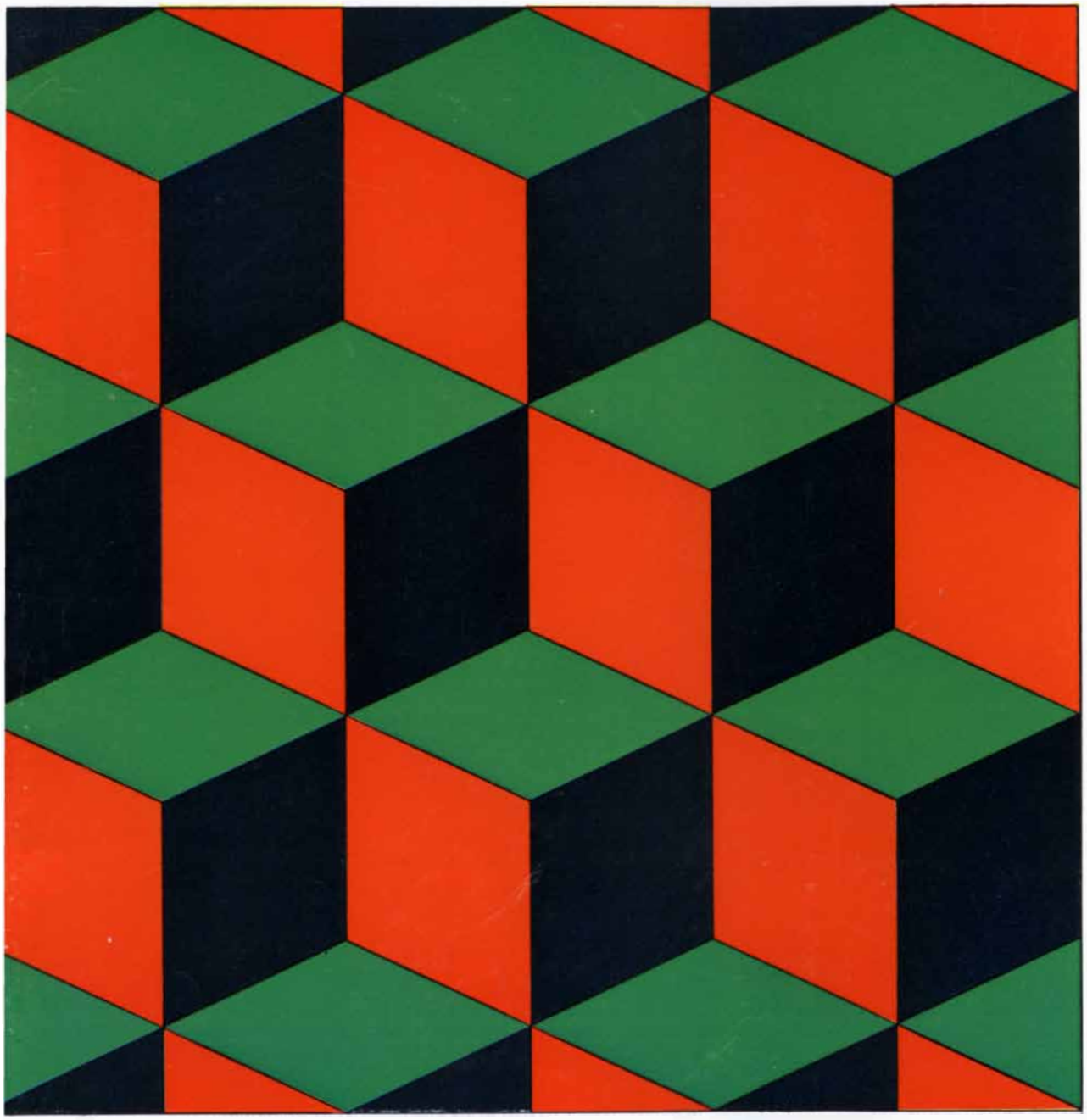
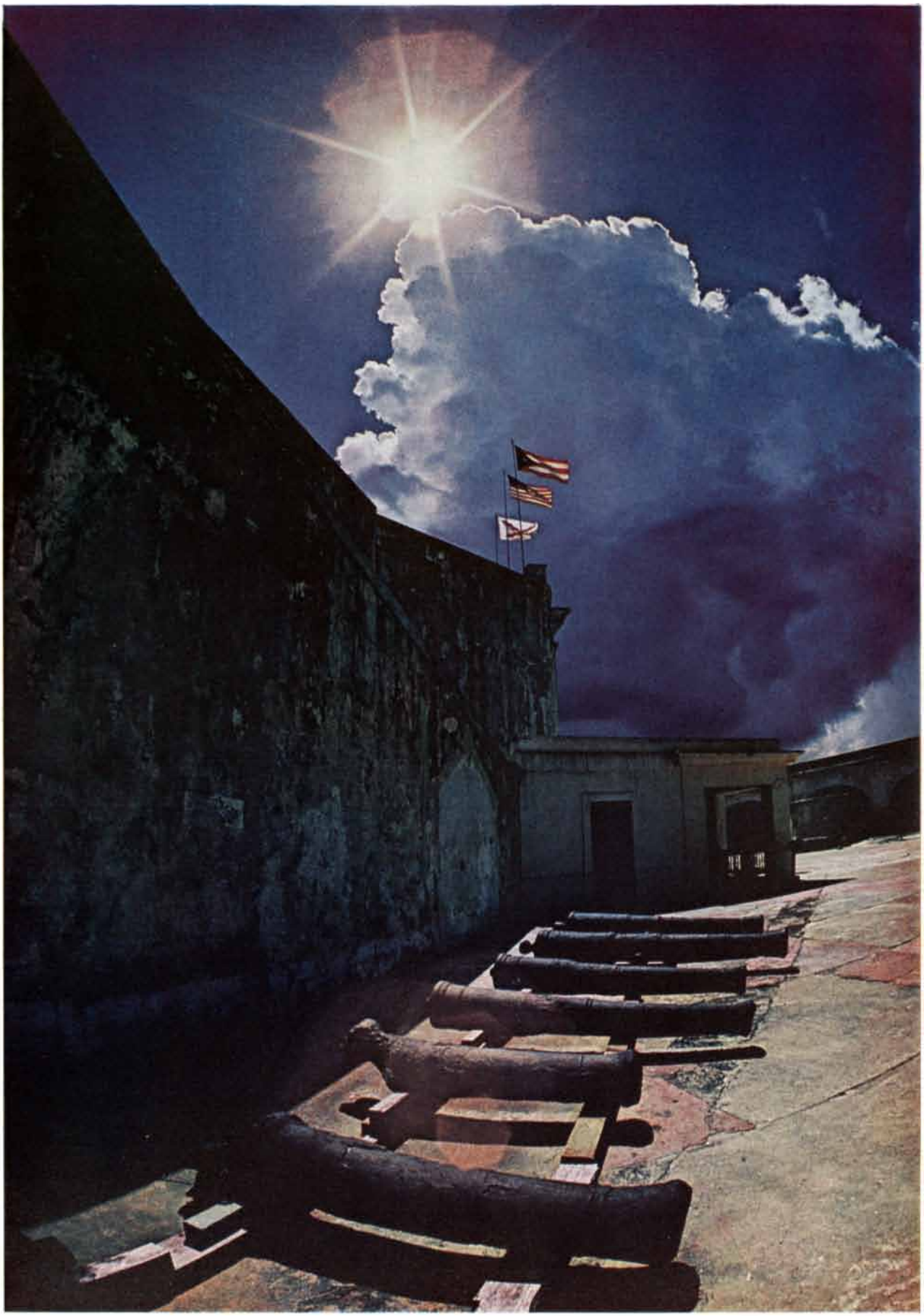
SCIENTIFIC AMERICAN



REVERSING FIGURES

ONE DOLLAR

December 1971



Spanish, American, and Puerto Rican flags over San Felipe de Morro Castle in San Juan.

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Established 1845 **SCIENTIFIC AMERICAN** December 1971 Volume 225 Number 6

ARTICLES

DEPARTMENTS

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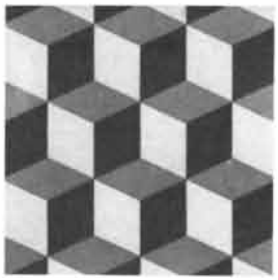

THE COVER

The pattern on the cover is an example of a class of ambiguous figures that exhibit depth reversal. The colored diamonds in the pattern are perceived as the surfaces of cubes. When the green diamonds are first viewed, they are seen either as the tops of one set of cubes or as the bottoms of another set of cubes. Then, if one looks steadily at the pattern for as long as a minute, the cubes reverse: what were the near corners of one set of cubes become the far corners of the other set. The cubes reverse spontaneously and often involuntarily, although with practice they can be made to reverse at will (see "Multistability in Perception," page 62). Such ambiguous figures have an intrinsic interest, and in addition an examination of why they seem to reverse provides information about the basic processes of perception.

THE ILLUSTRATIONS

Cover illustration by Jerome Kuhl

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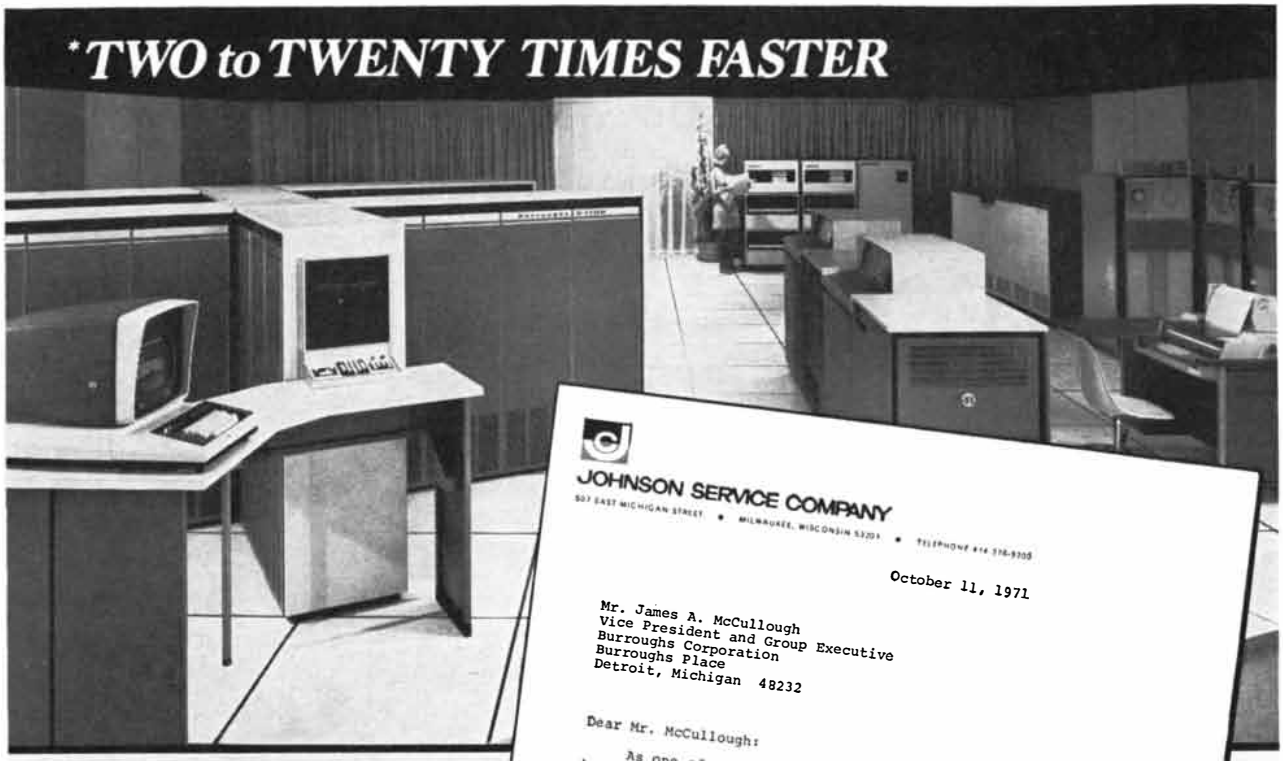
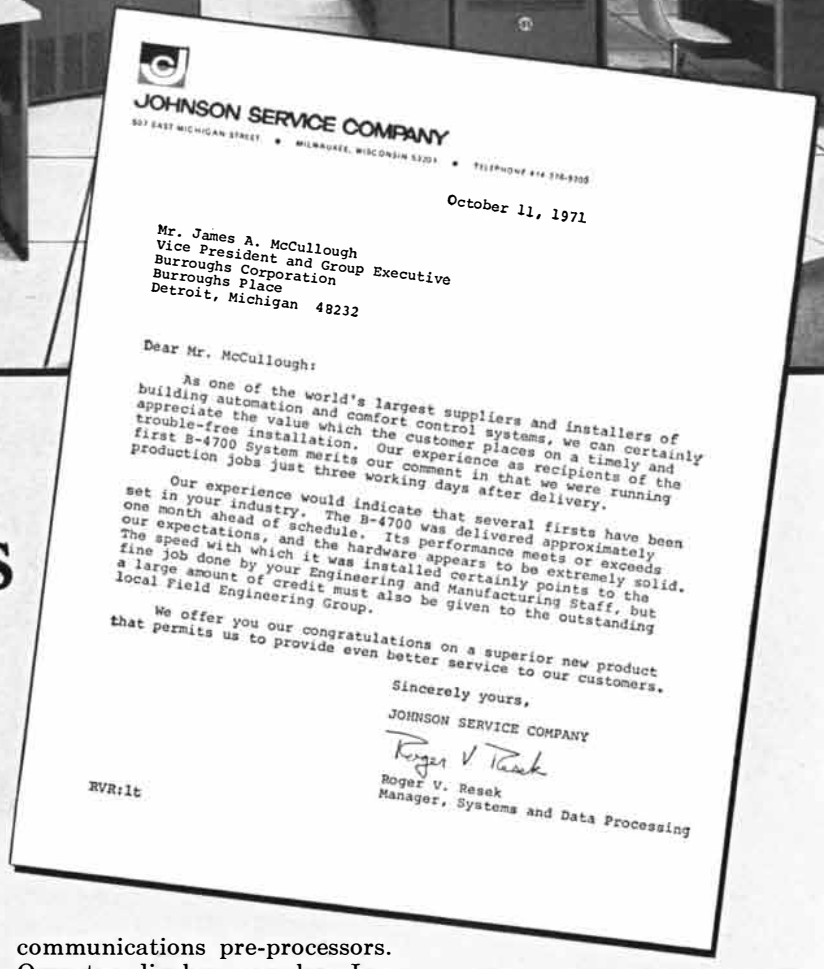
*TWO to TWENTY TIMES FASTER





JOHNSON SERVICE COMPANY

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October 11, 1971

Mr. James A. McCullough
Vice President and Group Executive
Burroughs Corporation
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Roger V. Resek

Roger V. Resek
Manager, Systems and Data Processing

RVR:lt

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LETTERS

Sirs:

I have read the issue "Energy and Power" [SCIENTIFIC AMERICAN, September] with interest, since it will help to bring many facts to a wider audience at a time when much misinformation is being made widely available. The detailed consideration of conversion efficiencies in the article by Claude M. Summers was particularly interesting, and I was hoping that he might mention some other efficiency factors that are most important to help the educated members of the public make better evaluations of controversial subjects in the news.

1. For pumped-storage plants, such as the one that Consolidated Edison wants on Storm King Mountain: What is the overall efficiency expected, expressed as the ratio of the power delivered to New York City from the system to the power initially generated by Con Edison's stations and fed to the storage system?

2. Machines now appear to be busy "eating up" the Western states with coal strip mining for such now infamous systems as the "Four Corners" electric power plants. Question: What is the *transmission-line* efficiency of this system for supplying power to, say, Los Angeles?

3. A similar question relates to the systems connections of "power grids." What is the transmission efficiency, say, for sending power to New York City from the Niagara Falls hydroelectric system?

4. The exciting possibility of flywheel storage systems for cars or subway cars has recently appeared in various technical sources. The energy storage per unit of *volume* in the flywheel is in principle independent of its (mass) density and is proportional to its continuing safe tensile-strength rating. By having an electric motor-generator attached to the flywheel, electric power (from utilities or a feedback from the drive motor-generator on braking or going downhill) is converted to mechanical stored kinetic energy. For a subway system the dynamic braking that feeds energy back to storage, rather than to brake heating, is quite attractive. What is apt to be quite important, however, is the *efficiency* of these various conversions. I have not seen any *numerical estimates.* Can the authors give any?

JAMES RAINWATER

Department of Physics
Columbia University
New York

Sirs:

Professor Rainwater's questions are significant in that they do involve controversial public issues and that answers have not been provided in the literature. They also emphasize the tremendous scope and complexity of problems involved in energy conversion. Answers to his questions will have to be generalized because modifying circumstances influence the numerical value of efficiency.

1. The efficiency of a hydroelectric plant is about 80 percent. The reverse process of pumping water to a higher elevation is also about 80 percent. Therefore the complete process of storage and retrieval is about 65 percent. The efficiency of the pumped-storage plant per se, however, is not as important as the effect it has on the remainder of the system. The large generators of the system should be operated at a constant base load to achieve maximum efficiency.

Loads above the base load, particularly the peak load, must be supplied by some auxiliary source such as a steam or gas turbine or a pumped-storage plant. When the system load is light, the large generators can be operated at close to the base load by pumping water into storage. When there is a heavy demand for power, the energy can be retrieved from storage while the large generators still operate at near maximum efficiency. Furthermore, the pumped-storage system contributes nothing to environmental pollution compared with that from the auxiliary steam or gas turbine. The actual values of overall efficiency of a particular system should be supplied by the engineers familiar with all related factors in that system.

2 and 3. Transmission-line efficiency is seldom referred to in the literature because it is quite high, and the equivalent term "transmission-line losses" is more meaningful. There are a great number of modifying factors and actual values for a specific system that again would have to be provided by engineers familiar with the details of the system.

For short moderate-voltage transmission lines, 50 miles or less in length, the real power losses are essentially proportional to the electrical resistivity of the conductor material, the length of the line and the square of the electric current in the conductor. For well-designed lines up to 110 kilovolts the real power-transfer efficiency excluding the transformers should be better than 97 percent.

For extrahigh-voltage transmission lines operating at voltages of 345, 500 and 765 kilovolts corona-loss and radio-interference considerations usually dictate the use of more conductor material than would be required on a current-carrying-capability basis. Such lines, however, transmit larger blocks of power over distances of several hundred miles, and generally include inductive-reactor and series-capacitor compensation elements. The real power-transfer efficiency of such lines should lie between 95 and 98 percent depending on the length of the line and assuming fair-weather conditions.

Transmission lines are designed for optimum economic performance, which involves investment costs as well as transmission-line losses. Therefore the best economic design may not be the most efficient.

