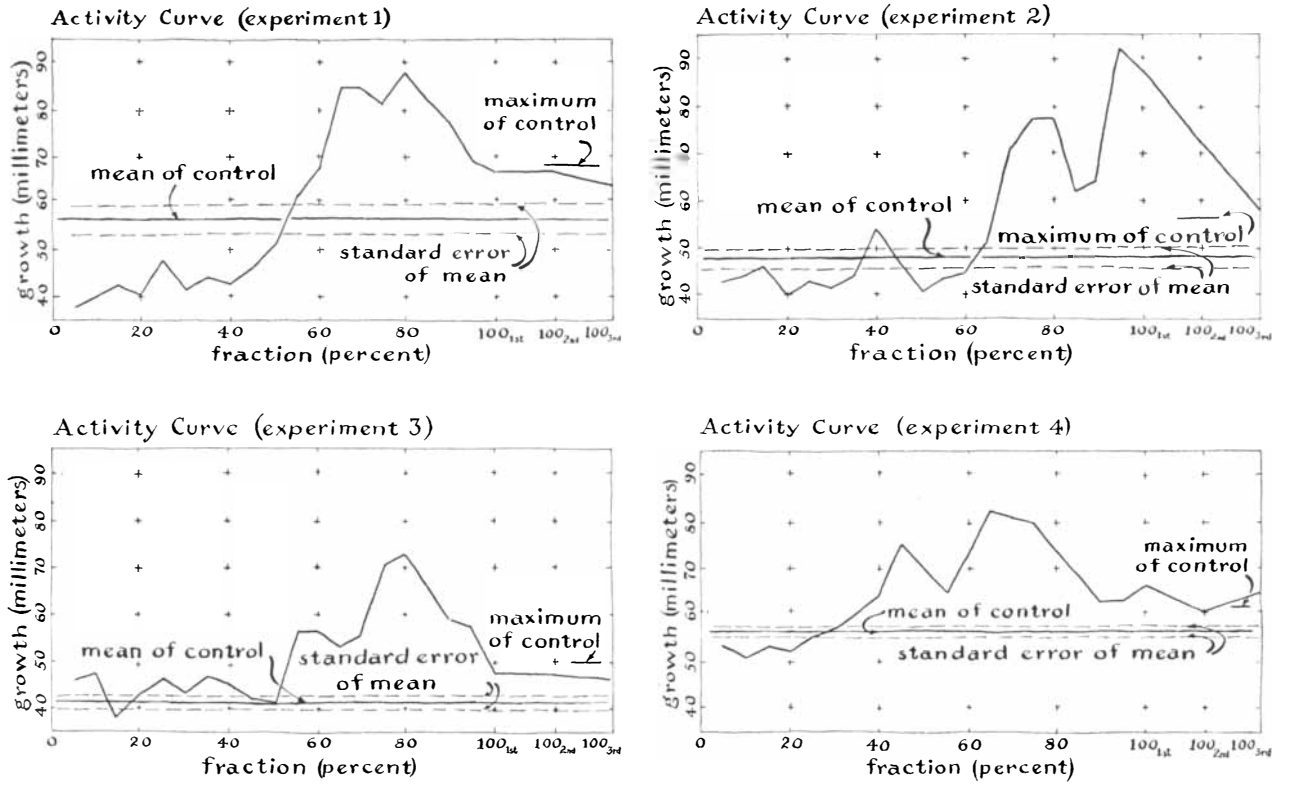
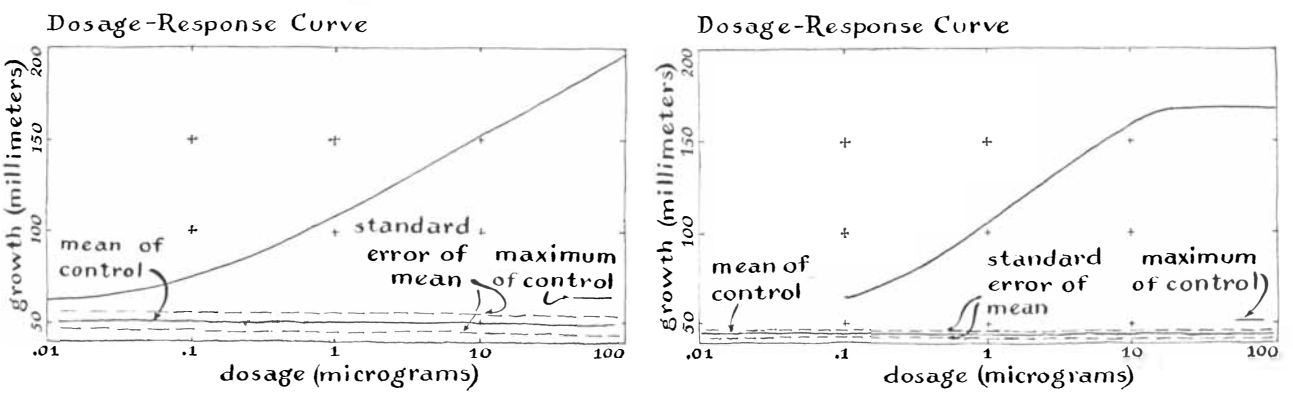


Results of four experiments on the response of seedlings to fractionated extracts of cantaloupe seeds.



Growth resulting from application of gibberellic acid to dwarf-5 seedlings (left) *and dwarf-1 seedlings* (right)

umn, and the mixture was washed three times with distilled water, which was removed by suction. After the third washing the water that had collected in the vacuum flask was discarded. Next I dissolved the plant extract in a 50-milliliter solution that was half acetone and half distilled water. The acetone was thereafter evaporated from the solution and enough water was added to increase the volume to 50 milliliters.

"That solution was added to the top of the chromatographic column and was passed through the carbon-Celite mixture by turning on the vacuum. Gibberellin-like substances adsorbed by the carbon-Celite mixture remain in the column but many of the other ingredients pass in solution to the flask below. This solution was discarded.

"The next procedure releases the growth-promoters from the column in controlled amounts. Twenty-one separate solutions of acetone and distilled water are made up in 10-milliliter units. The first unit consists of five parts of acetone by volume in 95 parts of water; the second, 10 parts of acetone in 90 parts of water; the third, 15 parts of acetone in 85 parts of water and so on in increasing increments of 5 percent acetone per unit to the 20th, which consists of 100 percent acetone, as does the 21st. Each unit of solution, beginning with the 5 percent acetone, is washed through the column consecutively and collected separately. The 21 separate fractions are then labeled and placed under a fume hood for evaporation to dryness. Each of the dry residues is then dissolved in one-milliliter solutions of 50 percent acetone and water, by volume, for application to the test plants.

"As test plants I used two genetically different dwarf mutants of corn (*Zea mays*). The first mutant, known as dwarf-5, responds to all nine gibberellins. The second, dwarf-1, responds to a different degree to some of the gibberellins and was used during a subsequent growth experiment that will be explained. I grew the seedlings at room

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temperature in the presence of light.

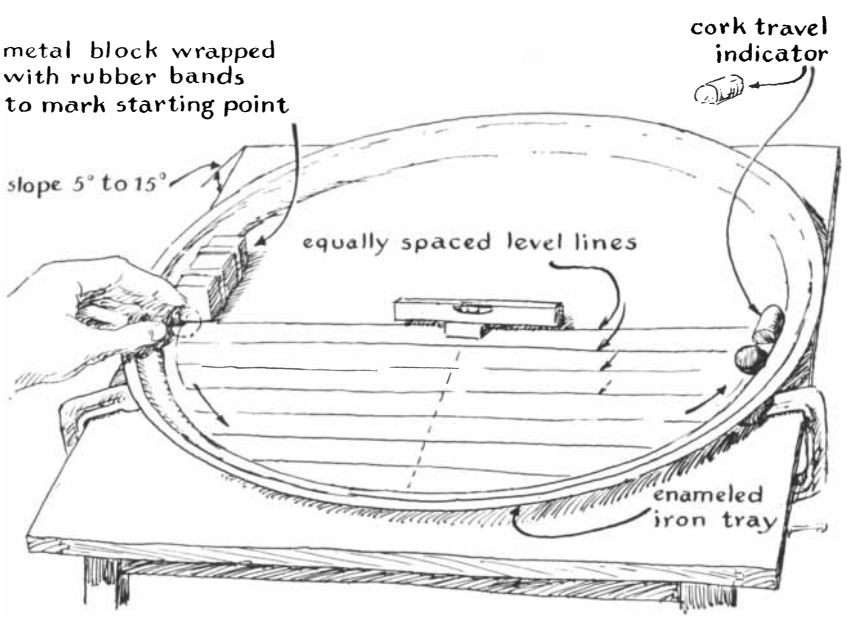
"I applied each fraction to a set of 10 plants, which were 10 days old, using .1 milliliter on each plant. The extract was applied by medicine dropper to the surface of the first unfolding leaf of each seedling. A group of 10 untreated plants was grown under identical conditions but was reserved as a control. Ten days following treatment the amount of growth of each plant was recorded by measuring to the nearest millimeter the length of the first two leaf sheaths.

"The measurements were then statistically reduced and plotted as graphs. To make the reduction I first found the total length to which both the first and the second sheath had grown for each plant. The sums of the lengths for each group of 10 plants were then added together, and the average sum of the lengths of the first two sheaths was determined for each group. In the case of the control plants, for example, the combined growth of both the first and the second leaf sheaths of all 10 plants was 558 millimeters, for an average of 55.8 millimeters. The deviation in the growth of each plant from the average growth of the group was computed by adding together the differences of the sums of the growth of the first and second leaves from the average growth of the first and second leaves. For instance, in the case of the control group the first and second leaves of the first plant grew to a length of 65 millimeters, 9.2 millimeters more than the average obtained from the measurements of 10 plants.

"In the case of the controls the sum of the squares of the individual deviations amounts to 921.6. This figure is used to compute the standard deviation, which is equal to the square root of the quotient that is obtained by dividing the sum of the squares of the deviation of each plant, in this case 921.6, by the total number of plants minus one, or in the case of the control group $\sqrt{921.6/9} = 10.1$ millimeters. Finally, the standard error of the arithmetic mean is computed by dividing the standard deviation (10.1 in the case of the control group) by the square root of the total number of plants in the group: $10.1/\sqrt{10} = 3.2$. Computations similarly made for each group of plants were then tabulated and the data used to make a graph of the growth response. These statistics were used to indicate whether differences in the two groups were meaningful or just due to chance.

"Six separate experiments were made. The accompanying table [*page 100*], listing the data of the first experiment, is representative. The second experiment was made to verify the results of the first. The third and fourth experiments were similar to the first two but used mutant dwarf-1 corn to help identify, at least to some extent, the presence or absence of specific kinds of gibberellins. The fresh weights of young cantaloupe seed extracted for the experiments were, beginning with the first experiment, 196, 201, 211 and 206 grams respectively. The accompanying graphs [*top of preceding page*] give the results.

"Experiments using identical procedures, except for the extraction, were



Tray calibrated for rolling-ball experiment

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also made on both mutant dwarf-5 and dwarf-1 with pure gibberellic acid for comparing the response to that of cantaloupe extract. The results are shown in the accompanying graphs [*second from top on page 101*].

"The experiments suggest that the cantaloupe contains 'gibberellin-like' substances. The plant extract produced a growth response in the two genetically different dwarf mutants that appeared to be identical with that of the known gibberellins. The peaks of the graphs, in addition to indicating the high activity of the extracts, suggest that at least two, and possibly more, gibberellins are present in cantaloupe. The fact that the peaks occupy approximately the same positions on the graphs of dwarf-5 and dwarf-1 also suggests that the same growth-promoter is active on both mutants.

"Finally I estimated the total amount of gibberellin-like activity. The seedling response to each fraction of the extract was compared with the response due to pure gibberellic acid. Then the amount of gibberellic acid that would have been necessary to cause the response to the extract was determined. The total GA_3 equivalents were multiplied by 10 because each value represented an average of 10 seedlings. The resulting estimate indicates that the extract applied to dwarf-5 mutants amounted to the equivalent of 40.8 micrograms of gibberellic acid per 397 grams of cantaloupe seed, or .1 microgram per gram. On dwarf-1 mutants the estimate was that the extract applied was equivalent to 45.2 micrograms of gibberellic acid per 417 grams of seed, or .11 microgram per gram. In other words, 86 micrograms of gibberellic acid would be required to produce the activity observed during the four experiments."

Some of the most entertaining experiments have been invented by compulsive doodlers, individuals who cannot sit with folded hands and minds in low gear during idle moments. Roger Hayward, who illustrates this department, is such a person; he has generated many off-hour inventions.

A recent letter is illustrative. "Some years ago," wrote Hayward, "I bought a set of steel balls graded in size from one inch to 1/2 inch in steps of 1/16 inch. I wanted them for use as gauges. As the occasion arose I added four more one-inch balls to the set, and over the years a number of smaller ones just seemed to accumulate. I also happened to have an old oval metal tray about 20 inches long. During a quiet evening a

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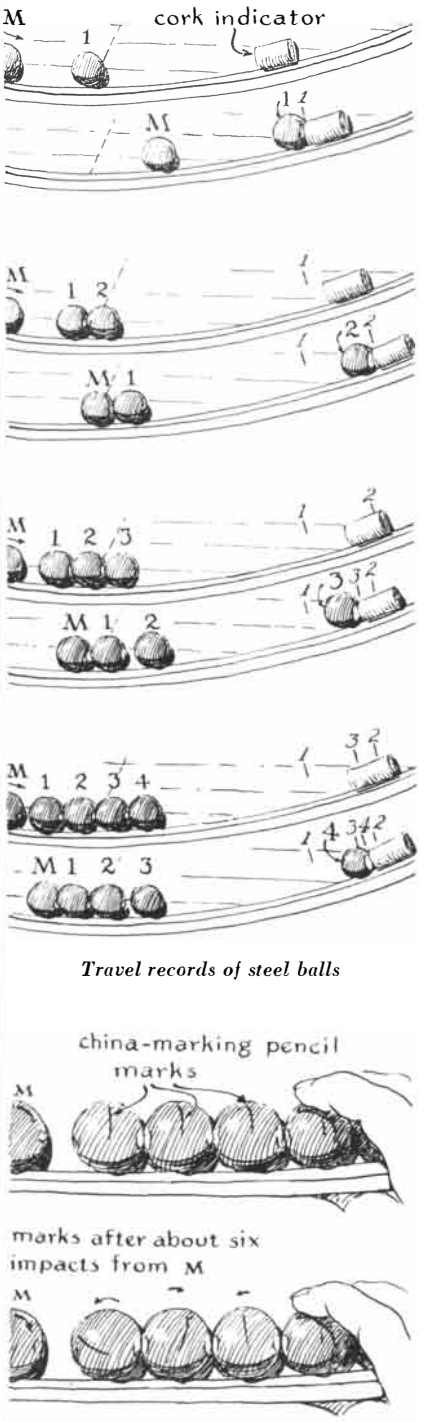
few months ago I picked up the tray and for no particular reason started to roll some of the balls inside the rim. Suddenly it occurred to me that here was a chance to learn something about how balls bounce off each other. I recalled from my student days at the Massachusetts Institute of Technology that it is difficult to calculate the change in velocity when two bodies collide, except in certain simple cases.