4. Flywheel storage is limited to certain applications where the time period between storage and retrieval is short. Under these conditions the overall efficiency can be from 70 to 75 percent, and is governed mostly by the efficiency of the drive motor-generator. If the

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NAME

NEW ADDRESS

OLD ADDRESS

time cycle between storage and retrieval is long, most of the stored energy is lost in windage and friction and eventually the efficiency becomes zero. In short-cycle applications flywheel storage is a good system considering efficiency alone, but there are other problems such as the gyroscopic action that must be considered in its application.

CLAUDE M. SUMMERS

Rensselaer Polytechnic Institute
Troy, N.Y.

Sirs:

Chauncey Starr ["Energy and Power," SCIENTIFIC AMERICAN, September] says, "If the underdeveloped parts of the world were conceivably able to reach by the year 2000 the standard of living of Americans today, the worldwide level of energy consumption would be roughly 100 times the present figure." This spectacular figure is fortunately incorrect: the U.S. has one-sixteenth of the world's population and according to Starr consumes about 35 percent of the world's energy. Therefore the correct ratio is not 100 but rather $16 \times .35 \times$ (ratio of year 2000 population to present population). If this population ratio is taken as 1.5, we get 8.4 as the factor by which world energy consumption would have to increase.

JOHN MCCARTHY

Stanford University
Stanford, Calif.

Sirs:

I am grateful to John McCarthy for calling attention to the arithmetical error in my article. The number in the text should have read 10 rather than 100.

This number can be easily calculated from the bottom illustration on page 40. The present per capita energy consumption in the U.S. is five times the average for the world (which includes the U.S.). If one assumes that the world population might increase as much as 100 percent in the next 30 years, then if that population were to achieve today's standard of living in the U.S., the worldwide annual energy consumption would be 10 times the present amount.

CHAUNCEY STARR

University of California
Los Angeles

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1921: "In the short space of two or three years the radio telephone has become a practical, everyday means of communication, available for all manner of purposes and exceeding by far the wildest dreams of the early workers in this art. Radio telephone stations are being installed as rapidly as possible in every leading center in the U.S. for the purpose of sending out news bulletins, baseball scores, stock reports, crop surveys, weather bulletins, sermons, public speeches and even music. These broadcasting stations, as they are called, are being installed and operated by large manufacturing companies, who are anxious to furnish such service in the positive knowledge that it will increase the demand for radio apparatus. Already in many an American family the evening's diversions depend a great deal on the activities of the broadcasting stations. With a loud-speaking telephone on the living-room table and with a simple receiving set the members of the family can receive all the news that is worthy of widespread attention, followed by a musical program."

"In *The Journal of Physiology* Dr. E. D. Adrian of Trinity College, Cambridge, presents in a paper of some length the results of investigations on the recovery process of excitable tissues. The chief conclusion that Dr. Adrian reaches is that the return of excitability in such tissues does not necessarily occur at the same time as the decline of the electric response. This conclusion can be explained satisfactorily on the membrane theory by means of a scheme put forward by F. R. Lillie. According to this scheme, the decline of the electric response is caused by a reduction in the permeability of the surface membrane and the return of excitability is due to a return of the membrane from a stable to a more unstable condition. It now appears more than ever probable that this interpretation is correct."

"It is urged upon all biologists, through the medium of *Science,* to exert a 'more serious effort to rescue a few fragments of vanishing nature.' It is pointed out that the appalling rate at which our native flora and fauna are disappearing is obvious to all except those workers whose outlook is bounded by the walls of their laboratories. That biologists, above all others, are in a position to 'appreciate the loss of a single species or of natural associations of species' is patent. They are, furthermore, in an advantageous position to bring out by propaganda and with the weight of authoritative counsel the value of this conservation."

"An experiment conducted lately by English investigators points strongly to the conclusion that bats avoid colliding with objects during their swift nocturnal flights not so much by their sense of sight as by their acute hearing. A number of these animals were blindfolded and released in a room crossed with many wires and having in one of the walls an aperture just ample enough to enable the bats to escape into an adjoining room. They easily avoided the wires and flew through the holes without coming in contact with the partition. It was discovered that while flying they emitted a note almost inaudible to the human ear, and from this it was presumed that they perceived sound vibrations that were reflected from the obstructions and were guided thereby."

SCIENTIFIC AMERICAN

DECEMBER, 1871: "The condition of the working classes in England has become so low and degraded that the attention of thoughtful men of all shades of opinion is attracted to it, and it is a serious question to know what remedy to apply to save a large population from sinking to a depth of corruption and misery unparalleled in the history of modern civilization. A plan has been proposed by Mr. Scott Russell, the architect of the Crystal Palace, the Great Eastern and other large works, to form two committees, 'a Council of skilled work-men' and 'a Council of legislators,' to whom shall be referred the discussion of the whole question and the suggestion of proper remedies. Mr. Russell says: 'While there is no finer breed of working man in the world than the British skilled workman, there is no civilized country in which his interests are so little cared for, and in which the institutions, laws and customs are so unfavorable to his material well-being and to his moral development.' "

"It is an established fact that whalebone is growing scarcer and higher in price every year, and disasters such as the recent one to the whaling fleet in the Arctic Sea send it up to an enormous price. Whoever will discover a satisfactory substitute for this article has the prospect of a large reward. The important point to aim at is to get a substance that has the required degree of elasticity without being liable to break."

"In view of the enormous and increasing consumption of tobacco it has become a question of very great importance what effect upon the general standard of health is produced by it. The agitation of this subject has been increased during the past two years, and pamphlets, essays and lectures have developed in full strength the arguments for and against tobacco using. As smoking is the most popular and most powerful method by which the stimulant effect of the plant is obtained, it is principally upon this habit that the battle is waged. We have from time to time presented some of the arguments on both sides of the question, our object being to assist in arriving at truth in so important a matter; and though our confirmed taste for smoking and our natural desire to find it a harmless practice have led us to peruse with particular care all that has been said in its favor, we avow that neither reading nor experience has convinced us that the general use of tobacco is other than an unmitigated evil."

" 'We have,' says the new British publication *Nature,* 'on various occasions alluded to the large amount of encouragement to the pursuit of science afforded by the governing powers of the United States, both by the Federal Government at Washington and by those of the individual states. The sums of money voted for such purposes by our American relations would make the hair of our economical Government officials in this country stand on end and would be certain to provoke angry comment in our House of Commons, while the number of scientific men paid for carrying out the investigations and preparing reports on various subjects of great practical value for the welfare of the country would almost bear comparison with the number we pay for doing nothing or for obstructing all rational improvements.' "

SCIENCE/SCOPE

Laser rangefinders for the U.S. Army's M551 Sheridan armored reconnaissance vehicle will be built by Hughes under a contract awarded recently by Frankford Arsenal in Philadelphia. The Sheridan rangefinder consists of a ruby laser, telescope-like optics, and associated control panels and electronics. The production award followed the successes of the prototype program, which was begun in February 1970, and of the laser for the M60A1E2 tank, for which Hughes produced 300 systems.

Infrared fusing of tin-lead circuits on printed circuit boards is faster, better, and safer than the conventional hot oil immersion technique, declared a Hughes engineer in a paper he delivered last month before the California Circuits Association Symposium in Los Angeles. In the new Hughes method, circuit boards are automatically conveyed through an 11-foot-long oven where infrared lamps heat them to 350 or 400 degrees, fusing the lead and tin into solder. The infrared oven produces more in one hour than the immersion method does in eight, insures operator safety, and because of its lower temperatures almost eliminates damaged boards.

The Phoenix weapon system which Hughes is developing for the F-14 fighter has so far "demonstrated all major design performance requirements" during flight tests in a TA-35 test-bed aircraft, according to the U.S. Navy. Its successes include: launches and hits at extremely long ranges; two missiles guided simultaneously to two widely separated targets; a hit against a tightly turning drone simulating a maneuvering fighter; and one missile fired against two targets in close proximity to each other which picked out the correct target and passed within lethal range.

Mutual radio frequency interference between communications satellites and terrestrial point-to-point microwave relay systems in the 6 gigaHertz range they share will be measured and evaluated by a computer-controlled receiver/analyzer system Hughes is developing for NASA's Goddard Space Flight Center. The system will be tested following the launch of NASA's Applications Technology Satellite F in 1973. Purpose of the experiment is to determine the minimum size of ground antenna systems and the minimum transmitter power satellites can use without suffering interference from terrestrial microwave links for TV programming.

Circuit and logic design engineers: Hughes has immediate openings for circuit designers with experience in electronic warfare RF, video, and digital circuitry, and for logic designers with recent experience using TTL and MSI for real-time digital processing, preferably in logic design of radar video processing and associated equipment. Requirements: BSEE, two to six years of applicable experience, U.S. citizenship. Please write: D.K. Horton, Hughes Aircraft Co., P.O. Box 3310, Fullerton, Calif. 92634. Hughes is an equal opportunity M/F employer.

New products from Hughes include a full-wafer bipolar LSI designed for high-speed signal processing and digital filtering; it is comprised of 52 full adders and 96 gates for an equivalent of 616 gates integrated on a 1½-inch silicon wafer, and operates at a rate of 8 million multiplications of two 8-bit words plus sign per second....and a low-voltage 16-stage CMOS circuit designed for use in electronic watches; it utilizes Hughes' low-voltage technology which allows N and P channel MOS transistors to be manufactured on the same chip.

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HUGHES

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THE AUTHORS

ANDREW M. GREELEY and PAUL B. SHEATSLEY ("Attitudes toward Racial Integration") are at the National Opinion Research Center in Chicago; Greeley is director of the Center for the Study of American Pluralism there and Sheatsley is director of the Survey Research Service. Greeley, who is also professor of higher education at the University of Illinois at Chicago Circle, was graduated from St. Mary of the Lake Seminary in 1954 with a licentiate in sacred theology. He received his master's and doctor's degrees in sociology at the University of Chicago in 1961 and 1962 respectively. Greeley has just completed a two-year study of the Catholic priesthood. He is the author of a forthcoming book, *That Most Distressful People—the Taming of the American Irish,* and is working on a novel about the Irish in Chicago. Sheatsley was graduated from Princeton University in 1936 and joined the National Opinion Research Center after a few years of work as a newspaper editor and public relations director for the Newark baseball team in the International League. He writes that he has a large collection of traditional jazz and blues records and is "sometime editor of an irregularly published periodical called *Blues Research.*" He is "also a member of the Society for the Study of High and Low Probabilities (which translates into a weekly poker game)."

STEPHEN P. MARAN ("The Gum Nebula") is head of the advanced systems and ground observations branch at the Goddard Space Flight Center of the National Aeronautics and Space Administration and also project scientist for the orbiting solar observatories. "I became interested in astronomy," he writes, "after joining the Junior Astronomy Club (then at the American Museum of Natural History) as a sixth grader. I joined mainly because the dues were only 25 cents per year and included a subscription to *Junior Astronomy News,* of which I later became editor-in-chief. At Brooklyn College I was mainly interested in sports and was manager of the varsity teams in four sports, as well as being basketball announcer." Maran was graduated from Brooklyn College in 1959 with a degree in physics; he obtained his master's and doctor's degrees in astronomy at the University of Michigan. He describes his hobbies as "growing indoor plants according to the Thalassa Cruso method and brewing exotic varieties of coffee." He wishes to state that the views expressed in the article are his own.

JOHN H. CROWE and ALAN F. COOPER, JR. ("Cryptobiosis"), are respectively assistant professor of biology at the University of California at Davis and assistant professor of biology at California State Polytechnic College. Crowe was graduated from Wake Forest University in 1965 and obtained his Ph.D. from the University of California at Riverside in 1970. He writes: "One of my favorite hobbies is backpacking in California's Sierra Nevada. The scenic beauty of these mountains also affords ample opportunity for me to practice another of my favorite hobbies, photography." Cooper received his bachelor's degree at California State College at Pomona in 1964 and his Ph.D. from the University of California at Riverside in 1969. His favorite avocation is restoring antique automobiles.

VLADIMIR HAENSEL and ROBERT L. BURWELL, JR. ("Catalysis"), are respectively vice-president and director of research of the Universal Oil Products Company and Ipatieff Professor of Chemistry at Northwestern University. Haensel was born in Germany and spent his early youth in Moscow; he came to the U.S. in 1930 at the age of 16. He received his bachelor's degree in general engineering at Northwestern in 1935, his master's degree in chemical engineering at the Massachusetts Institute of Technology in 1937 and his Ph.D. in chemistry from Northwestern in 1941. He began work with the Universal Oil Products Company in 1937. Burwell was graduated from St. John's College in 1932 and received his doctorate in physical chemistry from Princeton University in 1936. He has been at Northwestern since 1939.

FRED ATTNEAVE ("Multistability in Perception") is professor of psychology at the University of Oregon. He grew up in rural Mississippi and received his bachelor's degree at the University of Mississippi in 1942. After obtaining his Ph.D. from Stanford University in 1950 he taught for two years at the University of Mississippi, worked for the Air Force, "which tolerantly allowed me to spend five years doing basic research on visual perception," and spent a year at the University of California at Berkeley before going to Oregon. "I live in the country near Eugene," he writes, "surrounded by woods of oak and fir, in a never quite finished house that my wife and I have built for ourselves with sporadic help from family and friends."

KNUT SCHMIDT-NIELSEN ("How Birds Breathe") is James B. Duke Professor of Physiology at Duke University. Born in Norway, he received his Dr. Phil. at the University of Copenhagen in 1946 and joined the faculty at Duke in 1952. He writes that over the past decade he has studied "all sorts of animals: desert rodents and crab-eating frogs; ostriches, roadrunners and zebra finches; jackrabbits and bats; various reptiles such as lizards, snakes and turtles, and a variety of other animals including the famous egg-laying spiny anteater, the echidna." Much of his work has involved temperature regulation under heat load, particularly when the heat is produced by activity such as running or flying. This work, he says, "has developed into a general interest in the energetic cost of locomotion," involving studies of the energy expenditure for swimming, running and flying.

D. E. SMYLIE and L. MANSINHA ("The Rotation of the Earth") teach respectively at the University of British Columbia and the University of Western Ontario. Smylie holds a bachelor's degree in engineering physics from Queen's University at Kingston, a master's degree in mathematics from the University of Toronto and a doctorate in earth physics from the same institution. Mansinha was born in India and received all his education there except for his Ph.D., which he obtained from the University of British Columbia in 1963.

JOHN CARRINGTON ("The Talking Drums of Africa") teaches botany at the Kisangani campus of the Congo National University, where he went in 1965 after his mission station at Yalemba was destroyed by Basimba rebels. Except for furloughs he has been in the Congo since 1938, three years after he was graduated from the University of London. His comparative study of the drum language used by various tribes in the Upper Congo was the subject of his thesis for his Ph.D., which he received from the University of London in 1947. In 1970 he received a master's degree in plant taxonomy at the University of Reading. He writes that he is "currently interested in exploring the botanical lore of Upper Congo villagers and their expression of it in everyday life as well as in their literature and music."

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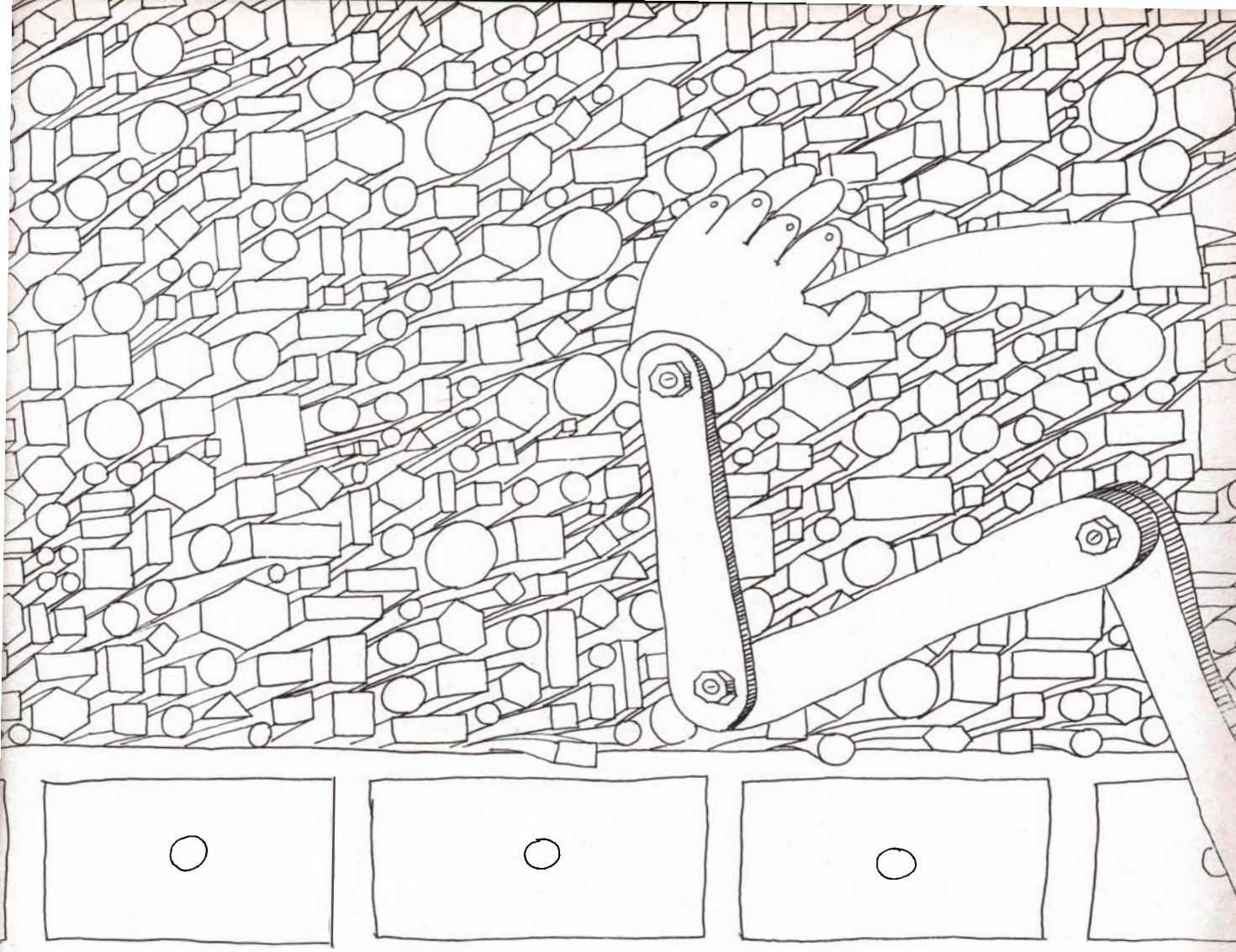

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Attitudes toward Racial Integration

The third in a series of reports spanning nearly three decades shows a continuing advance in the support of desegregation by U.S. whites. The trend has not been affected by the racial strife of recent years

by Andrew M. Greeley and Paul B. Sheatsley

We present herewith the third report in these pages on the findings of the National Opinion Research Center concerning the attitudes of white Americans toward the position black Americans should occupy in American society. Together the reports cover a period of almost 30 years, which is the length of time the Center has been sampling these attitudes. In that time the trend has been distinctly and strongly toward increasing approval of integration. For the most part the trend has not been slowed by the racial turmoil of the past eight years. We believe these findings have significant political implications.