"It also came to mind that if one ball



Travel records of steel balls

Effect of rolling energy

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falls a certain distance, measured vertically, it acquires a certain velocity, no matter whether the fall is vertical or down any sloping path. Barring friction losses, the ball will have the same velocity at the bottom of the path regardless of the slope. I calibrated my tray by drawing a series of horizontal lines from rim to rim one inch apart, with a vertical center line. (A china-marking pencil is good for the job because the 'lead' is made of soap and the marks wash off easily.) I taped a small bubble-level to the center of the tray so that the center line could be kept in the vertical plane [*see illustration on page 102*]. I needed an indicator for marking the excursion of the balls. A good one was made of a cork sanded flat on one side so that it would not roll. A rolling ball will push the cork up the slope and the cork will stay there. The cork absorbs some energy from the rolling ball, of course, but the resulting error can be minimized by rolling the ball several times. Eventually the cork is pushed to its end point, where its position can be recorded by the china-marking pencil. I found that a single ball of one-inch diameter would eventually push the cork to about six-sevenths of the distance the ball had rolled down the other edge of the tray, indicating a friction loss of about a seventh of the total fall.

"The next experiment was made to find out how much of the energy of a rolling ball is transferred to a similar ball with which it collides, as shown by the accompanying illustrations [*opposite page*]. When the missile ball was rolled from a height of six inches, the target ball rose to only 1½ inches, as measured on the slope. Obviously not all the energy was transferred. The experiment was then repeated with a pair of one-inch balls centered at the bottom. The No. 2 ball now rose somewhat higher than the single ball. When three balls were tried, the one at the outer end of the string, No. 3, failed to rise as high as had No. 2 in the previous experiment. With four balls, No. 4 rose higher than No. 3 but not so high as No. 2. Part of the energy of the missile ball appeared to reside in its spin; the spin energy was not fully transferred. In fact, when I used only one target ball, the spin that was transferred may well have inhibited the transfer of other energy and thus have accounted for the twin-ball performance.

"To test this supposition four balls were placed in contact at the bottom of the tray, each marked with a meridian arc, all arranged in parallel. The end ball was prevented from moving

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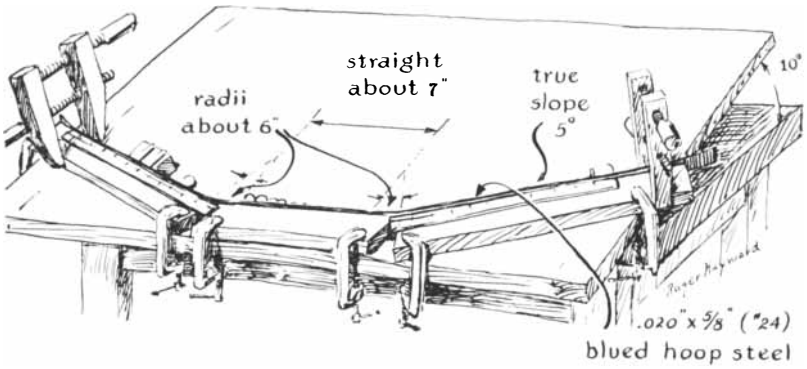
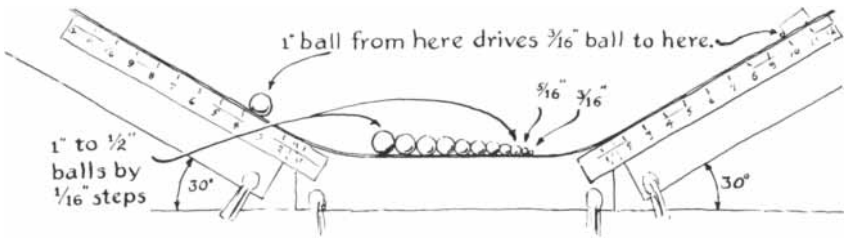
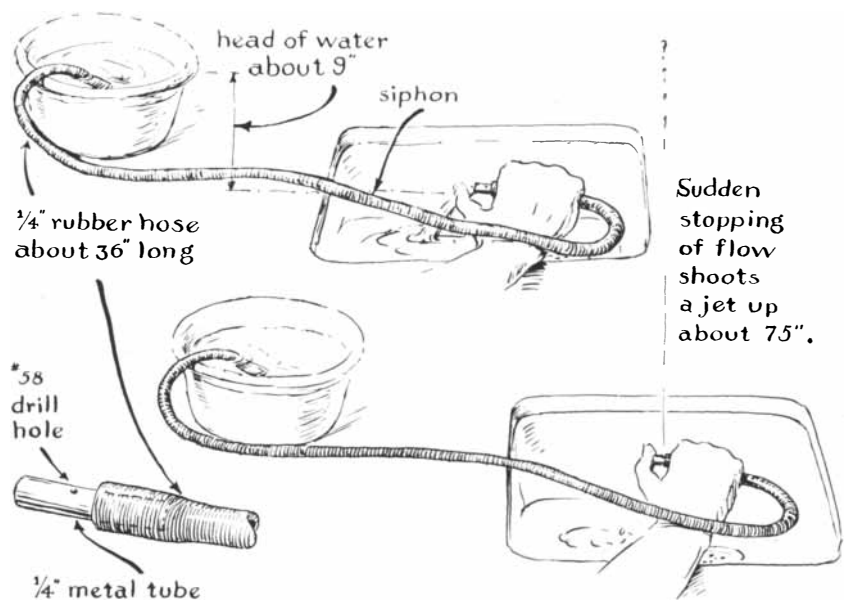




Improved apparatus for rolling-ball experiment



Apparatus for simulating a hydraulic ram

by finger pressure, and the missile ball was allowed to strike the target ball of the string several times. Six drops of the missile ball were enough to prove that the impact caused the balls to rotate in alternate directions by amounts that diminished toward the restrained ball. This observation made sense of the previous results. Rolling energy is a significant part of the total energy of the rolling ball, and it is transferred at lower efficiency than the energy of translation.

"Next I started putting sets of different-sized balls in the tray. A small ball absorbed only part of the energy, the missile ball continuing along after it. At this point a somewhat more sophisticated apparatus appeared to be desirable, so I improvised one from a drawing board, three blocks of wood, a thin metal strip and a set of clamps [*see top illustration above*]. With straight slopes for sides, rulers can be used to measure the rise and fall of balls. The steel strip that serves as the track must fit rather closely to the wooden back strips, particularly where the path curves, or inordinate amounts of energy are dissipated.

"With this new apparatus I repeated the first experiment, except that I used target balls smaller than one inch. A target ball 15/16 inch in diameter rose a little higher than the one-inch target ball, and a 7/8-inch ball went even higher. As I added smaller and smaller balls to the array the gains increased. With seven balls in the string the ball at the end, 9/16 inch in diameter, rose higher than the starting point of the missile ball. A 1/2-inch end ball climbed three inches higher than the missile ball's starting point. When I added a 5/16-inch ball to the end of the string, I had to lower the starting point of the missile ball to keep the end ball from jumping off the track and lower it still more for an end ball of 3/16 inch. With the starting point of the missile ball only 3¼ inches above the base line a 3/16-inch ball climbed 11 inches!

"Now I had to revise my thinking. There was no likely loss of total energy that could not be accounted for, but in the light of the low efficiency of energy transfer from ball to ball I had assumed that the system was substantially like that of a falling fluid. A small stream of water flowing from the low point of a large reservoir will rise no higher than the level of the reservoir. I had failed to see in the case of the balls that the energy is transferred by an elastic wave; the amount of energy transferred is not necessarily limited by the velocity of the impact. It would seem that a row of balls of graded sizes acts like an electric transformer, if one thinks of the mass as the current and the velocity as the voltage. By electrical standards the efficiency of the ball-transformer leaves much to be desired, of course.

"There is also a hydraulic analogue in the old, time-honored and largely forgotten hydraulic ram. In this device a large pipe filled with flowing water is suddenly blocked by a self-closing valve. The impact of the fluid mass drives part of the water into a separate chamber, compressing a volume of trapped air. When the flow stops, a valve closes and the trapped water is forced by the air to a substantial height. I spent the final moments of the evening experimenting with a simplified version of the hydraulic ram: a short length of rubber tubing that acted as a siphon between an elevated pan of water and the kitchen sink. At the discharge end of the tube I inserted a small piece of metal tubing with a .042-inch hole in the top. When I stopped the flow of water with my thumb, a narrow jet squirted more than six feet high out of the hole. The springiness of the compressed air in the ram is provided by the rubber; the springiness of the steel balls, by the elasticity of the steel."

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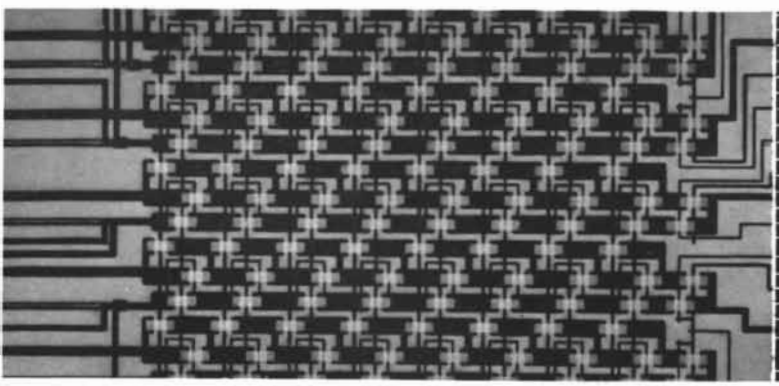
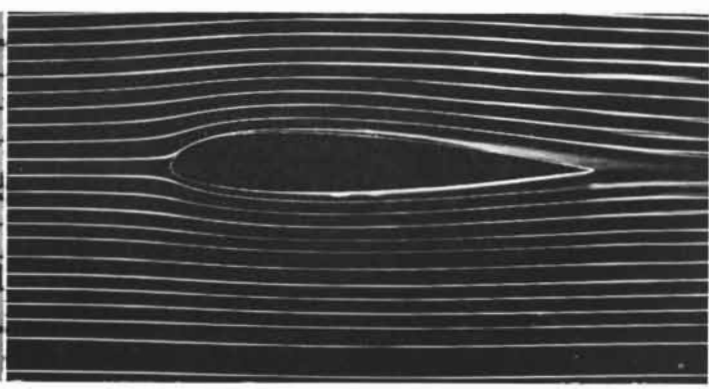
$$F \propto \frac{M_1 M_2}{r^2}$$

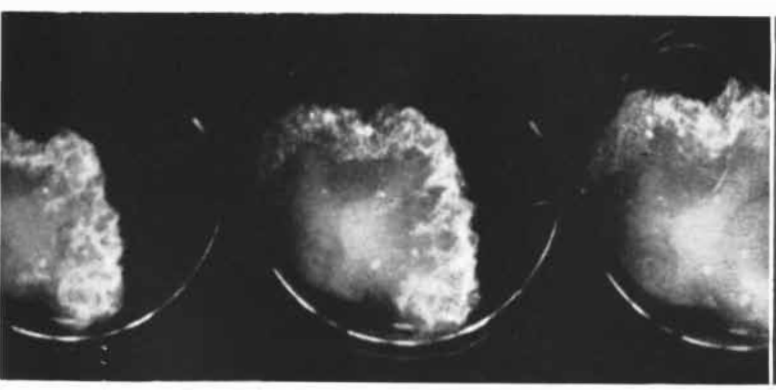
$$q_{rev} = T\Delta S$$

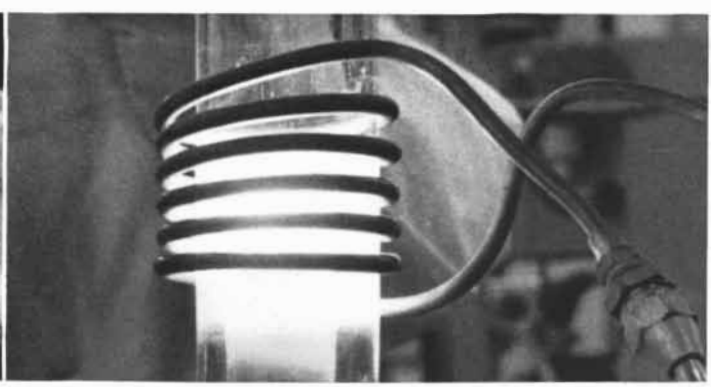




$$1 + 1 = 1$$
$$1 \times 0 = 0$$

$$L = \omega \frac{dm}{dt}$$





$$\frac{dw}{dt} = QF(t)$$

$$E = h\nu$$

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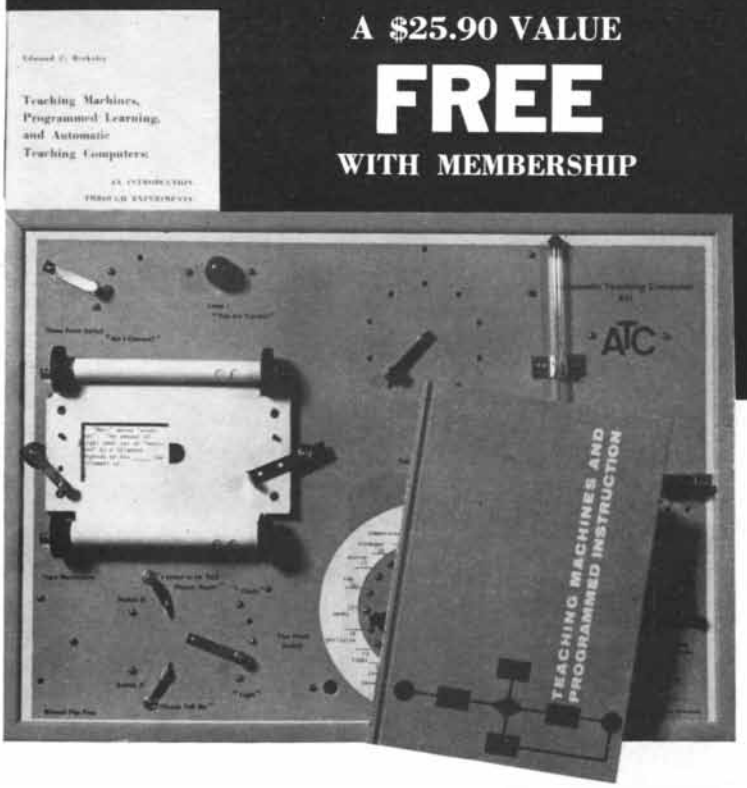

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BOOKS

Does decision theory have any meaning for statecraft?

by Marcus G. Raskin

STRATEGY AND CONSCIENCE, by Anatol Rapoport. Harper & Row, Publishers ($6.95).