Our sample usually consists of about 1,500 people, chosen to represent a spectrum of the population of adults in the U.S. About 1,250 of the people in the sample are white, and it is with the attitudes of whites that this article is concerned. With a sample of this size we are able to test for opinion by age, region, income, occupation, education, religion and ethnic origin.

Since the last report [see "Attitudes toward Desegregation," by Herbert H. Hyman and Paul B. Sheatsley; SCIENTIFIC AMERICAN, July, 1964] the U.S. has experienced what is probably the most acute crisis in race relations since the end of the Civil War. City after city suffered racial violence, with Watts, Detroit and Newark only the most conspicuous among them. Martin Luther King, the apostle of nonviolence, was assassinated and another spasm of riots shook the nation. King was replaced on the television screen by a far more militant brand of black leader. Stokely Carmichael, H. Rap Brown, Eldridge Cleaver, Bobby Seale and LeRoi Jones became nationally known. Newspapers carried accounts of blacks arming for guerilla warfare. The Black Panthers appeared on the scene, and in several cities there were gunfights between the police and the Panthers. Columnists, editorial writers and political analysts worried publicly about the "backlash." George Wallace did well in several primaries, and in the presidential election of 1968 he made the most successful third-party showing in many decades.

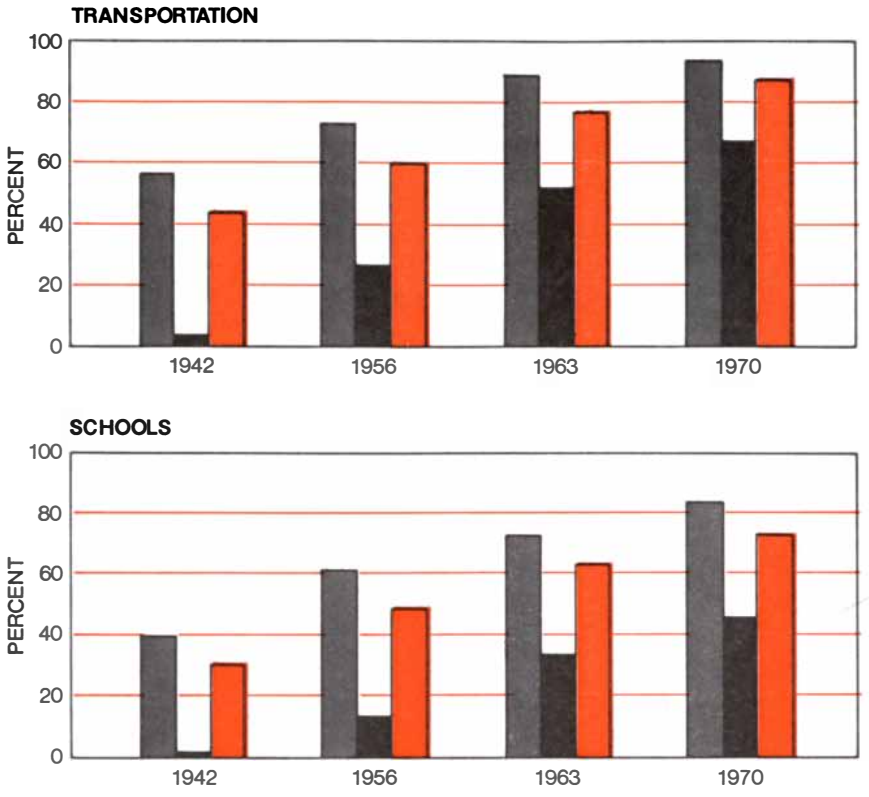
Concurrently with these dramatic events the attitudes of white Americans toward desegregation continued to change almost as though nothing was happening. The data do offer a certain amount of evidence of a negative reaction to black militancy; we shall return to this point. Even so, the negative reaction has not impeded the steady increase in the proportion of white Americans willing to endorse integration.

Two questions have been asked throughout the period covered by the National Opinion Research Center's surveys, which were conducted in 1942, 1956, 1963 and 1970. One question is: "Generally speaking, do you think there should be separate sections for Negroes in streetcars and buses?" The other question is: "Do you think white students and Negroes should go to the same schools or separate schools?"

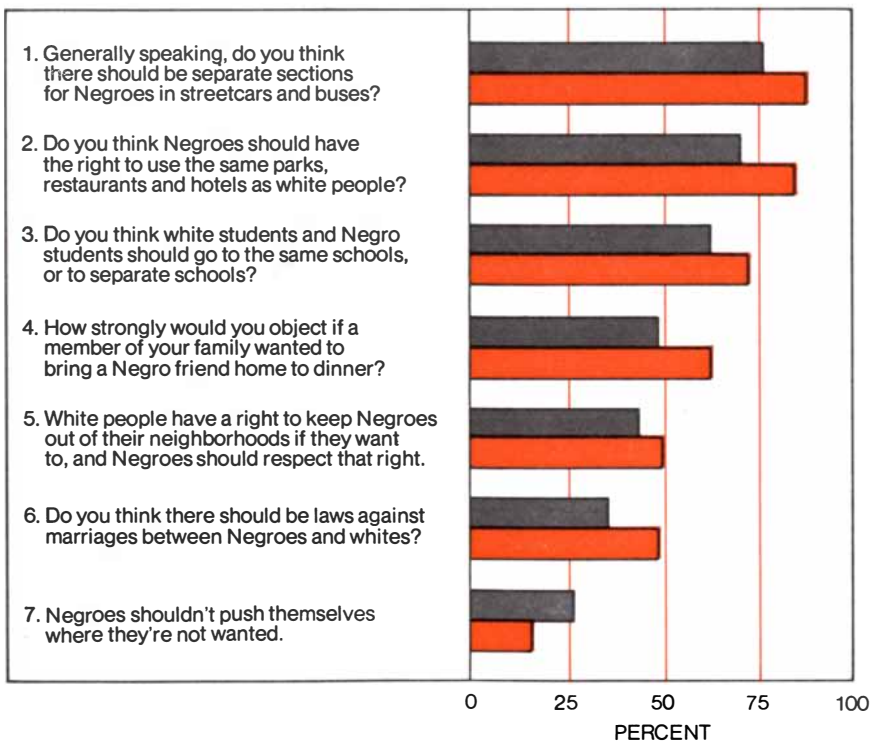
In 1942 some 44 percent of the white population was willing to endorse integrated transportation [*see top illustration on next page*]. By 1970 the proportion had doubled, reaching 60 percent in 1956 and 88 percent in 1970. In the South the change has been even more pronounced. Only 4 percent of white Southerners accepted integrated transportation in 1942; by 1970 the proportion was 67 percent.

Integrating transportation, then, is no longer a significant issue. In retrospect it may well be said that the right of blacks to sit where they wish in public vehicles is not a very important right, since obtaining it does not notably improve the welfare of black people. From the perspective of 1971 such an assertion is certainly correct, but when one recalls what the attitudes were in 1942 or even in 1956, the change is striking. In less than 15 years—since Martin Luther King's historic boycott in Montgomery, Ala.—integrated transportation has virtually disappeared as an issue.

The integration of schools, however, is still an issue, even though in the North the idea is now endorsed by eight of every 10 respondents. In 1942, 2 percent of whites in the South favored school integration. By 1956 the proportion had increased to only 14 percent. Since 1956—two years after the U.S. Supreme Court's decision in *Brown* v.



TREND OF WHITE OPINION on integration of transportation and schools is traced for 28 years in surveys by the National Opinion Research Center. For each of the four surveys cited the percentage of people giving an integrationist response is shown for the North (*gray*), South (*dark gray*) and nation (*color*). Questions were identical in each survey.



SCALED QUESTIONS were employed in 1963 and 1970 to test white opinion. The property of the scale is such that if a respondent has rejected one item, the likelihood is that he also rejected all the succeeding items. The bars at right reflect the percentage of integrationist responses elicited by each question in 1963 (*gray*) and seven years later (*color*).

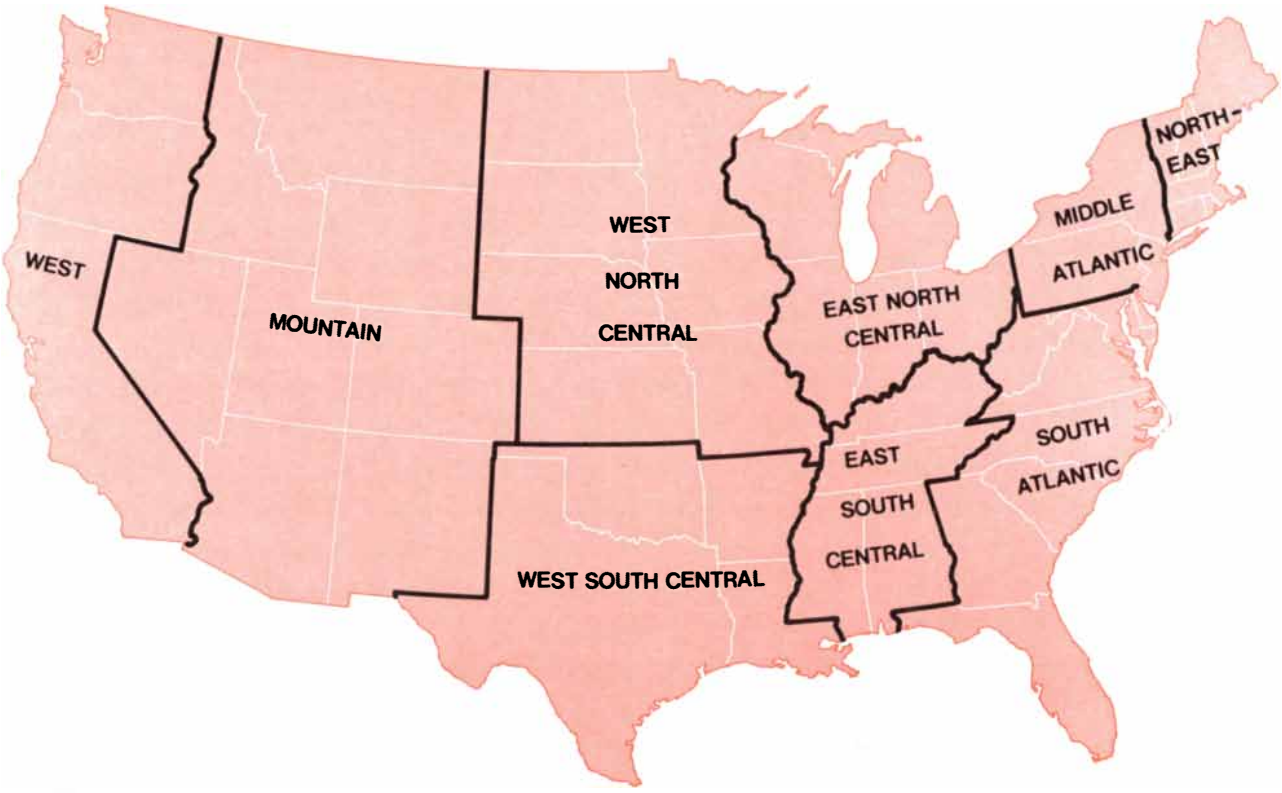
Board of Education—the proportion of Southern whites accepting school integration has increased sharply. Now almost half of them favor it. Nationally the support of whites for integrated schools is 75 percent.

An interesting pattern emerging in the successive surveys is that the proportion of the Northern white population supporting integration at one point in time is quite close to the proportion of the total white population accepting it at the next point in time. If the trend continues, one can expect a majority of the white population in every region to accept integrated schooling by 1977. Perhaps 60 percent of Southern whites will be willing to accept it. One could then say that desegregating schools had ceased to be a significant issue.

In 1963 the National Opinion Research Center employed in its survey a "Guttman scale" prepared by Donald Treiman of the Center's staff. The properties of a Guttman scale (named for Louis Guttman, now of the Israeli Institute of Public Opinion, who devised it) are such that if a respondent rejects one item on the scale, the chances are at least 90 percent that he will also reject all the items below it [*see bottom illustration at left*]. We used a similar scale in 1970. It has seven questions, relating successively to integrated transportation; integrated parks, restaurants and hotels; integrated schools; having a member of the family bring a black friend home for dinner; integrated neighborhoods; mixed marriages, and blacks intruding where they are not wanted.

The first six items on the scale show a consistent increase in support of integration between 1963 and 1970. Indeed, on transportation, public facilities, schools and having a black guest to dinner a large majority of whites respond favorably. Only neighborhood integration and mixed marriages still divide white Americans about equally. If present trends persist, it seems likely that both neighborhood integration and racial intermarriage will be accepted by 60 percent of the white population at the time of the next report by the National Opinion Research Center in about seven years.

Only on the last item of the Guttman scale does one find any evidence of a backlash response to events of the period from 1963 to 1970. In 1963 about 25 percent of the white population rejected the idea that "Negroes shouldn't push themselves where they're not wanted." By 1970 the proportion taking



NINE REGIONS of the U.S. appear in evaluations by the National Opinion Research Center of responses to the scaled questions. The regional designations are the ones employed by the U.S. Bureau of the Census. Alaska and Hawaii were not included in the sampling.

an integrationist stand on this issue had dropped to 16 percent. One can surmise that this change is a response to black militancy, but even if that is so, the change has not interfered with increasing support for specific aspects of racial integration.

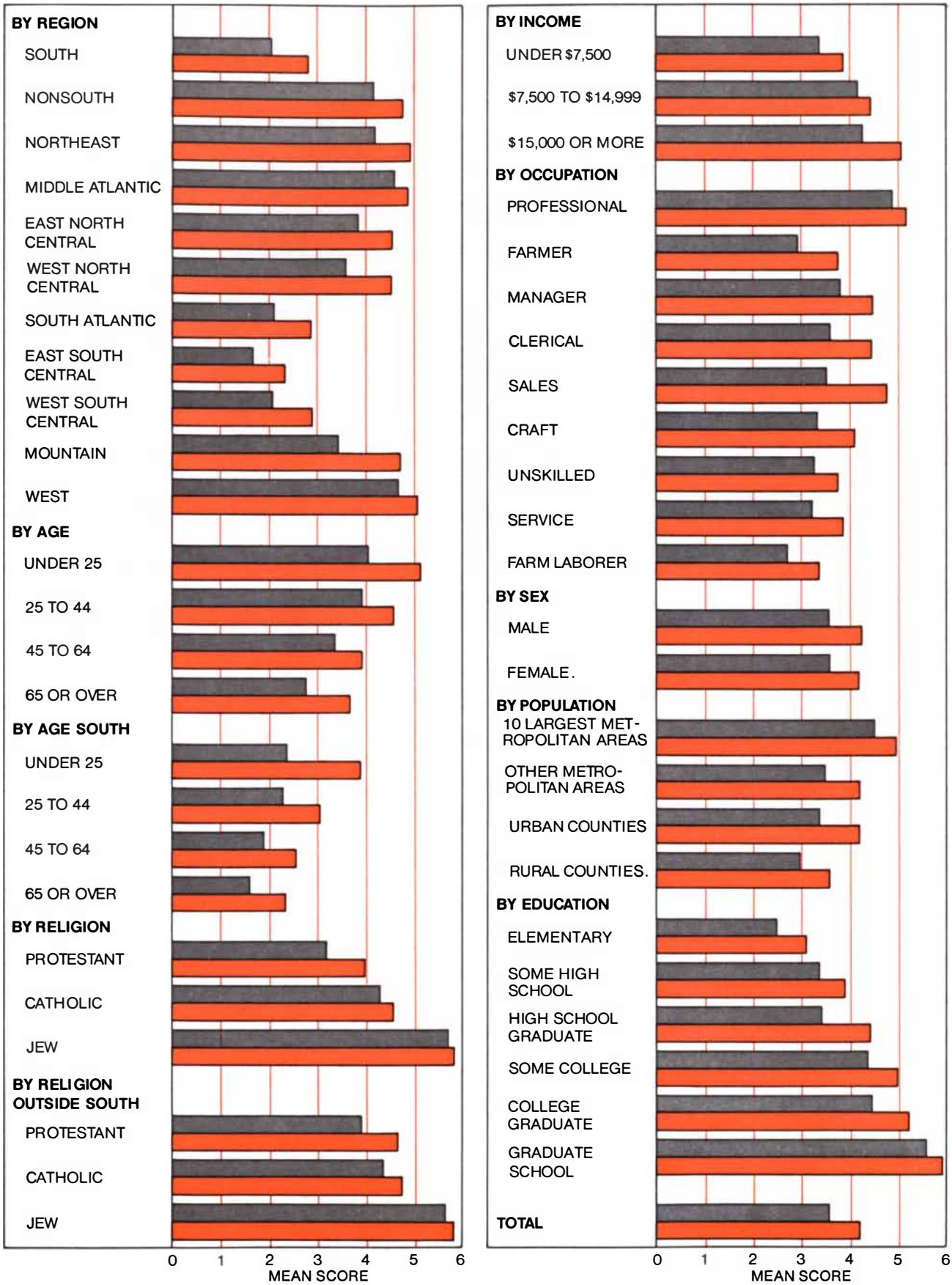
The seven items of the Guttman scale comprise a "pro-integration scale" on which each respondent can be assigned a score ranging from 0 to 7 depending on the number of pro-integration responses he gave: 0 if he gave none and 7 if he favored integration in all his responses. From there it is a small step to compute mean scores for various population groups to see where the strongest integrationist and anti-integrationist positions are. The mean score for all white Americans in 1970 was 4.2, indicating that the typical American accepts at least four of the seven integrationist attitudes. The mean score in 1963 was 3.57 [*see illustration on next page*]. Another way of putting it is that the average white American in 1963 could live with integrated transportation, integrated education and integrated parks, restaurants and hotels; he could accept, although just barely, a black dinner guest. In 1970 he was no longer concerned about having a black dinner guest and was no longer ready to totally reject the possibility of integrated neighborhoods.

As one might expect, the greatest differences are regional. The typical Southerner accepts completely only the first two items on the scale, although he leans toward the third. The typical Northerner accepts the first four items and is strongly disposed toward the idea of accepting neighborhood integration. The net change of mean score, however, has been somewhat larger in the South than in the North: .77 compared with .6.

Also as one might expect, the highest pro-integration scores are among people aged 25 and under, both in 1963 and in 1970. As one might not have expected, the most dramatic increase in any age group is among the young: the mean score for people under 25 has increased by 1.08. It is even more striking that young Southerners manifest the largest net rise in integrationist scores: from 2.35 to 3.87. In other words, Southerners under 25 were as likely to be integrationist in 1970 as Northerners aged 45 to 64, whereas in 1963 young Southerners were less likely to be integrationist than Northerners over 65. Moreover, Southerners at each of the three older age levels had higher pro-integration scores than the people at the next-younger age level had had in 1963. Thus one can say that the changing attitudes in the South entail not only the influx of a new generation but also an actual change of position by many older white Southerners.