Since the end of World War II the U.S. has spent some $800 billion on defense and defense-related items. This vast expenditure of money has brought about new social institutions and organizations, new technologies, new habits of thought and morality, a new language and a new constellation of interest groups. The martial spirit that prevailed attracted many of the ablest men in the country. Now, however, there is widespread doubt about the spirit of the time, the theories it nurtured and the people who developed them.

This disenchantment is due to changes in the attitudes of the U.S.S.R. and our allies, to the nuclear stalemate and to our own fear that a creeping bankruptcy is settling in the marrow of our society. The official ideology now seems to encourage the position that the arms race is foolish and that we should do something about it. The views of Senator Fulbright, the actions of President de Gaulle and Premier Khrushchev and President Johnson and the rediscovery by our government that we have grave domestic problems create the impression that the cold war is ending. Because of boredom, exhaustion or common sense—perhaps all three—something has happened that may augur a more constructive future.

Since we appear to be at the end of an era, a book such as *Strategy and Conscience,* by Anatol Rapoport of the University of Michigan, is significant as an indication of the kind of thinking and judgment on international politics that can be expected from scholars and intellectuals in the near future. From Rapoport's preface the reader learns that he was moved to write his book because he felt that the strategist's arguments, while they were clinical and objective in style and intent, led to immoral and disastrous political consequences. But stating it in these terms is, as Rapoport learned, not quite enough. He could not convince his academic colleagues, most of whom eschew moral issues in favor of academic politesse and so-called value-free research. Nor did he think he could be heard in the larger political and strategic arena, arguing as he was only the conventional wisdom and morality of great philosophers.

Consequently he undertook to disprove the strategists on their own grounds, by analyzing the methodological tools they use to make decisions, choices and recommendations for action. He succeeds in showing the shortcomings of these methods and the dubious value of translating them into strategic recommendations. In the last third of the book he undertakes to examine what he believes to be the real issues between ourselves and the communist (but non-Chinese) world.

Rapoport begins by reviewing the status of rational decision theories and the information such theories demand if they are to be an "effective guide to action." He examines the various kinds of decision theory: formal decision theory (which is the closest to logic and mathematics and includes the theory of games), prescriptive decision theory (which is exemplified by operations research) and descriptive decision theory (which applies the methods of the behavioral sciences). He concludes that each is lacking as a useful guide to the decision-maker.

The basic rules of formal logic and game theory—consistency, instrumentality and transitivity—cannot be used very meaningfully in the political context. The idea of consistency, that is, not preferring A_1 to A_2 at the same time one prefers A_2 to A_1, may be useful in books on logic and game theory, but it does not really apply in statecraft; there contrary policies are followed not capriciously but out of inability to recognize contradiction. The idea of instrumentality, that is, the use of logical instruments that will lead the decision-maker to a preferred action, is easy to grasp symbolically, but the symbols do not seem very powerful where people, policies and long periods of time are involved. The idea of transitivity, that is, if we prefer A_1 to A_2 to A_3 we will also prefer A_1 to A_3, is equally hard to translate into social actions. It is not enough for the decision-maker to be able to put a set of preferences in logical order; he must know if his decision is likely to be right.

Yet it is not totally inaccurate to say that there is a certain order of preferences to which individuals in government hold in making decisions. Early in the Kennedy Administration some of the President's advisers thought in terms of conserving "credit points" with him; it was considered strategically wise not to speak out on every issue because one's "effectiveness" would be lessened. But how could one rationally order those questions on which not to speak? During the summer of 1961 the White House concerned itself with the issues of whether or not to build a civil defense program, go into Vietnam, tighten the defenses of Berlin, resume nuclear testing and adopt a "counterforce" system of defense. If a policy-maker knew that his views were running against the mainstream, he might choose the "most important" issue to make his weight felt and be silent on the rest. But obviously problems of the same general magnitude cannot be distinguished on a preference scale. The citizen would not expect or want from his leaders an ordering of priorities on questions as important as these were. Virtually all questions of high policy have important moral components that tend to be absolute.

Rapoport points out that in a complex situation decision theory cannot guarantee a single right answer. But are not a few answers that have a high probability of being right useful to the decision-maker? Here the trouble is that the factors in making the decision must be weighted according to *their* probability. There is a tendency to think of a probability as being inherent in the event

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rather than in something the individual who is trying to predict the event has done. As Rapoport observes: "In this light, probabilities which we assign to events become reflections of our preferences rather than of our knowledge." To put it another way, we tend to dictate the answers by the questions we ask.

In the "two-man zero sum" game of game theory what one player wins the other loses. Built into the game is the assumption of rationality (selfish interest) on the part of the opponents; consequently there are right and wrong moves. This leads to a paradox: If all the plays are known in advance and the opponents are equally skilled, then the outcomes are known in advance; yet if they are known in advance, then it is necessary for the opponents to make nonrational moves in order to take advantage of each other. According to Rapoport, empirical studies of behavior in zero-sum games suggest that stochastic learning theory, "a mathematical model of a process in which the variables of interest are sets of probabilities associated with possible outcomes," is a better predictor of human behavior than game theory is.

Conflicts in real life are seldom zero-sum games; that is, when one player loses, the other does not necessarily win. Such a game is called a nonzero-sum game. Rapoport concludes that under these circumstances decisions ultimately depend on the ethical orientation of the decision-maker. It would appear that game theory cannot be used to make real-life decisions in any way that divorces the decision-maker from his value preferences.

The present state of game theory is primitive, and so is the technique of mathematically simulating situations in which decisions must be made. For purposes of statecraft, game theory and simulation methods do not allow for moral and political considerations except in the crudest sense. They assume no historical perspective; events are considered as being discrete from history. Whether morality, politics and history can be built into game theory and simulation methods remains to be seen. In Rapoport's discussion of simulation techniques he makes clear that even this deductive approach is severely limited by the range of problems it can solve. Finally, there is no serious concern in decision theory with the role of psychological factors. "In their place," writes Rapoport, "one finds mostly formalized assumptions or standardized clichés." Psychologically the very word "game" implies play activity in which wish fulfillment and deep anxiety manifest themselves. Where the game has no purpose beyond itself it may act as a cathartic for the players, but where the game is applied to political problems or real situations it merely reflects its original components: anxiety and wish fulfillment. The adoption of game theory and simulation techniques could be viewed as an indication of our own beliefs in ritualistic symbols disguised as rationality, rather than as an effort to find useful tools for statecraft.

In view of all these limitations Rapoport discusses so well, one may ask why decision theory is so important to the Department of Defense and to large business organizations. Why is it that these institutions flirt with the theories when they have only marginal utility? The answer is that large modern organizations are insatiable consumers of scholarly knowledge, ideas and theories. Any knowledge that is remotely related to the activities of the organization is fair game; it is an article of faith that in order for the organization to survive it must be at the "frontier" of knowledge. Knowledge, however, may be useful to the organization in curious ways. It helps administrators to conceal from themselves what they are really doing. (In the case of nuclear strategists the reality is genocide.) It also has symbolic and ceremonial value. Thus a computer is most important as a symbol, not because it is relevant or useful. The computer is an ornament to the ceremonial Ph.D. who uses his degree to assert "Don't question what I am doing."