The mean scores of the various groups can be summarized by saying that there is an increase in integrationist sympathies in all segments of the white population, with the most notable changes at present taking place among people whose scores in the past were the lowest. The net result is that groups at the extremes seem to be moving toward a more central position. For example, the Jewish score is still higher than the Protestant score, but the Protestant score is catching up. People who have been to graduate school still score higher than people who went no further than grammar school, but the difference between the two groups is narrowing. Similarly, whites in large cities continue to be more likely than whites in rural areas to endorse integration, but again the difference is declining. Finally, unskilled workers and service workers now have scores closer to the scores of professionals.

To a certain extent this catching up is a statistical artifact. People with high scores in 1963 did not have much room for improving the scores by 1970. Nonetheless, the diminishing differences indicate that the turbulence of the past



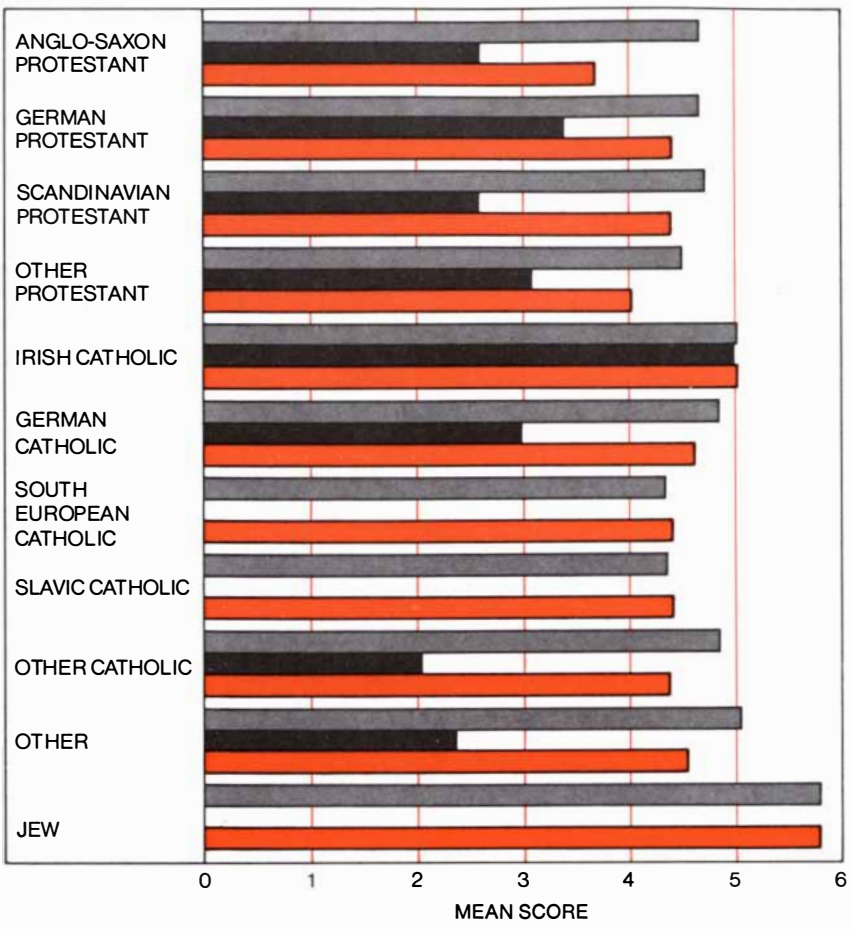
CHANGING SCORES on the pro-integration scale are depicted by various groupings for 1963 (*gray*) and 1970 (*color*). The range of scores is obtained by assigning each respondent a rating of 0 to 7 depending on the number of pro-integration responses he gave to the scaled questions. His score was 0 if he gave no pro-integration replies and 7 if he took an integrationist position on all the questions. The individual scores were used to compute the mean scores shown here for the various regions and groups and for the nation.

few years has not interfered with increasing sympathy for integration, even among people who were least likely to have been sympathetic in the early 1960's. Their scores on the integration scale can increase more rapidly than the scores of people who sympathized with integration in 1963 because there is more room for improvement in their scores. It is not a statistical artifact that the scores continue to increase. That phenomenon reflects changing attitudes in the midst of turmoil and conflict.

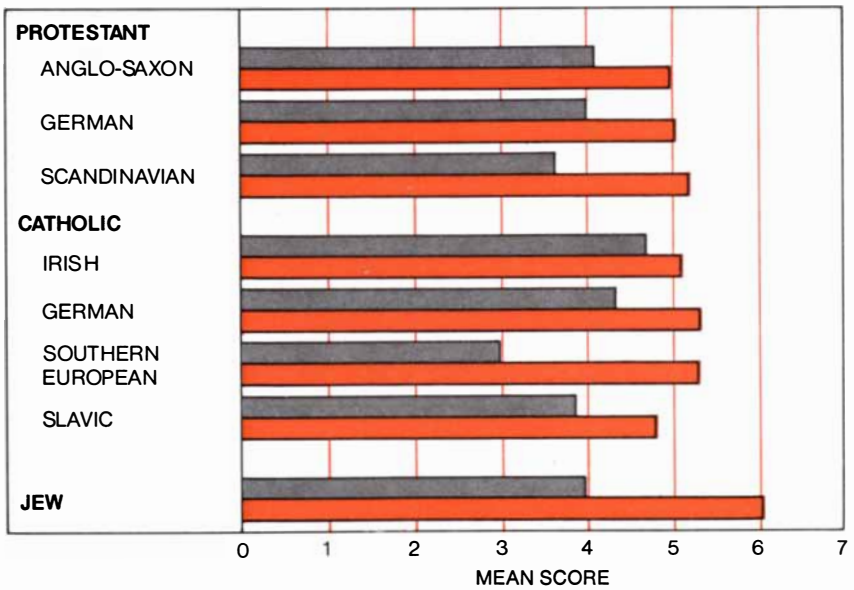
Popular mythology would lead one to believe that if there is a backlash, it would be most likely to appear among the "white ethnic" groups, because they are less securely established in American society and also are the people most likely to be in direct conflict with newly militant blacks over such issues as jobs, education and housing. No ethnic-background question was asked in 1963, so that we are unable to compare the attitudes of white ethnics in 1963 and 1970. The 1970 scores alone, however, provide little evidence for the existence of a white backlash [*see top illustration at right*]. When the ethnics are compared with white Protestants in the North (the only comparison that is valid since most ethnics live in the North), it turns out that Irish Catholics and German Catholics have a higher average score on the integration scale than the typical white Protestant Northerner does. Catholics of southern European origin (mostly Italian) and Catholics of Slavic origin (mostly Polish) scored only slightly below Anglo-Saxon Protestants. Whatever direct confrontations there may be between blacks and Catholics of southern European and eastern European origin, they have had only a marginal effect on the integrationist sympathies of these two groups. It is also interesting to note that Irish Catholics are second only to Jews in their support of integration.

Considering the integrationist sentiments of ethnic groups by educational background, one finds that insofar as there is a white ethnic backlash it seems to be limited to people who have not finished high school [*see bottom illustration at right*]. (The sample here is small, so that the finding is at best suggestive.) Among people who have graduated from high school, only Slavic Catholics have scores lower than the white Protestant mean (and not much lower). Irish Catholics, German Catholics and southern European Catholics have scores that are higher than the Anglo-Saxon Protestant mean.

One of the most sensitive issues in



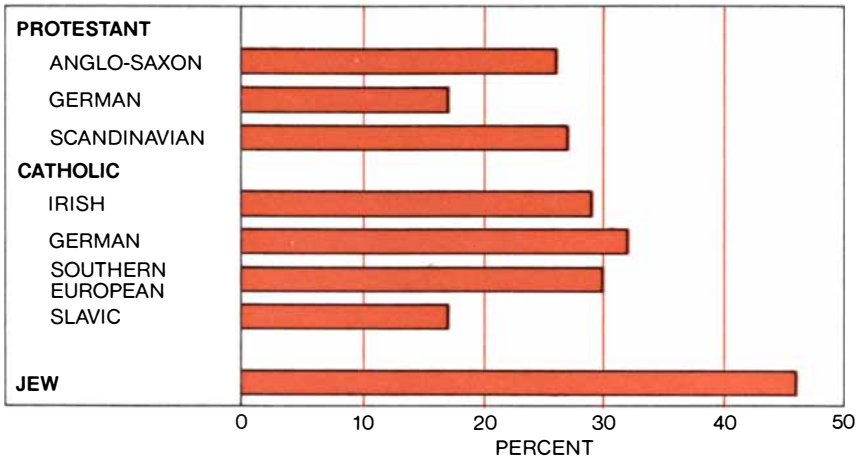
RELIGIOUS DISTRIBUTION of integrationist responses to the scaled questions is depicted by region for the questions asked in 1970. The distribution also reflects certain ethnic groupings. In each case the mean scores are shown for the North (*gray*), the South (*dark gray*) and the entire country (*color*). Three groups had little representation in the South.



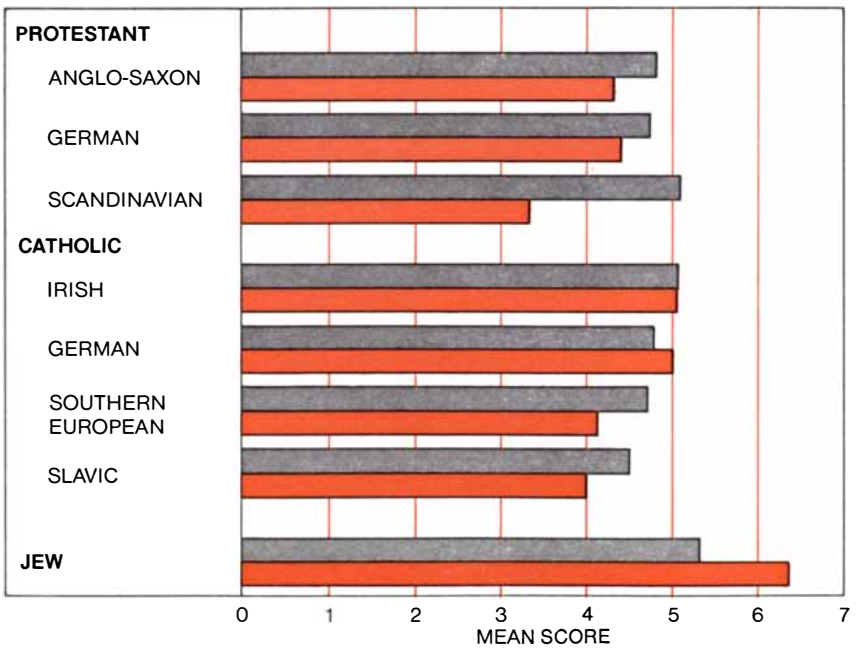
EDUCATIONAL BACKGROUND of Northern whites responding to the scaled questions is shown by religious and ethnic groupings. Mean scores are shown according to whether the respondents had less than a high school education (*gray*) or had at least been graduated from high school (*color*). Many respondents in the second group went beyond high school.

Northern urban politics is open-occupancy legislation, which forbids racial discrimination in housing. An item measuring attitudes on this subject was included in the 1970 survey [*see upper illustration below*]. Three of the four ethnic groups—the Irish, the Germans and the largely Italian southern Europeans—are slightly more likely than Northern Anglo-Saxon Protestants to support such legislation. Only among the Slavic Catholics is there less inclination to be in favor of open-housing laws.

The question of the relation between blacks and white ethnics is a complicated one, lying largely beyond the scope of this article. On the basis of the data available to us, however, there seems to be no evidence of racism among white ethnics except in the Slavic Catholic group. To the extent that a backlash exists even in that group, it seems to be concentrated among the less educated people. The other three Catholic ethnic groups are, if anything, even more integrationist than the typical Northern Protestant white—although less so than the typical Northern Jew.



ATTITUDES ON HOUSING appear in the percentages of Northern whites who gave integrationist responses to the question, "Would you favor or oppose making it against the law to refuse to sell or rent houses and apartments to Negroes?" Eight groups are shown.



ETHNIC VIEWS are portrayed according to the residential situation of the respondents. The bars show the mean scores on the list of scaled questions of Northerners living in neighborhoods with a black population of less than .5 percent (*gray*) and people in more integrated areas (*color*). The analysis was made to test the assumption that proximity to blacks might lower the scores of ethnics who are in competition with blacks for housing and jobs.

Why, then, is the popular image of the "hard hat" ethnic racist so powerful? Our colleague Norman Nie has suggested that the reason may well be that the ethnics, particularly those from southern and eastern Europe, are "next up the ladder" from blacks and are most likely to be in competition with them for jobs and housing. We were able to put this hypothesis to a crude test by dividing the respondents to our survey into two groups, one comprising people who live in places where fewer than .5 percent of the residents are black and one comprising people who live in places with a higher proportion of blacks. Our supposition was that ethnics would be more likely to be in the latter group and that scores on the integration scale would be lower in that group.

Although the number of respondents is small, the findings indicate confirmation of Nie's suggestion [*see lower illustration at left*]. Every ethnic group in an integrated area had a lower integration score than members of the same ethnic group in nonintegrated areas except the Irish Catholics, the German Catholics and the Jews. The differences between Anglo-Saxon Protestants and southern Europeans were slight when the comparison was made among people living in nonintegrated areas. Thus there does seem to be a correlation between lower scores and feeling "threatened." It is interesting to note that living close to blacks raises the level of Jewish support for integration. German support rises slightly with propinquity, but the Irish score is unaffected.

In the light of our various findings one inevitably asks: Where is the backlash? It could be said to appear in the responses to the item on blacks intruding where they are not wanted. The decline between 1963 and 1970 in the proportion of whites willing to reject the item is, however, fairly evenly distributed in the white population, although it is somewhat less likely to be observed among the young and among the better educated [*see illustration on opposite page*]. It is also somewhat less likely to be observed among Catholics than among Jews and Protestants. (Here is further evidence against the validity of the notion that there is a "white ethnic racist backlash.") In short, if the extent to which whites are now somewhat more likely to say that blacks should not intrude where they are not wanted is a measure of negative response to black militance, the response is fairly evenly distributed among the Northern white population.

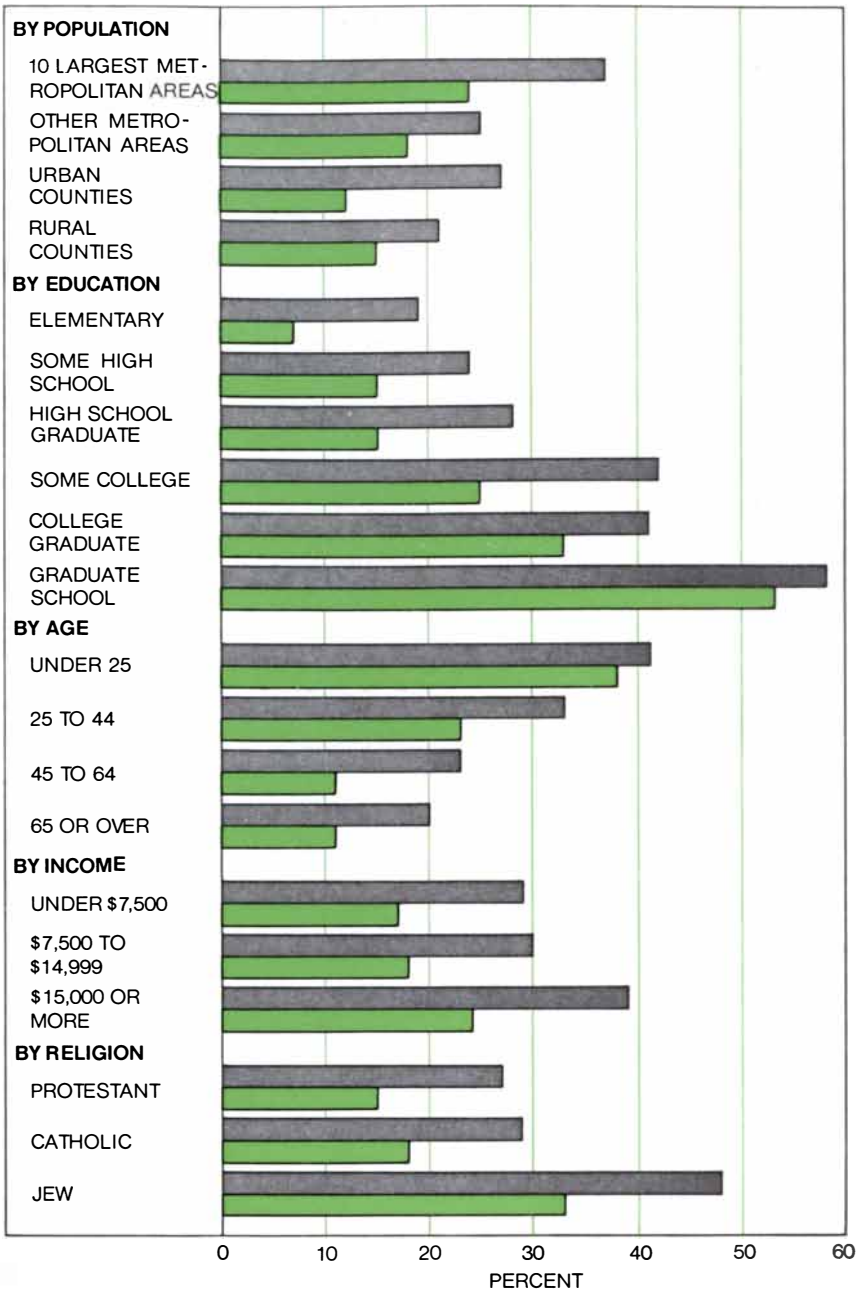
Two important observations are in or-

der. First, attitudes are not necessarily predictive of behavior. A man may be a staunch integrationist and still flee when his neighborhood is "threatened." A man with segregationist views may vote for an integrationist candidate if the key issues of the election are nonracial.

Second, responses to the interviewers from the National Opinion Research Center may reflect what the white American thinks he ought to say rather than what he believes. Nonetheless, even a change in what one thinks one ought to say is significant. In any case, no one can measure another person's inner feelings with full confidence. If someone asserts that notwithstanding our evidence white ethnics are racists, it seems to us that a claim is being made to some kind of special revelation about what the white ethnic really thinks.

Although a change of attitude does not necessarily predict a change in behavior, it does create a context in which behavioral change becomes possible. Increasing support for school integration, for example, makes it somewhat easier for official policies of school integration to be pursued. The increase in support for integrated neighborhoods may facilitate at least tentative solutions to the vexing problem of changing neighborhoods in Northern cities. In sum, changing attitudes—even the dramatic ones monitored by our group over the past 30 years—do not by themselves represent effective social reform, but one can see them as a sign of progress and as creating an environment for effective social reform.