Although analysis such as game theory may help us to understand better the process of rational decision-making, when it is inserted into the political process it ends up as an instrument of power and rationalization for promoters. During the Kennedy Administration many people in the Department of Defense found themselves using the developing language of game theory and operations research. The fact remains that the basic decisions as to the size of the nuclear-weapons stockpile, the number of missiles, the number of airplanes and so on were invariably decided on political grounds. In 1960 the Democratic party made a campaign issue of a "missile gap" that favored the U.S.S.R. Yet when the Democrats won the election and the missile gap proved to be nonexistent, the production of missiles was not inhibited. It could be argued that the reason it was not was that the strategists had sold their superiors the counterforce argument, which demanded an unlimited number of missiles. The political advisers of the Kennedy Administration believed they needed a "first strike" force to prove to NATO that its defense commitment was credible. In actuality the number of missiles finally arrived at had only the vaguest relation to such requirements. It should come as no surprise that the figures were a compromise between the White House, the Secretary of Defense and the Joint Chiefs of Staff.

Yet there are still strategists who cite the theory of decision-making to show how nuclear weapons can be used to attain national political objectives. Rapoport concludes that for them the only reality is unending fear of nuclear war and total dedication of ourselves to a "security" that tends to destroy the institutions it seeks to preserve. He rejects this nightmarish world of wooden assumptions and considers the problems with which serious statecraft must now concern itself.

He takes up the central core of the American dream and the communist dream, their ideological relation to each other and the possibilities for competitive and cooperative coexistence. In examining these possibilities he discusses the ideology of the cold war and the cold-war syndrome, in which one's own society is all good, in which it operates in particular ways that themselves are ideal and in which the other society is all evil. Of course many strategists did not accept this simplistic dichotomy consciously. But those who think of the cold war in terms that go beyond job security, social status and other forms of self-interest always seem to return to the acceptance of this proposition.

In Rapoport's attempt to deal with the good-evil barrier and to show the actual relation of the society of the U.S. and that of the U.S.S.R. he asks: "Is the enemy an enemy? Need he be an enemy? If not, what must be done in order that he become an enemy no longer?" Although these questions are a vast improvement over the governing assumptions of the cold war, there are other questions that might be more useful: Are all segments of communist society the enemy? Who among us is the enemy of someone else, and why? What habit of mind has made it possible for human beings to accept the idea that hundreds of millions of other human beings are as alike as peas in a pod and all enemies?

Most important, is there a way, within the context of the system of sovereign states, in which one can accept certain

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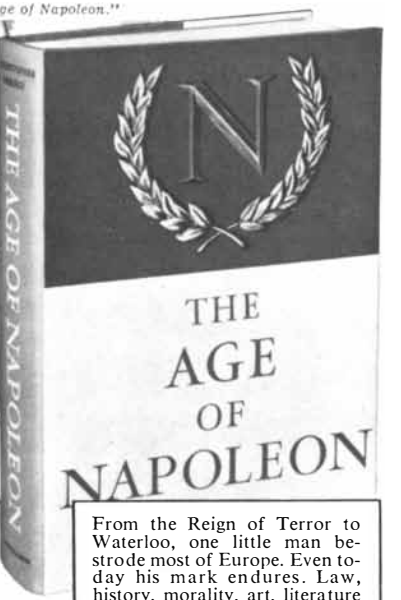
"Distribution of the Eagles," by David. Napoleon presents imperial standards to his troops. An illustration from "The Age of Napoleon."

Versailles Museum



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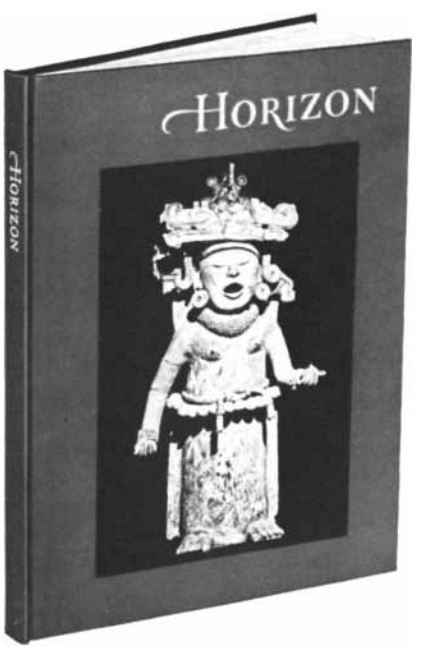

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rules so that there is agreement on the framework of relations without agreement on their content, or on the outcome of every problem? For example, at the end of World War II there were two somewhat opposed concepts of world order and the instrument for obtaining it, the United Nations Organization. One view was that for the organization to work there had to be an identity of interests on issues between the great powers, notably the U.S. and the U.S.S.R. If the great powers were to fall out on a particular issue, it followed that the United Nations should and would be worth nothing. The second view was that it was unnecessary for an identity of interests to obtain between the great powers as long as there was agreement on a framework of relations. It is probable that in international affairs the nations will have to retrace their steps toward the latter interpretation. This will become a *sine qua non* for peaceful competition as old alliances and ideologies wash away. In other words, whether or not the U.S. and the U.S.S.R. become friends is not so important as the more general question of whether or not both nations will accept a political and legal framework within which particular points of disagreement will not cause the international order to collapse.

In his comparative analysis of the two societies Rapoport notes that although each society is different from the image it has of itself, some self-proclaimed ideals of both societies still exist; for example, "our much publicized freedoms, the freedom from arbitrary relentless persecution, the freedom of social criticism, freedom to speak out without necessarily suffering drastic consequences," are all real. Similarly, whatever its shortcomings, the Soviet society believes in the ideal of the socially responsible individual who participates actively in a collective effort toward a goal ardently desired by all. Rapoport sees the two views as being, at least theoretically, complementary. This will not be news to those steeped in 20th-century U.S. social criticism; Charles A. Beard, Thorstein Veblen, John Dewey and John R. Commons all dwelt on the possibilities of combining such principles. Rapoport believes the wide recognition of this complementarity might lead to a kind of ideological disarmament: once we and the Russians perceive that we share many of the same quandaries, we might renounce genocide as a potential instrument of policy.

Rapoport's opinions about pragmatism and the "problem-solving" attitude deserve critical attention because these ideas have wide currency among intellectuals, although they do not always bear the same names. He sees pragmatism as a philosophical enemy that must be slain and problem-solving as its unholy twin that must at least be severely wounded. The strategist is "hemmed in by a compulsion to approach all situations in the 'problem-solving' mood." The problem-solving method is deficient because it rests on a theory of rationality that assumes that men perceive their interests, set an order of priorities on them and then pursue that order. What Rapoport seems to overlook is that problem-solving and true pragmatism rest on this very realization. What he calls pragmatism is really only a vulgar perversion of it.