It is not our intention to argue that the data point to a need for more militant or less militant action by blacks. The appropriate strategy for blacks is also beyond the scope of this article. To note that American attitudes have changed is not to suggest that all is well in American society; it is merely to note that there has been change. Presumably no one will argue that the fact of change should go unrecorded because it will diminish the motive to work for further change.

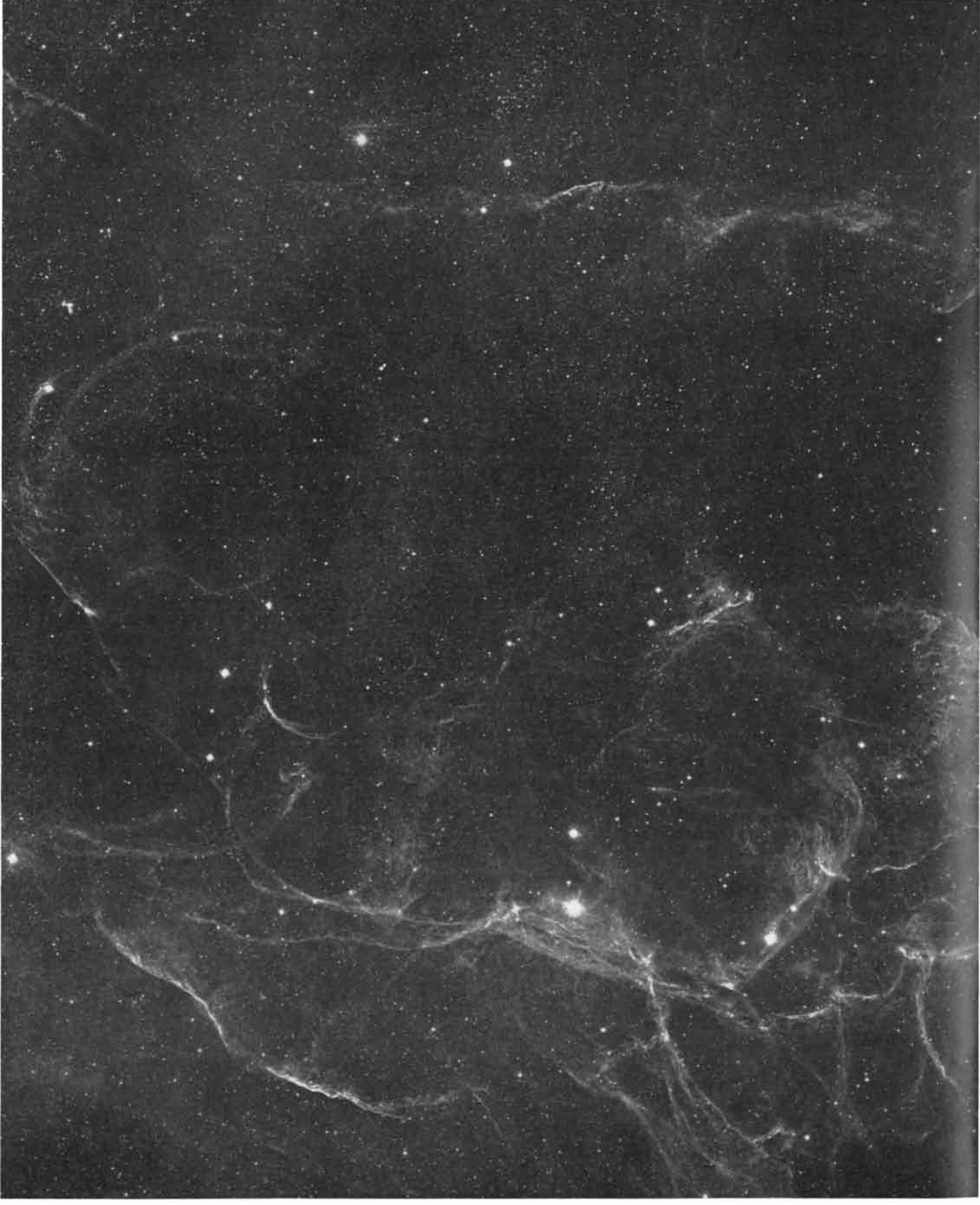


EVIDENCE OF BACKLASH appears in a uniform decline between 1963 (*gray*) and 1970 (*color*) in rejection by Northern whites of the proposition that blacks should not intrude where they are not wanted. Even this change of attitude, however, did not alter the prolonged trend toward greater acceptance of integration by whites on more specific issues.

It has been argued recently that American politics are politics of the center, albeit a floating center. We do not want to deny the utility of such a model, but we would point out that at least on the matter of racial integration the center has floated consistently to the left since 1942. We would also note that the shift has not been impeded (or accelerated either) by the racial turmoil of recent years.

The political significance of these conclusions is twofold. On the one hand, the political leader who adjusts his style to an anti-integration backlash is, on the basis of our data, adjusting to something that does not exist. On the other hand, the leader who thinks social conditions are suitable for leading the center even further to the left on the subject of racial integration would find strong support for his strategy in the findings made by the National Opinion Research Center.

We cannot say with measurable precision that sustained pressure by the national leadership is the reason for the increasing support for integration since 1942. It does seem reasonable to argue, however, that if every president since Franklin D. Roosevelt had not endorsed an integrationist position, the change of attitude monitored by our surveys might not be anywhere near as impressive as it is. By the same token it is reasonable to argue that if the present Administration and future ones put forward the case for integration more forcefully, they will find basic attitudinal support among the nation's white people.



VELA *X* SUPERNOVA REMNANT, a wispy structure located roughly at the center of the Gum Nebula, appears in this photograph, made in blue light by Bart J. Bok of the University of Arizona with a 24-inch telescope at the Cerro Tololo InterAmerican Observatory in Chile. A pulsating radio source, or pulsar, has recently been discovered near the center of the region, but it has not yet been identified optically. A photographic mosaic showing a much larger region of the Gum Nebula appears on pages 22 and 23.

THE GUM NEBULA

This enormous cloud of ionized hydrogen is the largest known nebula in our galaxy. Its full extent and nature are currently the subject of considerable controversy among astrophysicists

by Stephen P. Maran

Early in 1938 the late Otto Struve and his colleagues embarked on a pioneering investigation of gaseous nebulas in the Milky Way, using a powerful new spectrograph at the McDonald Observatory on Mount Locke in southwestern Texas. This instrument, with an effective length of 150 feet, was more efficient at detecting small nebulas than was the spectrograph at the Yerkes Observatory in Williams Bay, Wis., where Struve had been observing earlier. In addition some southerly stars that were unobservable at Williams Bay were among the important targets of the work on Mount Locke.

The first observations with the new spectrograph were made in February, 1938, and by the following year more than 50 regions of the sky had been studied. Then on February 10, 1939, Struve and his colleagues detected a faint nebula near the bright star Gamma-2 Velorum, low in the southern sky in the constellation Vela. The evidence consisted of red light emitted at a wavelength of 6,563 angstroms, an emission characteristic of hydrogen atoms in gaseous nebulas. A few nights later the observers searched for nebulosity in the vicinity of Zeta Puppis, another bright star located in the constellation Puppis some 7.5 degrees north of Gamma-2 Velorum. In this case the observations were inconclusive, in part because of the confusing effects of "airglow" radiation from molecules in the upper atmosphere, and Struve concluded that there was "probably no emission."

Since 1939 astronomers have studied the Vela-Puppis area in the optical, radio, ultraviolet and X-ray bands of the electromagnetic spectrum with increasingly sensitive techniques, and today we know that both stars observed by Struve are immersed in an enormous region of ionized hydrogen that retards and broadens the signals from pulsars, absorbs the background radio emission from our galaxy and envelops a number of interesting and perhaps related objects. At one time it was even suspected that the solar system might lie within the outer bounds of this giant cloud of gas. Although that possibility has since been ruled out, the full extent and nature of the region, now called the Gum Nebula after the late Australian astronomer Colin S. Gum, are still under investigation and are currently the subject of considerable controversy.

The survey that first indicated the great extent of the Gum Nebula was begun in 1950 by C. W. Allen at Mount Stromlo near Canberra in Australia. Allen worked with a 130-foot nebular spectrograph patterned after the 150-foot instrument at the McDonald Observatory. A single observation with the Mount Stromlo instrument produced a good spectrogram of a selected spot in the sky. Moreover, it was possible to detach the Schmidt camera section of the large spectrograph and use it to photograph the sky directly through a prism mounted on its front end. This stratagem had the advantage of simultaneously recording the spectra of all sufficiently bright objects in the 10-degree field of view, although the spectra were of poorer quality. Spectrograms obtained by both methods quite early in the history of the Mount Stromlo survey suggested that the nebula near Gamma-2 Velorum was larger than had been realized.

By February 5, 1952, when a forest fire swept Mount Stromlo, Gum had taken charge of the survey there. The fire caused considerable damage on the observatory grounds, and the 130-foot spectrograph was one of the casualties. The Schmidt camera was salvaged and repaired, however, and it was soon in service again. Gum now used it primarily for filter photography. A red filter enabled him to emphasize the hydrogen light, and in fact it was on a mosaic assembled from several of these pictures of the Vela-Puppis region that the nebula was first clearly seen [*see illustration on next two pages*].

The sensitivity of the Schmidt photographs was limited by the airglow and by the collective light of many dim stars in the Milky Way. Thus, although the nebula appeared on the mosaic as an irregular loop with a diameter of 20 degrees, Gum recognized the possibility that its fainter portions might cover an even larger area. Indeed, he noted that a small nebula toward the east, at a radial distance of 20 degrees, might be part of the same object.

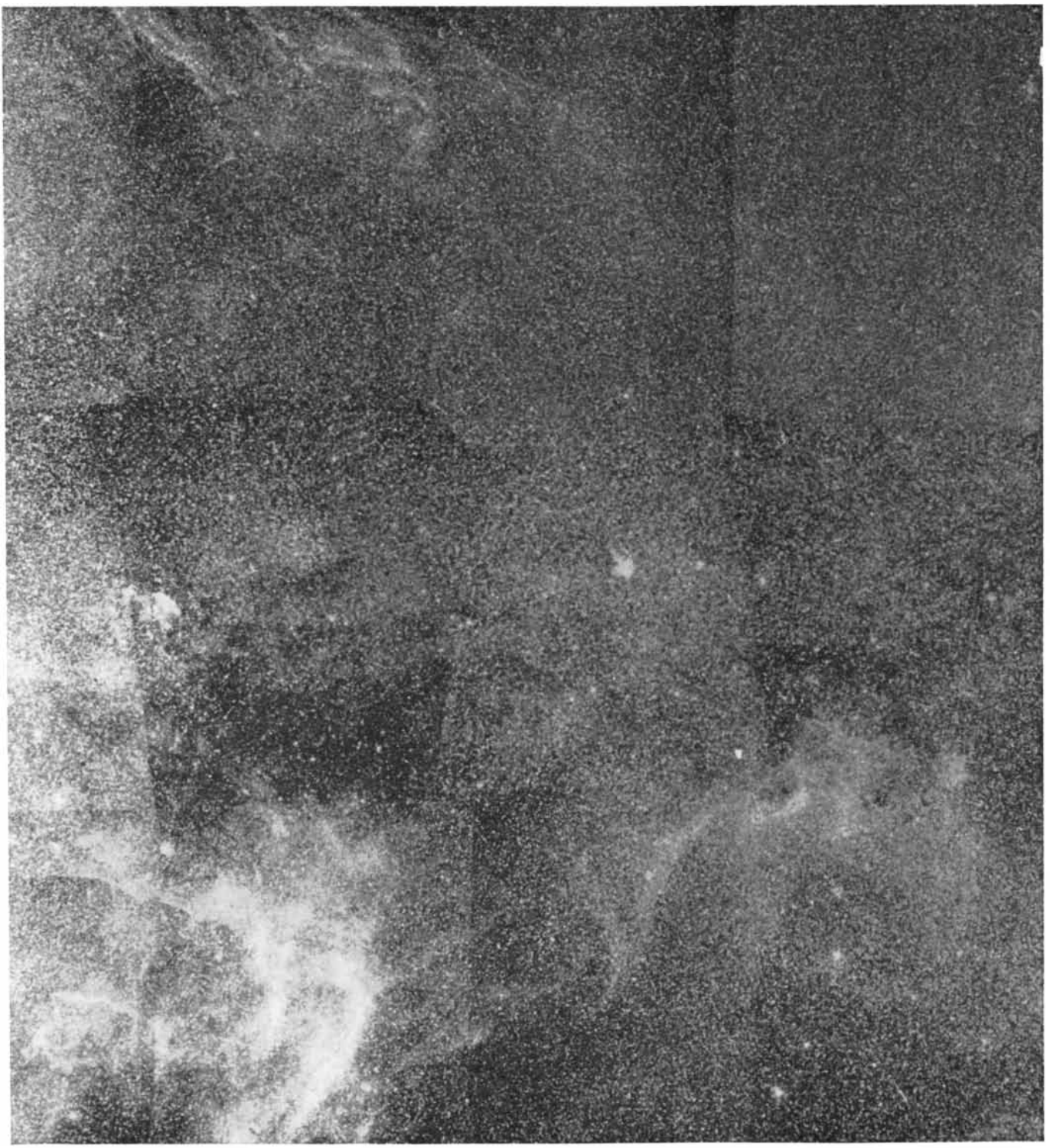
The term "nebula" formerly was applied indiscriminately to distant celestial objects of diffuse appearance. Later it was shown that some, such as the Great Nebula in Andromeda, were actually galaxies, that is, organized systems of stars, star clusters, gas and dust resembling our own Milky Way. "Nebula" now means a cloud of gas and dust, one of the many components of a galaxy. These objects are classified in terms of their physical characteristics, and the various types are found to correspond to distinct processes of formation or mechanisms of luminosity. For example, a planetary nebula (such as the Ring Nebula in Lyra) is a small shell centered on a single star that is thought to have ejected it, and shines by the fluorescence process: ultraviolet light from the star excites the nebular atoms, which then emit photons of light at visible wavelengths. Supernova remnants (such as the Crab Nebula) are produced by the explosion of a massive, highly evolved star; they expand at velocities as high as

10,000 kilometers per second and radiate as a result of collision with the ambient interstellar gas and also through the "synchrotron" process (in which electrons emit radiation as they spiral outward along lines of magnetic force). Reflection nebulas (such as those found in the Pleiades star cluster) shine because they contain dust particles that scatter the light from adjacent stars. Dark nebulas (such as the Horsehead Nebula in Orion) are similar clouds that lack illuminating stars. H II regions (such as the Great Nebula in Orion) consist of interstellar matter in which hydrogen, the most abundant gas, is ionized by the ultraviolet light from nearby hot stars; unlike planetary nebulas and supernova remnants, these objects do not consist of matter ejected by the associated stars. The H II regions are also known as

GUM NEBULA is shown in this photographic mosaic made in red light by A. W. Rodgers, C. T. Campbell, J. B. Whiteoak, H. H. Bailey and V. O. Hunt at the Mount Stromlo Observatory near Canberra in Australia. The predominantly red glow of the nebula is attributable to light emitted as a result of the recombination of ionized hydrogen atoms; this radiation, referred to as hydrogen-

Strömgren spheres after the astrophysicist Bengt Strömgren, who worked out the theory that enables one to calculate their diameter from the temperatures and luminosities of the exciting stars and the density of the gas.

Gum interpreted his nebula as a Strömgren sphere ionized by the combined effects of Gamma-2 Velorum (actually one member of a double star) and Zeta Puppis. This explanation, although questioned on at least one occasion, was generally accepted until quite recently. The rather crude information available in 1952 suggested 170 parsecs as the most likely distance for Gamma-2 Velorum. (A parsec is equal to 3.26 light-years.) Simple trigonometry then implied a diameter of 60 parsecs for the 20-degree loop, making it large but not unique among the known H II regions.



alpha emission, is characteristic of the light emitted by gaseous nebulas. The long dimension of the photographic mosaic is approximately 50 degrees of arc. The entire nebula, including fainter outlying regions, covers an area measuring at least 60 by 30 degrees. A chart showing the positions of some of the prominent features of the nebular region is presented at the top of the next page.