Since the beginning of the cold war the meaning of pragmatism has been corrupted to the point where the concept has been used to justify expedience, immorality and plain silliness. What people have claimed in the name of pragmatism would surely cause John Dewey to stir in his grave. People now justify the arguments of power politics in the name of pragmatic thought. Nothing could be further from the pragmatic view. In his analysis of the security of nations Dewey said that if nations were to come to grips with the problem of war, small steps in the context of a system that permitted war would do nothing more than improve or rationalize the system: "It is not a step we need, it is a right about face; a facing in another direction; and when we have committed ourselves to facing in another direction we have all further time to take steps. No advance in human history that was of any great importance was made by taking steps along old lines.... Taking steps along old lines aids in perfecting problems and methods that are already established, but never to initiate the great steps in human progress. These always come by finding a new method of attack on the problem. I believe that the fallacy which most paralyzes human effort today is the idea that progress can take place by more steps in the wrong direction."

It is unfortunate that Rapoport uncritically accepts the strategist's characterization of himself as a pragmatist who uses the problem-solving method. Dewey would agree with Rapoport that the knowledge and methods needed to solve a particular problem vary with the subject matter of the problem. The knowledge and methods needed in statecraft, the constituent parts of which are politics and morality, are not the same as those needed in mathematics or formal logic.

What kind of knowledge *can* be used by statecraft? Borrowing Jerome B. Wiesner's phrase, Rapoport calls it knowledge that yields insights. "Insight knowledge does not immediately and appreciably add to the knower's ability to change the environment. Rather, it produces changes within the knower. These changes may be very profound, as, for example, in perceptions and attitudes concomitant to maturation or in the growing identification with others or in the process of socialization."

In pleading for more insight knowledge Rapoport makes the assumption that such knowledge is unpragmatic. He criticizes the problem-solver because he tries to change the problem instead of changing himself. But surely pragmatic thought has never recognized a dichotomy between the problem and the individual acting on the problem. It is obvious (and Dewey, William James and Charles Sanders Peirce recognized this) that the problem cannot be changed unless the problem-solver is himself changed. Pragmatic thought begins with the problem-solver's intrinsic involvement in the problem.

The picture of insensitivity and quick gain that Rapoport has of the true pragmatist does not comport with the facts. Thus, for example, Rapoport's notion that pragmatists could not understand the deeper meaning of the confessions of the Moscow trials, "namely that the confessions were genuine acts of blasphemy," is ironic; the one person who understood more clearly than anyone else what the meaning of the Moscow trials was in exactly this blasphemous sense was Dewey, who was chosen by intellectuals to sift the evidence about Leon Trotsky and the trials.

Then what is strategic thought if it is not pragmatic? It is pragmatism gone wrong. Let us hope that its roots lay only in the "opportunities" of the cold war and not in the human condition.

Short Reviews

COLLECTED SCIENTIFIC PAPERS, by Wolfgang Pauli, edited by R. Kronig and V. F. Weisskopf. Interscience Publishers ($70). When Wolfgang Pauli was 20 years old, he wrote for the German *Encyclopedia of Mathematical Sciences* a treatise-length article on the theory of relativity that Einstein himself described as a "grandly conceived work" almost beyond praise. This treatise is to

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the present day the most penetrating, lucid and sure critical appraisal of relativity. Pauli fulfilled this promise. He was one of the giants of modern physics, and his exclusion principle, for which he won a Nobel prize in 1945, is only one of many contributions. His early interest in relativity, which continued throughout his life, guided his approach to the problems of physics; this is indicated by his unceasing search for symmetry and invariance. He worked in field theory, spectroscopy and the behavior of electrons in solids; he was a brilliant analyst of experimental data. For his scientific integrity and breadth of understanding he earned the title of "the living conscience of theoretical physicists." The editors of this two-volume collection have gathered everything he published, not only books, chapters in handbooks, papers and scientific journals but also book reviews, casual articles, lectures and the like. Included are a portrait and a brief preface; a biographical essay would have been desirable.

THE MYTH OF THE BRITANNICA, by Harvey Einbinder. Grove Press, Inc. ($7.50). All general encyclopedias are myths, although it may be that the *Britannica* myth is king-sized. The world is too big and too old and modern knowledge too extensive and too diversified to make possible the realization of the dream of the 18th-century encyclopedists. In an age that requires 50-volume encyclopedias of a single subject such as physics or chemistry, the notion of a universal compendium of knowledge that will usefully serve every kind of reader is an absurdity. The *Britannica*, as many have long known and as this book devastatingly demonstrates, is full of blunders, inaccuracies, anachronisms and other defects. Einbinder exhibits one pathetic example after another of the *Britannica*'s outmoded critical views, Victorian barnacles, biographical misjudgments, historical *gaffes*, scientific errors and the like. He criticizes the wholly inadequate process of continuing revision and the pretentious claims that the manufacturers of this product trumpet throughout the land. The *Britannica* is best suited to the needs of the high school student preparing a composition or the casual inquirer in search of the birth date of Swinburne or the longitude of Guam or the habitat of the secretary bird. This is not to deny that the great bulk of its material is reasonably accurate and that it has numberless admirable articles. But just as it is unsatisfactory to consult a table of logarithms that has many mistakes even if 99.9 percent of the entries are correct, so it does not do much good to consult the *Britannica* on a subject of serious interest unless one is prepared to cross-check what it says. There the volumes sit on the shelf, massive, impressive, imperial and yet not trustworthy. Perhaps the plight of the *Britannica* has a salutary side: it reminds us that knowledge is growing and changing, that the world is large and man is small and that except in matters of faith there is no pope.

SCIENCE IN ARCHAEOLOGY, edited by Don Brothwell and Eric Higgs. Basic Books, Inc., Publishers ($17.50). ARCHAEOLOGY AND THE MICROSCOPE, by Leo Biek. Frederick A. Praeger, Publisher ($11). THE SCIENTIST AND ARCHAEOLOGY, edited by Edward Pyddoke. Roy Publishers, Inc. ($6.95). It has been observed that the archaeologist is in many respects a detective. His task is to reconstruct past human activities on the basis of incomplete but abundant and diverse clues. More and more in recent years the archaeological detective has turned to the natural sciences for methods and instruments to help him find clues and interpret them. These three books, among which there is a good deal of overlap, are concerned with various contributions of natural science to archaeology. The 600-page volume by Brothwell and Higgs contains articles by 55 specialists on such subjects as radiocarbon dating, archaeomagnetism and thermoluminescence, environmental studies of climate, soils, plants and animals, researches in the biology of early man, the radiological examination of human remains, blood groups and prehistory, the analysis of artifacts by techniques from statistics to spectroscopy. Although it is quite uneven in the quality of the articles, this is a useful reference work illustrated with many photographs, line drawings and tables. Biek, a physical chemist, writes on the use of chemicals, X-ray apparatus, magnetometers, subatomic-particle counters and other tools of the archaeological laboratory and relates interesting anecdotes from his own experience as head of the Ancient Monuments Laboratory of the British Ministry of Public Building and Works. Pyddoke's compilation treats of, among other things, surveying by means of the electrical resistivity of the soil, the use of soil science in archaeology, pollen analysis as a means of reconstructing the past history of vegetation, the dating of bone and the archaeological applica-

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tions of radioactivity. Both of the last two volumes are also well illustrated.

THE ANALYTICAL ENGINE: COMPUTERS—PAST, PRESENT AND FUTURE, by Jeremy Bernstein. Random House ($2.95). This little book, which substantially reprints two articles in *The New Yorker,* offers a clear, lively, literate once-over of computers. One of the best things about the sketch is that it is not gushy or bug-eyed. The author knows the importance of keeping the machine, however grand, in its place—in the closet like a vacuum cleaner, not in a shrine.

JANE'S ALL THE WORLD'S AIRCRAFT: 1963–1964, edited by John W. R. Taylor. McGraw-Hill Book Company ($39.50). As usual, the new *Jane's* is larger than its predecessor, with more facts and figures and hundreds of new illustrations of aircraft, drones, sailplanes, air-cushion vehicles, missiles, space vehicles and aircraft engines. The editor comments that the current aviation scene has more than its share of paradox. For example, although airlines "continue to find difficulty in filling half of the available seats in the costly jet transports introduced over the past five years, they are already queuing up to buy supersonic airliners, which will be even more costly to buy and more difficult to operate at full capacity."

LECTURES ON GAS THEORY, by Ludwig Boltzmann. University of California Press ($10). The first English translation, by Stephen G. Brush, of Boltzmann's brilliant treatise (first published in the 1890's) on the kinetic theory of gases. This prodigiously gifted physicist brought out his masterpiece at a time when atomic theory was under heavy attack, a circumstance that greatly disturbed him and that is thought to have contributed to recurrent episodes of severe mental depression culminating in his suicide in 1906. Within a few years of this tragedy the atomic theory was fully confirmed and the book was for more than a quarter of a century, until the advent of quantum mechanics, the authoritative expression in this branch of physics.

MICROGRAPHIA, by Robert Hooke. Dover Publications, Inc. ($2). A facsimile reprint, with the original illustrations beautifully reproduced, of this incomparable book by the inexhaustibly quarrelsome and inexhaustibly imaginative secretary and demonstrator to the Royal Society of London. There was very little in the physical sciences of the 17th century into which Hooke did not poke his meddlesome and creative finger, and he must have been as much of a pain to Isaac Newton (who drew heavily on some of his ideas) as the fleas, flies and other household insects he studied under the microscope and first exhibited to the world in his magnificent drawings. This is one of the best books yet to appear on Dover's long list of reprints, which is saying a great deal.

HEALTH PROGRESS IN THE UNITED STATES: 1900–1960, by Monroe Lerner and Odin W. Anderson. The University of Chicago Press ($6.50). A statistical and interpretive summary of major trends in mortality and morbidity in the U.S. during the 20th century, presented as a report of the Health Information Foundation. For living longer and being less often cut off by infectious diseases we pay the price of a sharp increase in death from heart disease and cancer; for our pleasures, follies, proficiencies and ambitions we pay by accidents and mental illness.

THE WORLD OF THE PAST, edited by Jacquetta Hawkes. Alfred A. Knopf ($20). A two-volume anthology of archaeological history—the discoveries and the discoverers—set out in the words of those who made the finds, observed or interpreted them. Miss Hawkes provides a long introduction and brief notes for each selection. Some of the selections are rather scrappy and convey little to the reader; many, however, are full and recapture the excitement of the event. Although the work has limitations and curious omissions, probably no one could have done a better job than Miss Hawkes; the reader can look forward to some fine browsing.

THE CONCISE OXFORD DICTIONARY. Oxford University Press ($5.50). The fifth edition of this fat little book by the brothers Fowler has been completely revised and reset with numerous corrections and additions to bring the book up to date. Some new technical and scientific words have been added, such as "maser," "permafrost" and "servomechanism," and a few colloquialisms. This, however, is not the forte of the C.O.D.; it is what it always has been, the most stylish and satisfying one-volume dictionary designed for literate practitioners of each of the two or more cultures.

ELSEVIER LEXICON OF INTERNATIONAL AND NATIONAL UNITS, compiled by W. E. Clason. American Elsevier Publishing Company, Inc. ($4.95). A handy pocket-sized multilingual guide—English, German, Spanish, French, Italian, Japanese, Dutch, Portuguese, Polish, Swedish and Russian—to some 300 international unit terms and to the national or local units current in 69 countries. The range is from acres and amperes to trolands and years.

Notes

COSMICAL ELECTRODYNAMICS: FUNDAMENTAL PRINCIPLES, by Hannes Alfvén and Carl-Gunne Fälthammar. Oxford University Press ($9.60). The second edition of a book that first appeared 15 years ago, with the text updated and the treatment expanded.

A TREASURY OF SCIENCE, edited by Harlow Shapley, Samuel Rapport and Helen Wright. Harper & Row, Publishers ($6.95). The fifth edition of this book has been revised and enlarged to include new material on radio astronomy, the genetic code, the use of new drugs in the treatment of mental disorders, plasma physics, strange particles, space flight and so on.

ANCIENT LAW, by Henry Sumner Maine. Beacon Press ($2.45). A reprint of a classic 19th-century work on comparative jurisprudence that relates the foundations of law to the structure of the societies in which it arose.

MANAGEMENT AND THE WORKER, by F. J. Roethlisberger and William J. Dickson. John Wiley & Sons, Inc. ($2.65). A reprint of a well-known study of factory workers and industrial relations conducted at the Hawthorne Works of the Western Electric Company during the 1930's.

YEARBOOK OF ASTRONOMY: 1964, edited by J. G. Porter. W. W. Norton & Company, Inc. ($3.95). The notes and data for the use of amateur astronomers that are the staple of this annual have been brought up to date for 1964, and there are a number of articles on special subjects such as the *Mariner* expedition to Venus, telescope mountings, celestial navigation, the short-period comets and recent advances in astronomy. Paperback.

LANGUAGE: ITS NATURE, DEVELOPMENT AND ORIGIN, by Otto Jespersen. W. W. Norton & Company, Inc. ($2.45). A soft-cover reprint of one of the great books on language, which recounts the history of linguistics, the

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development of language, the causes of semantic and phonetic change, the origin of grammatical endings, etymology and related topics.

THE PROTEINS: COMPOSITION, STRUCTURE, AND FUNCTION, VOLUME I, edited by Hans Neurath. Academic Press ($22). This is the first volume of the second edition (the first was published some 10 years ago) of an authoritative and critical treatment of this major subject.

SOCIAL STRUCTURE AND PERSONALITY, by Talcott Parsons. The Free Press of Glencoe ($8.50). A collection of essays published over a period of 10 years by a leading figure in U.S. sociology.

STUDIES IN MATHEMATICAL PSYCHOLOGY, edited by R. C. Atkinson. Stanford University Press ($11.50). The first volume in a new series of annuals that is to include lengthy research papers dealing with theoretical and theoretically oriented experiments or with mathematical developments in psychology and closely allied scientific areas.

PRIMITIVE MOTILE SYSTEMS IN CELL BIOLOGY, edited by Robert D. Allen and Noburô Kamiya. Academic Press ($22). Proceedings of a symposium on the mechanism of cytoplasmic streaming, cell movement and the saltatory motion of subcellular particles, held at Princeton University in 1963.

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BRAINS OF RATS AND MEN, by C. Judson Herrick. Hafner Publishing Company ($6). A reprint of a pioneering work that gives an admirable summary, from a general biological point of view, of what was known some 35 years ago about mental processes. It is worth observing that many of the problems and questions so clearly raised by Herrick continue to resist modern investigators.

INDEX OF ADVERTISERS

AUGUST 1964

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HIGH VOLTAGE ENGINEERING CORPORATION 12
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POLAROID CORPORATION, THE 58, 59
Agency: Doyle-Dane-Bernbach-Inc.

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QUESTAR CORPORATION 39

RCA ELECTRONIC COMPONENTS AND DEVICES 75
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SUPERSCOPE, INC. 66, 67
Agency: Weverka & Associates Inc.

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