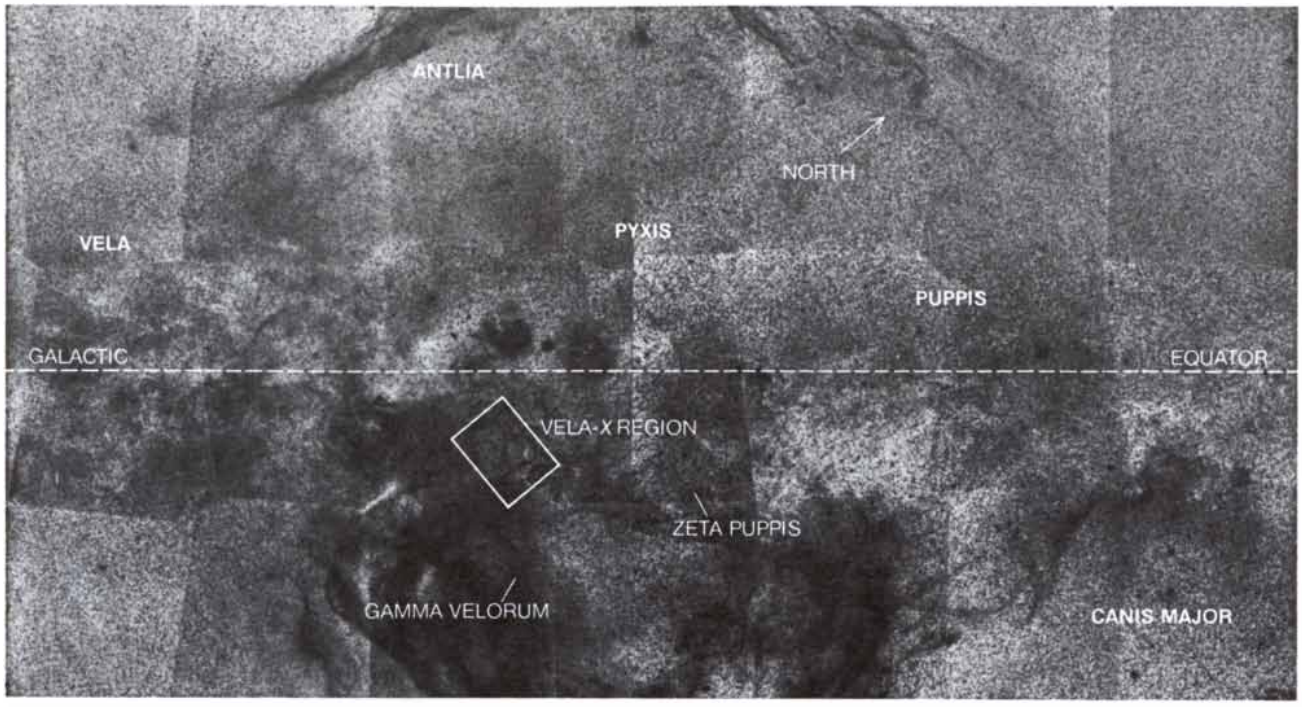
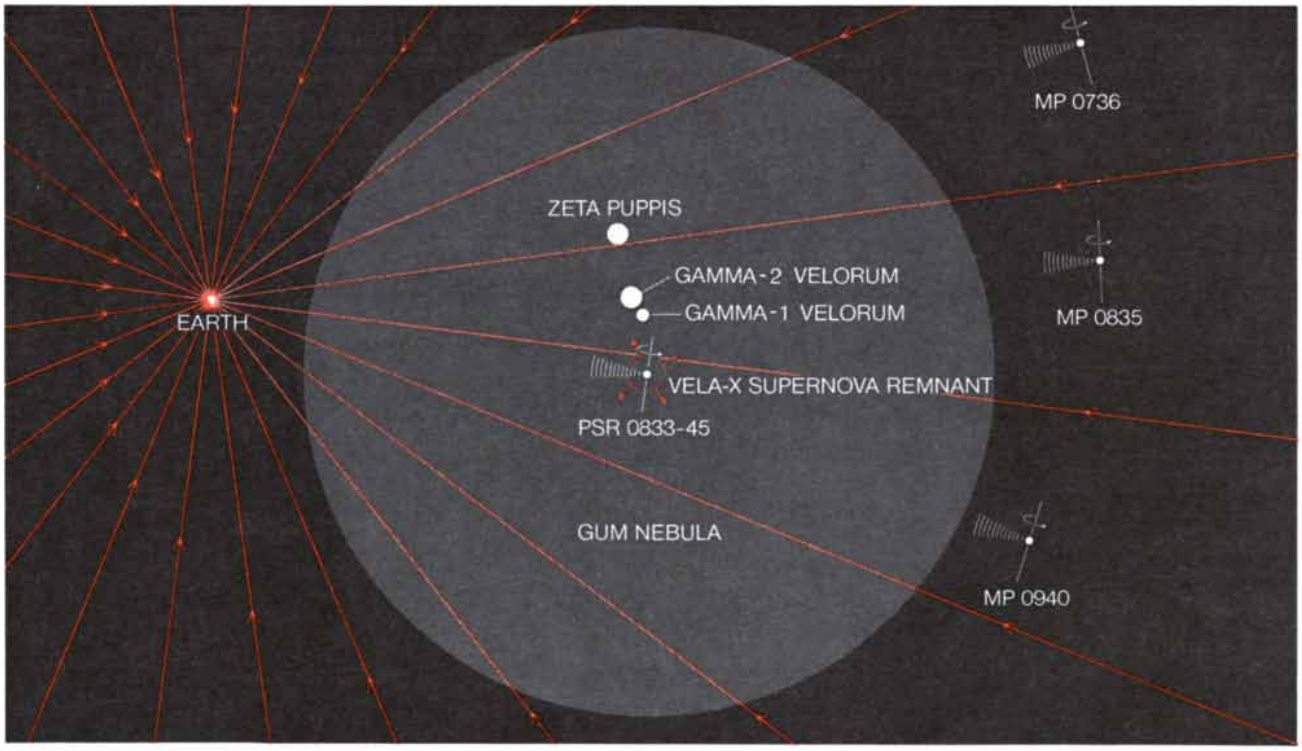


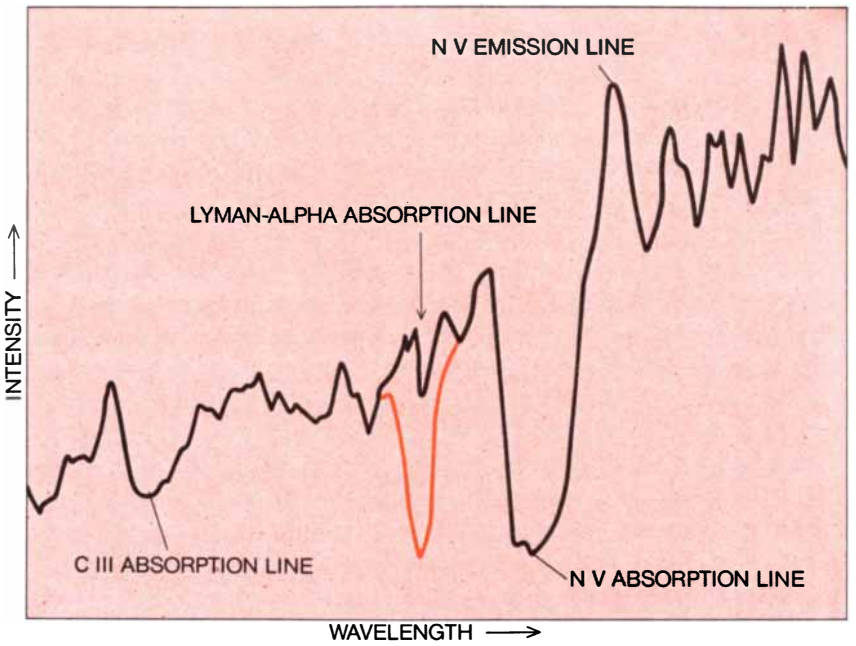
CHART OF GUM NEBULA is superposed on this reduced negative of the mosaic on the preceding two pages. The rectangle corresponds to the area of the Vela *X* supernova remnant shown in the photograph on page 20. Constellations are denoted by heavier type.



SIZE OF GUM NEBULA and its distance from the earth are drawn to scale in this illustration. Measured in parsecs (a unit of astronomical distance equal to 3.26 light-years), the nebula is about 360 parsecs in radius and its center lies about 460 parsecs from the earth. Stars are not drawn to scale; moreover, their exact spatial relations within the nebula are not known. The physical properties of the nebula were determined from several kinds of observations. The galactic background radiation (*long colored arrows*), consisting of low-frequency radio waves emitted by the "synchrotron" process from cosmic ray electrons moving through the magnetic field of the galaxy, was mapped with a satellite-borne antenna, which found a deficiency in the direction of the Gum Nebula, indicating absorption by the ionized gas of the nebula. Radio pulses from three pulsars (designated MP 0736, MP 0835 and MP 0940) seen through the nebula are retarded twice as much as those from the central pulsar (designated PSR 0833–45), indicating that the first three pulsars lie beyond the nebula or just within its far edge. Ultraviolet absorption attributable to interstellar neutral gas outside the nebula has been observed by rocket-borne detectors, indicating that the near edge of the nebula is some 100 parsecs from the earth.

To reduce the confusing effect of the airglow and thus increase the sensitivity of his search for nebulas, Gum selected a photographic emulsion and a filter that together excluded the strongest airglow emissions while recording light in a band 250 angstroms wide centered on the red emission line of hydrogen (the hydrogen-alpha line). He also developed a technique for coping with the background starlight in the brighter parts of the Milky Way, within five degrees of the galactic equator. This technique involved making an additional photograph of each field with a different filter-emulsion combination that isolated wavelengths in a band centered at 6,000 angstroms. A dim nebula, shining predominantly in the light of hydrogen, would be recorded only on the hydrogen-alpha photograph, whereas the stars would appear on both pictures. Gum matched a positive transparency of the hydrogen-alpha exposure with a negative of the other one and then used the "sandwich" to expose a paper print. On the final record the starlight was nearly canceled, whereas nebulas appeared as dark, diffuse areas. By these means Gum was able to record fainter portions of the large nebula in Vela-Puppis, and as a result in 1955 he raised his estimate of the dimensions of the gaseous region to 40 by 30 degrees.

The 1955 analysis of the Gum Nebula was based both on the Australian survey and on photographs taken by Bart J. Bok and his associates at the Boyden Station of the Harvard College Observatory at Bloemfontein in South Africa. In the same year Gerard de Vaucouleurs, who had been observing at the Yale-Columbia Southern Station near Canberra, announced the discovery of a faint nebula near the south celestial pole that seemed to lack an exciting star. In 1956 Gum confirmed the discovery and suggested that the exciting stars were actually Zeta Puppis and Gamma-2 Velorum, some 35 degrees away. In other words, he proposed that the De Vaucouleurs object was a distant fragment of the large nebula. Meanwhile Rudolph Minkowski of the Mount Wilson and Palomar Observatories found other fragments on Palomar Observatory Sky Survey plates of the northern parts of the Gum Nebula, and Campbell M. Wade, Jr., of the Boyden Station recorded additional faint nebulosities. Taking all these new findings together, Gum appraised the size of the nebula once again and judged it to be 60 by 30 degrees. The dimensions of the Gum Nebula seemed to grow with each new set of more sensitive observations, and at this point Gum suggested that the solar system might lie near or even within the boundaries of the nebula.



ULTRAVIOLET SPECTRUM of Zeta Puppis, a bright star located within the Gum Nebula, contains a prominent downward peak (*color*) attributable to the absorption of the starlight by interstellar neutral hydrogen located between the earth and the near edge of the nebula. The discovery of this Lyman-alpha absorption feature in such spectrographic records led to the conclusion that the Gum Nebula does not in fact envelop the solar system, as had previously been suspected. The tracing is based on an analysis of sounding-rocket data by Edward B. Jenkins of Princeton University. The black curve represents the intrinsic ultraviolet spectrum of Zeta Puppis, that is, the ultraviolet spectrum as it would appear if there were no absorption by interstellar hydrogen. Other prominent spectral features indicated include a bright emission line (*upward peak*) associated with ionized nitrogen (N V) and two blue-shifted absorption lines (*downward peaks*) attributable to absorption within the stellar atmosphere by ionized carbon (C III) and ionized nitrogen (N V).

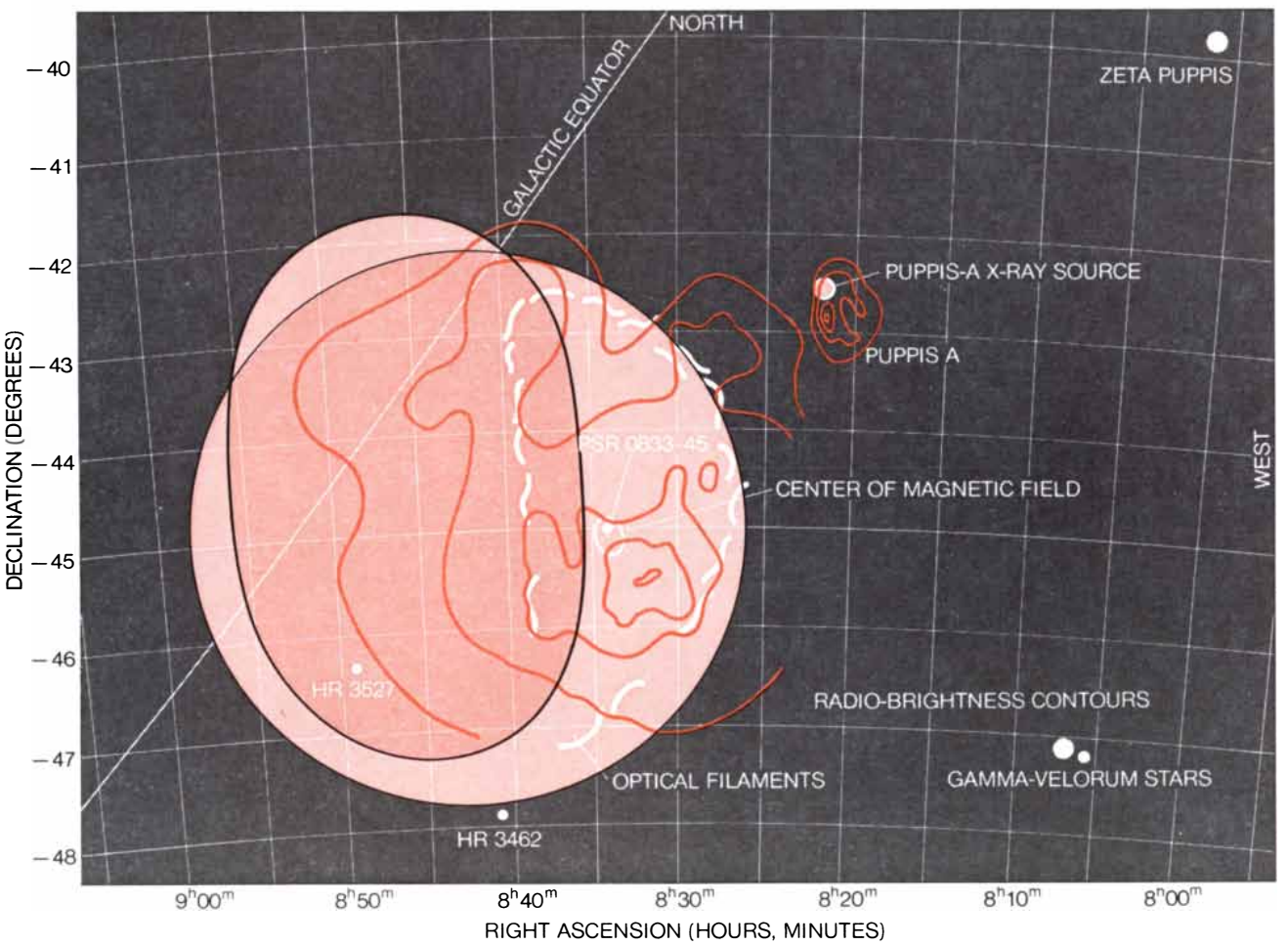
In 1960 Gum died in a skiing accident in the Swiss Alps. Since he surveyed the nebula other hydrogen-alpha observations, notably those made by Hugh M. Johnson at Mount Stromlo, have revealed additional outlying fragments at radial distances of some 40 degrees, and progress with other techniques has led to several independent clues to the properties of space in the direction of Vela-Puppis. Last year John C. Brandt, Theodore P. Stecher and I (all of the Goddard Space Flight Center of the National Aeronautics and Space Administration) and David L. Crawford of the Kitt Peak National Observatory reviewed this information and took a new look at the size and nature of the Gum Nebula. The appearance of the nebula had led Johnson to speculate that rather than being a Strömgren sphere it might be the remnant of an explosion, presumably of a giant supernova. No evidence has been found to support the conjecture, and it appears to us that the truth lies somewhere between this notion and Gum's opinion that the nebula is a Strömgren sphere.

We found that the nebula is even larger than had been thought, although it clearly does not envelop the solar system. This conclusion follows from several investigations conducted with sounding rockets by George R. Carruthers of the Naval Research Laboratory, by Donald C. Morton, Edward B. Jenkins and Neil H. Brooks of Princeton University, and by Andrew M. Smith and Stecher of the Goddard Space Flight Center. These experiments recorded the spectra of the nebular stars Gamma-2 Velorum and Zeta Puppis in the ultraviolet-wavelength region. A key result was the observation of a broad absorption line at 1,216 angstroms, the wavelength of the characteristic Lyman-alpha line of neutral hydrogen. This feature is not typical of the spectra of these stars; since it cannot be formed by neutral hydrogen in their atmospheres, which should produce a much narrower absorption line, it is attributed to interstellar neutral (un-ionized) hydrogen. The gas must be somewhere along the lines of sight from the earth to Gamma-2 Velorum and Zeta Puppis. The two stars

are both quite hot, with temperatures of between 30,000 and 40,000 degrees Kelvin (degrees Celsius above absolute zero), as judged both from the rocket spectra and from ground-based observations. This means that they must ionize the interstellar hydrogen to distances of many parsecs, as Gum had recognized. Thus the neutral gas cannot be near Gamma-2 Velorum and Zeta Puppis but must lie nearer our end of each line of sight [*see bottom illustration on page 24*]. It follows that the Gum Nebula does not reach all the way to the earth.

The strength of the Lyman-alpha absorption lines enables us to determine the total number of neutral hydrogen atoms along the line of sight. This quantity, called the "column density" of hydrogen, is expressed as the number of atoms in a column with a cross section of one square centimeter. If we knew the average number of hydrogen atoms per cubic centimeter in the column, then we could derive its length and hence the distance to the edge of the Gum Nebula. The abundance of hydrogen in our region of the galaxy has been estimated from observations of the radio-emission line of hydrogen at a wavelength of 21 centimeters. Moreover, the density of interstellar hydrogen found locally within the solar system has been determined from measurements with an ultraviolet photometer on the OGO-5 (Orbiting Geophysical Observatory 5) satellite. This instrument observed the brightness of the sun's Lyman-alpha light that is scattered by the interstellar gas. On the basis of these estimates of hydrogen abundance and the column density of hydrogen from the sounding-rocket experiments, the distance to the edge of the Gum Nebula is about 100 parsecs.

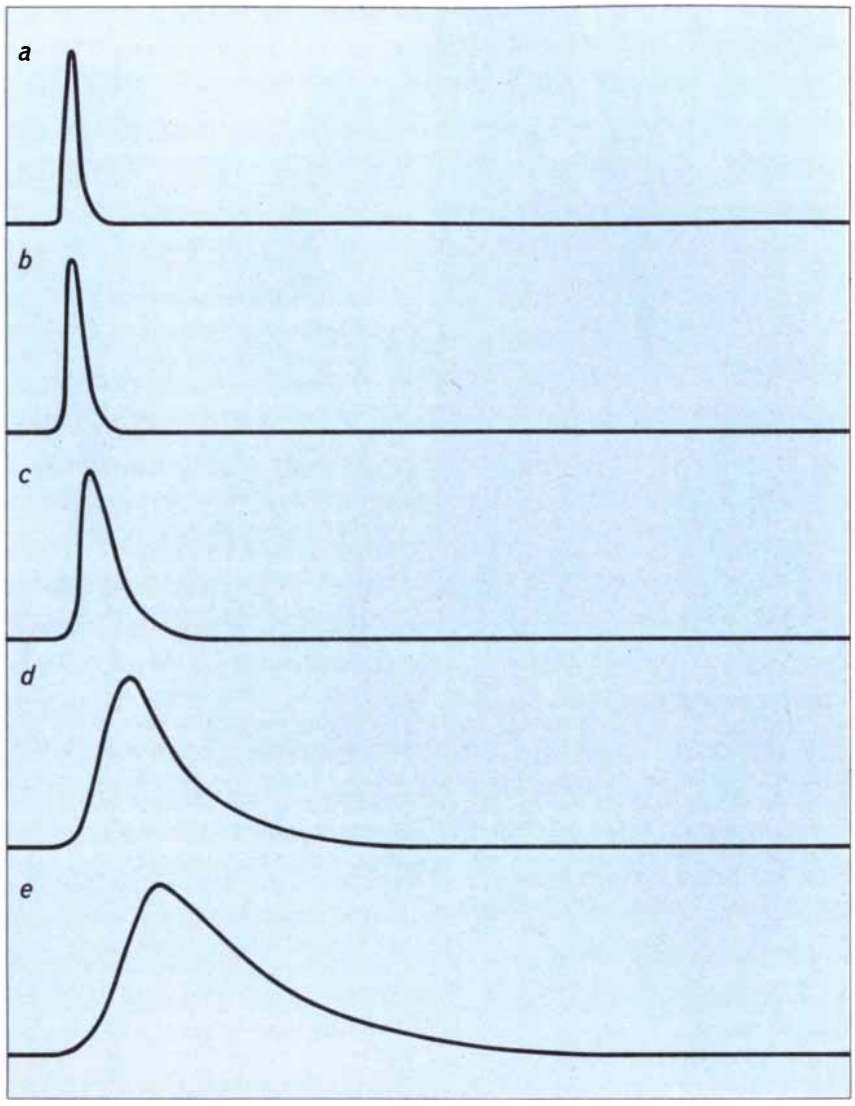
How far away is the center of the Gum Nebula? This question was tackled by several astronomers who studied the bright star Gamma-2 Velorum and its fainter companion Gamma-1 Velorum. Together with Zeta Puppis, they were assumed to lie at the center of the nebula, based on Gum's interpretation of it as a Strömgren sphere. The distance to these stars is too great to be measured trigonometrically from the base line of the earth's orbit. Instead the distances have been estimated by comparing the spectra and apparent brightnesses of these stars with those of "standard"



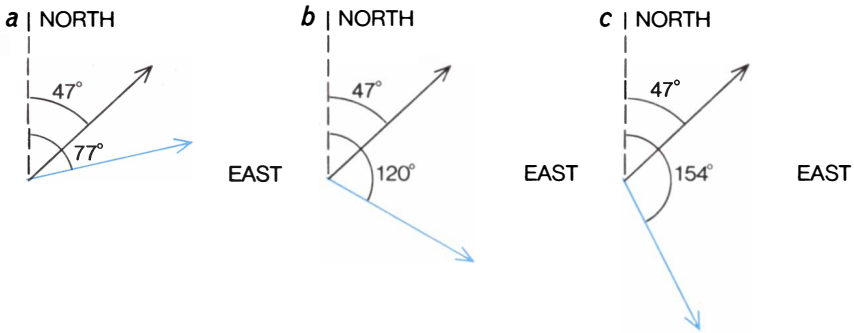
VELA *X* REGION of the Gum Nebula is depicted schematically in this chart, based on one prepared by Alan N. Bunner of the University of Wisconsin. The conspicuous optical filaments of the Vela *X* supernova remnant are represented by the curved white lines. The radio emission from Vela *X*, believed to be due to the synchrotron process, is represented by the colored contours. The orientation of the magnetic field in the Vela *X* remnant is indicated by the small white ellipse. X-ray-emitting regions in two different energy ranges have been observed by rocket-borne detectors: the large colored elliptical area corresponds to the lower energy range; the large colored circular area corresponds to the higher energy range. Absorption lines in the spectra of HR 3527 and HR 3462, two stars located behind Vela *X*, have been observed to have large Doppler shifts; these shifts, attributable to the movement of matter in the Vela *X* region along the line of sight, make it possible to infer the expansion rate of the supernova remnant and hence the age of the entire Gum Nebula; the estimate obtained in this way is about 30,000 years. (Observations of the pulsar PSR 0833–45, on the other hand, suggest that the supernova explosion may have taken place as recently as 11,000 years ago.) The Puppis *A* source, which emits both radio waves and X rays, is an older supernova remnant lying beyond the Gum Nebula.

stars whose distances are thought to be fairly well known. In practice this is not a very accurate procedure, and the distance estimates for the Gamma Velorum stars have ranged over nearly a factor of three, from the value of 170 parsecs once adopted by Gum to the value of 460 parsecs derived by Lindsey F. Smith at Mount Stromlo in 1968. In recent years Crawford and Strömgren have developed a relatively reliable method for obtaining stellar distances by means of photometry at six wavelengths in the visible spectrum. During our study of the Gum Nebula, Crawford, visiting the Cerro Tololo InterAmerican Observatory in Chile, applied this technique to Gamma-1 Velorum. Crawford also discovered a small cluster of stars that is apparently associated with the Gamma Velorum stars (the cluster is technically called a *B* association), and he derived a mean distance for the entire group of 460 parsecs. We regard this measurement, which confirms the earlier work of Smith on Gamma-2 Velorum, as being the most accurate value available for the distance to the Gamma Velorum region. If these stars lie near the center of the Gum Nebula, and if the nebular boundary is 100 parsecs from the earth as indicated by the neutral-hydrogen observations, then the radius of the nebula is about 360 parsecs, or 12 times Gum's original estimate. This dimension is measured in the plane of the galaxy, which is also the approximate plane of symmetry of the nebula. The nebula has a flattened appearance in the photographic mosaic presumably because there is less interstellar gas present at large distances from the galactic plane.

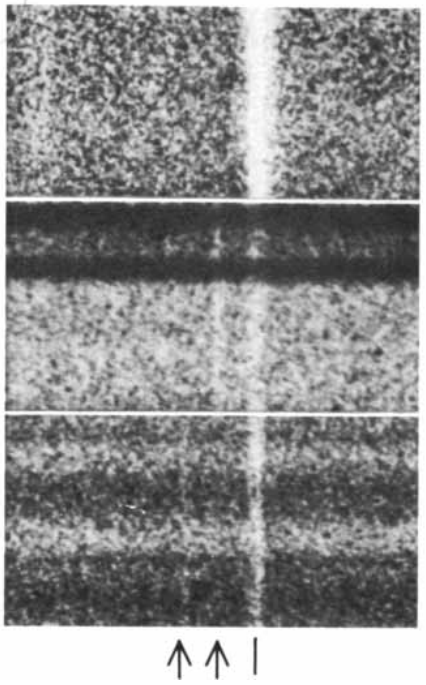
The Gum Nebula's radius of 360 parsecs makes it the largest nebula known in our galaxy. The distance of 460 parsecs to its apparent central stars also happens to agree with previous estimates of the distance to Vela *X*, an object centered at a point about five degrees to the northeast of Gamma-2 Velorum; therefore Vela *X* must also lie in the central part of the nebula. Vela *X* is the expanding gaseous remnant of a supernova explosion. It has a striking filamentary appearance in visible light [*see illustration on page 20*] and, like the Crab Nebula, it is a source of synchrotron emission at radio wavelengths. The radio source has a diameter of about five degrees; the intensity and linear polarization of the source were mapped by Douglas K. Milne between 1963 and 1966 with the 210-foot radio telescope at Parkes in Australia. Since the plane of polarization of synchrotron radiation



BROADENING OF RADIO PULSES from PSR 0833–45 also takes place as a result of their passage through the Gum Nebula. Again the effect increases with wavelength; the five curves show the average pulse shape at wavelengths of 21 centimeters (*a*), 47 centimeters (*b*), 73 centimeters (*c*), one meter (*d*) and 1.2 meters (*e*). Length of base line is one period of the pulsar (89.2 milliseconds). Curves were obtained by J. G. Ables, M. M. Komesaroff, D. J. Cooke and V. Radhakrishnan of the Commonwealth Scientific and Industrial Research Organization in Sydney, Australia, and P. A. Hamilton of the University of Tasmania.



POLARIZATION DIRECTION OF RADIO PULSES from the pulsar PSR 0833–45 is rotated by electrons and magnetic fields in the Gum Nebula in a manner that increases with wavelength. The arrows denote the orientation of the plane of vibration of radio waves traveling from the pulsar to the earth at three different wavelengths: 11 centimeters (*a*), 17.4 centimeters (*b*) and 21 centimeters (*c*). The black arrows show the polarization as emitted by the pulsar; the colored arrows show the polarization as rotated by passage through the nebula and observed on the earth. The illustration is based on observations made by Radhakrishnan and his colleagues at the C.S.I.R.O. Radiophysics Laboratory.



EXPANSION RATE of Vela *X* supernova remnant and hence the age of the Gum Nebula (30,000 years) were inferred from the Doppler shifts of an absorption line (*arrows*) attributable to singly ionized calcium in the spectrograms of two stars, HR 3527 (*middle*) and HR 3462 (*bottom*), whose light passes through Vela *X*. The spectrogram of a third star, HR 3456 (*top*), also located beyond Vela *X*, does not show such lines. This suggests that the absorbing calcium atoms are clumped in filaments and the line of sight to HR 3456 does not intersect a filament. The observations were made by George Wallerstein and Joseph Silk with a new large spectroscope at Cerro Tololo.

is perpendicular to the direction of the magnetic field, Milne was able to interpret the polarization data and prepare a chart of the magnetic-field directions at various points in Vela *X* [*see illustration on page 26*]. He found a field pattern with a center that does not coincide with the center of the radio-brightness contours but lies slightly to the northeast. In 1968 a pulsating radio source, or pulsar (designated PSR 0833–45), was discovered close to this position by Michael I. Large, A. E. Vaughan and Bernard Y. Mills at the Molonglo Radio Observatory in Australia.

The radio pulses from PSR 0833–45 travel through half of the Gum Nebula en route to the earth. Several other pulsars are observed through the nebula, including MP 0736, MP 0835 and MP 0940, all of which were also discovered at Molonglo. Propagation through the nebular plasma exerts at least four conspicuous effects on the radio pulses: (1) the pulses are broadened [*see top illustration on preceding page*]; (2) their plane of polarization is rotated [*see bottom illustration on preceding page*]; (3) they fluctuate in intensity, and (4) their arrival time is delayed. Each of these effects is dependent on wavelength in a manner that is determined by the properties of the nebula. Effects 1 and 3 are caused by irregularities, or "clumps," in the distribution of electrons; 2 is caused by the distribution of electrons and magnetic field along the ray path; 4 depends on the column density of electrons. Thus by observing the time at which a pulse arrives at the earth in different wavelengths one can infer the column density of electrons along the lines of sight to pulsars. These quantities were found to be about twice as large for MP 0736, MP 0835 and MP 0940 as for PSR 0833–45, indicating that the first three pulsars are probably beyond the nebula or just within its far side.

In the analysis of the Lyman-alpha absorption measurements we made the simplifying assumption that all the neutral hydrogen on the line of sight to the nebular center was outside the nebula. Similarly, in analyzing the pulsar data on the column density of electrons we assumed that they are all located inside the nebula. Hence the length of the column of electrons that retards the pulses of PSR 0833–45 is the radius of the Gum Nebula: 360 parsecs. With this length and the observed column density we can derive the average number of electrons inside the column. This number, the actual electron density, is .18 electron per cubic centimeter. The appearance of the Gum Nebula is quite inhomogeneous, indicating that there are wide fluctuations around the mean density. In fact, the nebulosities seen in the hydrogen-alpha photographs are probably the densest parts of the Gum Nebula; we believe they are immersed in a much more tenuous ionized gas, too faint to appear on the currently available records.

The Gum Nebula is much larger than the Strömgren sphere that Zeta Puppis and the Gamma Velorum stars are capable of producing. We recognized the magnitude of the problem when we made a simple energy calculation. We multiplied the average number of electrons per cubic centimeter by the total volume of the nebula and found the total number of electrons it contains. We then multiplied this number by the energy needed to strip a single electron from a hydrogen atom. The resulting product is the total energy that was originally involved in the ionization of the Gum Nebula, about 5×10^{51} ergs. This enormous quantity is comparable to the total energy radiated by a star during its lifetime. However, because the ionized gas will recombine to the neutral state in 100,000 to a few million years in various parts of the nebula, depending on the local density, that much energy would have to be released within comparable intervals to keep the nebula ionized. Consequently no star, not even several stars, could maintain the Gum Nebula indefinitely as a Strömgren sphere. On the other hand, a supernova event can release 10^{52} ergs, and since a supernova remnant, Vela *X*, is located in the center of the Gum Nebula, we concluded that the nebula was ionized by the supernova.

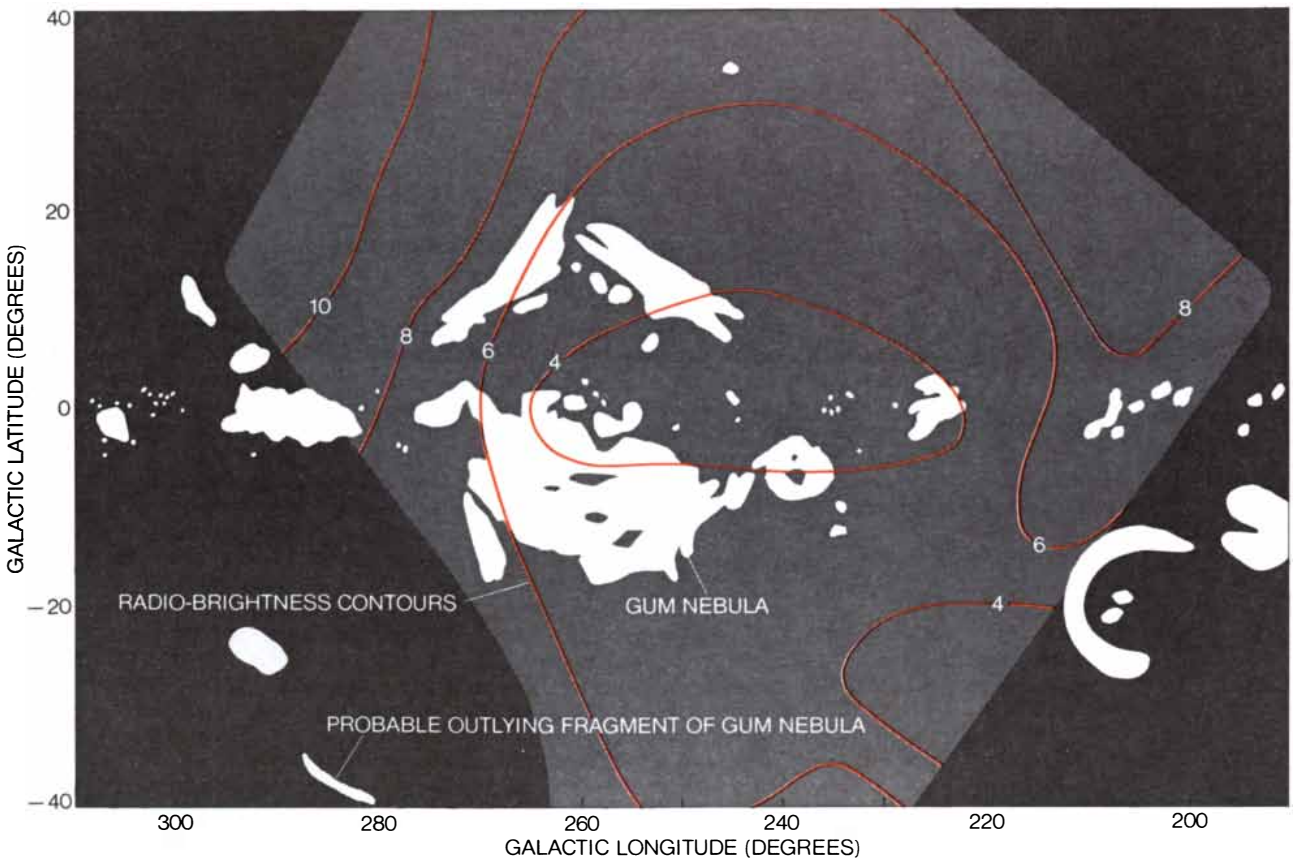
According to this new interpretation, the Gum Nebula is not a Strömgren sphere in the usual sense, since no star is present to keep it ionized. We regard it as a new kind of nebula: an H II region that was created in a sudden event and is gradually returning to the neutral state. As such it must have a lifetime much shorter than those of smaller nebulas. In the meantime it gives us a large-scale picture of the distribution of matter in a region of the galaxy that is temporarily shining as a result of the supernova explosion. We have suggested the term "fossil Strömgren sphere" to describe the object. Precisely this kind of nebula was predicted a few years ago by Philip Morrison and Leo Sartori of the Massachusetts Institute of Technology in an analysis of light emissions from supernovas.

If the Gum Nebula was produced by the Vela *X* supernova, then the supernova must have exploded in fairly recent times, since the nebula is still a highly ionized region. Indeed, there is observational evidence on two counts to support this idea. The age of the pulsar in Vela *X*, PSR 0833–45, has been estimated from its present pulse rate and the rate at which this rate is slowing down. The resulting age estimate, according to Paul Reichley, George Downs and G. A. Morris of the Jet Propulsion Laboratory of the California Institute of Technology, is about 11,000 years, a very recent event on the astronomical time scale. An independent age estimate comes from the expansion rate of the supernova remnant. Although lateral motion of the Vela *X* filaments has not yet been detected on photographs, George Wallerstein and Joseph Silk, observing at Cerro Tololo, have found unusual blue-shifted absorption lines of singly ionized calcium in the spectra of two stars, HR 3527 and HR 3462, that appear to lie behind the remnant [*see illustration on*

opposite page]. The blue shifts, attributable to the Doppler effect, are too large to be accounted for by ordinary motions of interstellar atoms. (The largest blue shift found by Wallerstein and Silk, in the spectrum of HR 3462, corresponds to a radial velocity of about 170 kilometers per second.) Instead the high-velocity lines are ascribed to absorption of the background starlight by calcium ions in the expanding gases of the supernova remnant. Allowing for geometrical foreshortening and deceleration of the expansion, the observed radial velocities can be used to estimate the time at which the expansion began, since the present size of the supernova remnant is known. The result—some 30,000 years ago—is larger than is suggested by the slowing down of the pulsar, but it is still comfortably young for the fossil-Strömgren-sphere interpretation of the Gum Nebula.

There are still a great many obscurities in the story of the Gum Nebula. Fortunately new observations are under way that should improve the basic data on the nebula. The RAE-1 (Radio Astronomy Explorer 1) satellite has mapped the low-frequency radio emission of the galaxy in the direction of the nebula. The results [*see illustration below*] show that this background radiation is absorbed by the dissociated electrons and atomic nuclei in the nebula. By determining the amount of absorption, Joseph K. Alexander of Goddard has derived a mean temperature for the nebula of about 50,000 degrees K. Rocket measurements of X rays from Vela *X* by Frederick Seward's group at the Lawrence Radiation Laboratory of the University of California show that the lower-energy X rays are also absorbed and yield an independent estimate of the total column density of hydrogen (neutral and ionized) between the earth and the center of the Gum Nebula. The French D2-A satellite, launched in April, 1971, is carrying a hydrogen-alpha photometer with which Jacques Blamont is repeating Gum's survey by photoelectric means above the interfering effects of the earth's atmosphere. With the OAO-2 (Orbiting Astronomical Observatory 2) satellite Jenkins and Blair D. Savage are studying the Lyman-alpha absorption in the spectra of a larger sample of stars in the region of the nebula.

On the theoretical side there is a serious debate under way on the mechanism by which the ionizing energy was originally supplied to the Gum Nebula by the supernova. Some physicists dispute the idea of Morrison and Sartori that a supernova explosion can liberate as much as 10^{52} ergs directly in the form of photons of radiation. There is a fairly widespread suspicion that processes by which the mechanical energy of such an explosion can be converted to the ionizing photons deserve consideration. Collision of the expanding supernova remnant with the surrounding interstellar gas, transformation of the newly formed pulsar's rotational energy into ultraviolet radiation, ionization of the nebula by cosmic rays from the explosion—all these possible energy sources for the Gum Nebula are under study.



RADIO-BRIGHTNESS CONTOURS (*color*) in the vicinity of the Gum Nebula were measured at a wavelength of 76 meters by an antenna carried by the RAE-1 (Radio Astronomy Explorer 1) satellite. The decreased brightness in the region of the nebula shows that this low-frequency background radiation is absorbed by the nebular plasma; by comparing these data with observations at shorter wavelengths one can arrive at an estimate of the nebula's temperature (approximately 50,000 degrees Kelvin). The map is based on one prepared by Joseph K. Alexander of the Goddard Space Flight Center of the National Aeronautics and Space Administration. The light gray area shows the extent of the region that has been completely surveyed so far by the satellite. The irregular white patches indicate parts of the Gum Nebula made visible by hydrogen-alpha radiation. (Some unrelated nebulas are also shown.)

CRYPTOBIOSIS

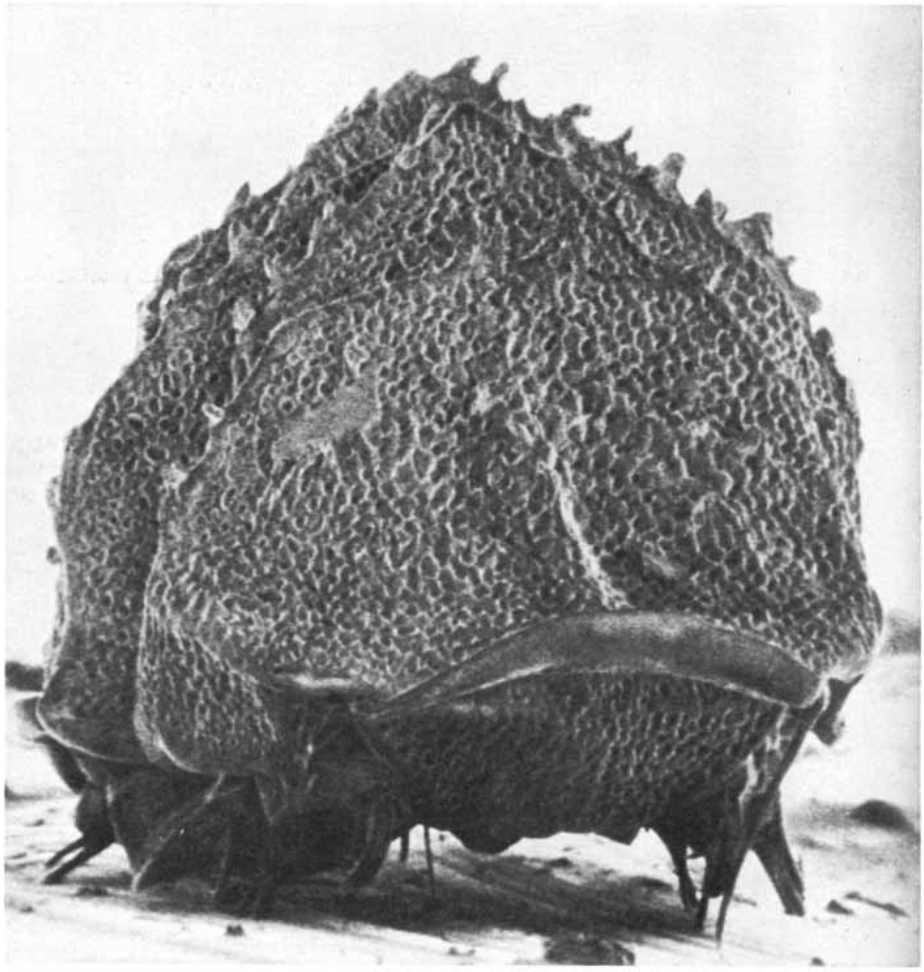
The term refers to the deathlike state of certain primitive animals that have been almost completely dehydrated. When the animals are moistened, even after decades, they revive.

by John H. Crowe and Alan F. Cooper, Jr.

The first man to demonstrate that the line separating life from death is far from clear-cut was the pioneer microscopist Anton van Leeuwenhoek. Writing in 1702 to the Royal Society of London about "certain animalcules found in the sediment on the roofs of houses," he reported the result of evaporating a droplet of water that sheltered one of the animalcules in question, evidently either a rotifer or a free-living nematode. "I found that when all the water was evaporated, so that the creature was no longer covered with water, nor could move itself as usual, it then contracted itself into an oval figure, and in that state remained, nor could I perceive that the moisture evaporated from its body, for it preserved its oval round shape unhurt." To see if this deathlike state of suspended animation was reversible Leeuwenhoek dried out several score animalcules, placed them in a glass and covered the motionless organisms with water. "I stirred the whole about," he wrote, "and perceived some of the animalcules lying closely heaped together. In a short time afterward they began to extend their bodies, and in half an hour at least a hundred of them were swimming about the glass."

This curious phenomenon, the ability of certain lower invertebrates to survive in a state of suspended animation, has been of much interest to biologists ever since. It was once called anabiosis, or "return to life," because for a long time experimenters believed that the dried animals had actually died and that when they were moistened they returned to life. This apparent resurrection was even cited during the 19th century as evidence in support of the theory of spontaneous generation. Man has been preoccupied with death ever since his first recognition of his own mortality. The prospect that any organism was able to return to life after death thus held an immeasurable fascination.

The phenomenon is now called cryptobiosis, or "hidden life," a name coined in 1959 by David Keilin of the University of Cambridge in an effort to purge studies of the subject of their resurrectionist taint. The life processes in cryptobiotic organisms are not readily detectable, and as we shall see the properties of such organisms while they are in suspended animation defy some of the standard definitions of what being alive entails. Nonetheless, the animals



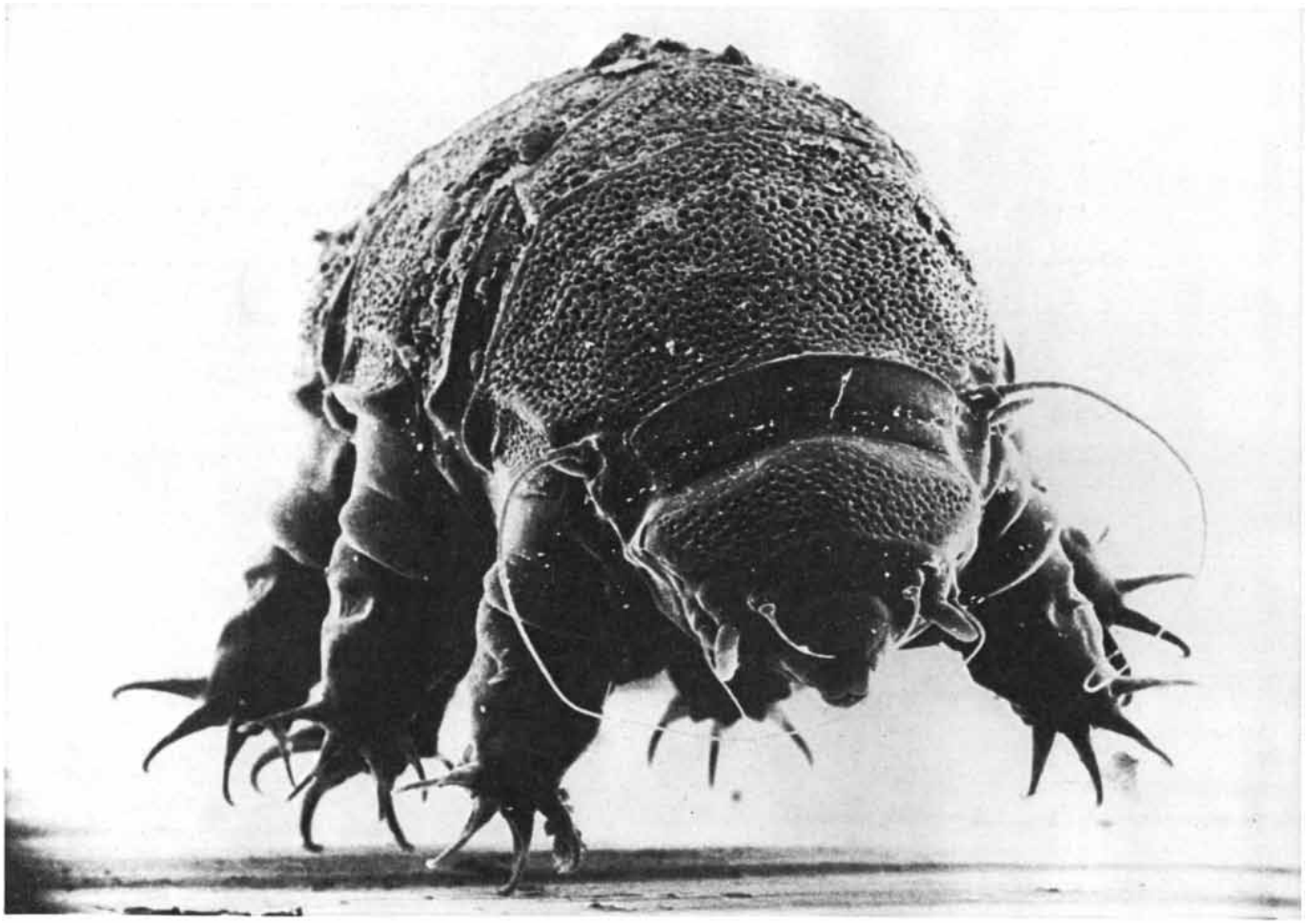
CRYPTOBIOTIC ANIMAL, a primitive arthropod-like tardigrade, has contracted into a barrel-like configuration in this scanning electron micrograph. Contraction prepares the animal for dormancy. Water now accounts for no more than 3 percent of its body weight.

are far from dead in their dried state and their revival is scarcely a supernatural event.

Two major categories of living things normally exhibit cryptobiosis. Those that do so only during their early stages of development include both animals and plants; among them are the spores of bacteria and fungi, the seeds of higher plants, the larvae of certain insects and the cysts, or thick-shelled "winter eggs," of some crustaceans, notably the brine shrimp (*Artemia*). The second category, comprising those organisms that can enter the cryptobiotic state at any stage of their life history, includes a number of bacteria and three groups of invertebrates. The latter are the simple "wheel animalcules" that form the phylum Rotifera (the majority of which inhabit freshwater ponds), the wormlike and generally microscopic members of the phylum Nematoda (whose free-living forms abound in moist soil) and the "water bears," primitive arthropod-like animals that constitute the phylum Tardigrada (which exist both in ponds and in moist land environments). Because most of our own work has been done with nematodes and tardigrades, this discussion will deal primarily with adult species of these two phyla. The study of adult forms has its advantages; in juveniles undergoing rapid development it is often difficult to distinguish adaptations that are characteristic of maturation from those that are characteristic of cryptobiosis.

It is not known just how long a cryptobiotic organism can persist in a state of suspended animation. Some nematodes have been revived after being kept in the dried condition for 39 years. A museum specimen of moss that had been kept dry for 120 years yielded a number of rotifers and tardigrades. When the animals were moistened, a few of them revived, but all died within a few minutes. They had of course been in the dry state for an exceptionally long period of time. Even under natural conditions, however, cryptobiosis greatly extends the normal life-span. Ernst Marcus of the University of São Paulo has estimated that a tardigrade would have a life-span of less than a year if it never entered the cryptobiotic state, whereas one that alternated active and cryptobiotic periods might survive for as long as 60 years.

While animals of all three groups are in a state of cryptobiosis they exhibit phenomenal resistance to environmental extremes that would be instantly lethal if the animal were active. In the 1920's P. G. Rahm of the University of Freiburg found that cryptobiotic rotifers and tardigrades were able to survive exposure to extreme temperatures. They remained viable when they were heated for a few minutes to 151 degrees Celsius, far above the boiling point of water. They survived when they were chilled not just for a few minutes but for days to minus 200 degrees C. More recently Henri Becquerel of the University of Paris has bettered Rahm's record for re-



ACTIVE TARDIGRADE is magnified 150 times in another scanning micrograph. This micrograph and the one on the opposite page were made at the Facility for Advanced Instrumentation of the University of California at Davis. Both show the tardigrade species *Echiniscus arctomys*. The usual habitat of the organisms is damp soil. Water normally makes up 85 percent of their weight.

sistance to cold. With cryogenic apparatus he found that rotifers and tardigrades could survive exposure to a temperature at the brink of absolute zero: .008 degree Kelvin.

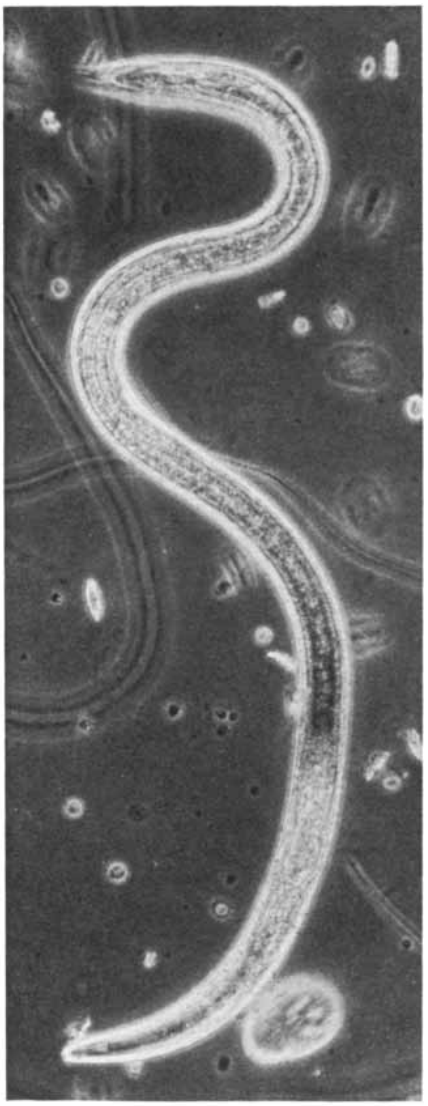
The organisms also show great resistance to ionizing radiation. Raoul M. May and his colleagues at the University of Paris have reported that in the case of tardigrades the X-ray exposure required to kill 50 percent of those exposed within 24 hours was a staggering 570,000 roentgens. (The dosage required to produce the same percentage of fatalities in a human population is scarcely 500 roentgens.) We have found the animals resistant to exposure not only to radiation but also to vacuum. Nematodes have survived 48 hours in a vacuum equivalent to a pressure of four or five millimeters of mercury and tardigrades have survived briefer exposures to vacuums as extreme as a millionth of a millimeter of mercury. The tardigrade seen in the illustration on page 30 affords an example. It was exposed both to high vacuum and to electron bombardment in a scanning electron microscope for half an hour; moistened on removal from the microscope, it revived and moved around for a minute or so before it died.

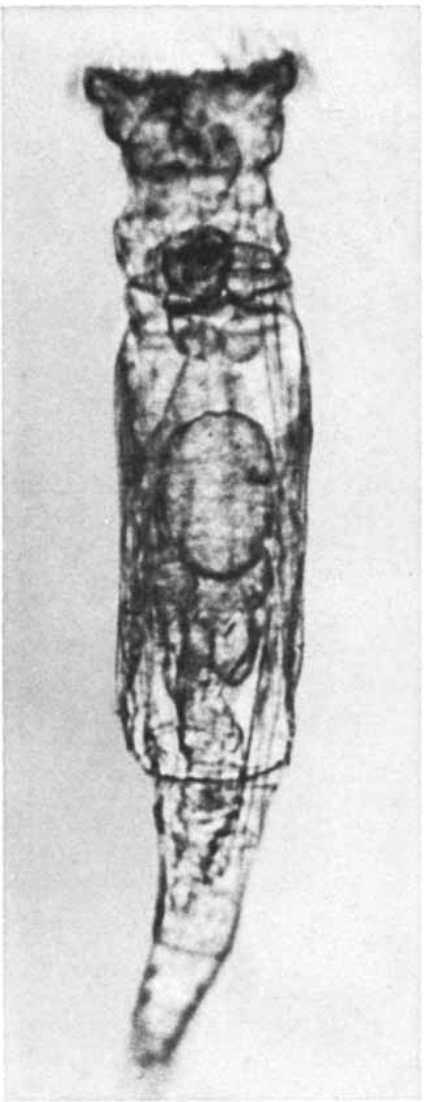
Does cryptobiosis produce a complete suspension of metabolic activity? Until recent years there was little direct evidence on this point. Then in the early 1950's two Polish experimenters devised an ingenious experiment to measure the consumption of oxygen by dried tardigrades. Andrew Pigoń and Barbara Weglarska of the Jagiellonian University in Cracow used as their measuring apparatus a miniature "Cartesian diver," which worked as follows. They placed the dried tardigrades in an air pocket at the bottom of a capillary tube. The rest of the tube contained a salt solution (which maintained the air at a known level of relative humidity) and a droplet of sodium hydroxide (which would absorb carbon dioxide). This was the "diver"; it was then weighted so that it had neutral buoyancy, was sealed and was placed in a tank of water. If the tardigrades were converting oxygen into carbon dioxide, the diver would lose buoyancy and sink as the oxygen was consumed and the sodium hydroxide absorbed the carbon dioxide that took its place. Exceedingly small changes in volume can be measured in this way.

Using Cartesian divers containing salt solutions of different strengths, Pigoń and Weglarska measured the oxygen consumption of the dried tardigrades at a number of different relative humidities [*see bottom illustration on opposite page*]. They found not only that the seemingly inert animals were taking up oxygen but also that the rate of uptake rose logarithmically as the humidity increased. Even at the lowest level of relative humidity, however, a discernible uptake of oxygen continued.

Recently B. D. Bhatt and Richard A. Rohde, working at the University of Massachusetts, used the Polish investigators' method to determine the oxygen uptake of dried nematodes. Their results paralleled the earlier findings with tardigrades; even at the lowest level of relative humidity a small but perceptible metabolism was evident.

Although these results suggest that oxidative metabolism continues in the cryptobiotic state, the issue is confused by still other observations. For example, it is known that the animals' longevity is increased if they are kept in an oxygen-free atmosphere during cryptobiosis. The most detailed studies of this phenomenon, which seems at odds with the concept of continuing metabolism, have been made by James S. Clegg of the University of Miami. He has found that when the dried winter eggs of brine shrimp were stored under normal atmospheric conditions for 15 years, virtually none of the crustaceans could be revived. On the other hand, when the cysts were stored for 10 years in a vacuum and then for five years under normal atmospheric conditions, some 22 percent of the cysts produced normal animals after they were moistened. Whether the cysts had been stored in the open air or in a vacuum, all showed the same high concentration of carbohydrates at the end of





OTHER ANIMALS that can survive lengthy dehydration belong to the phylum Nematoda (*left*), which includes many free-living species that inhabit moist soil, and the phylum Rotifera (*right*), most of whose species live in freshwater ponds. Species from these phyla evidently were the "dead" animalcules Anton van Leeuwenhoek was able to "restore to life."

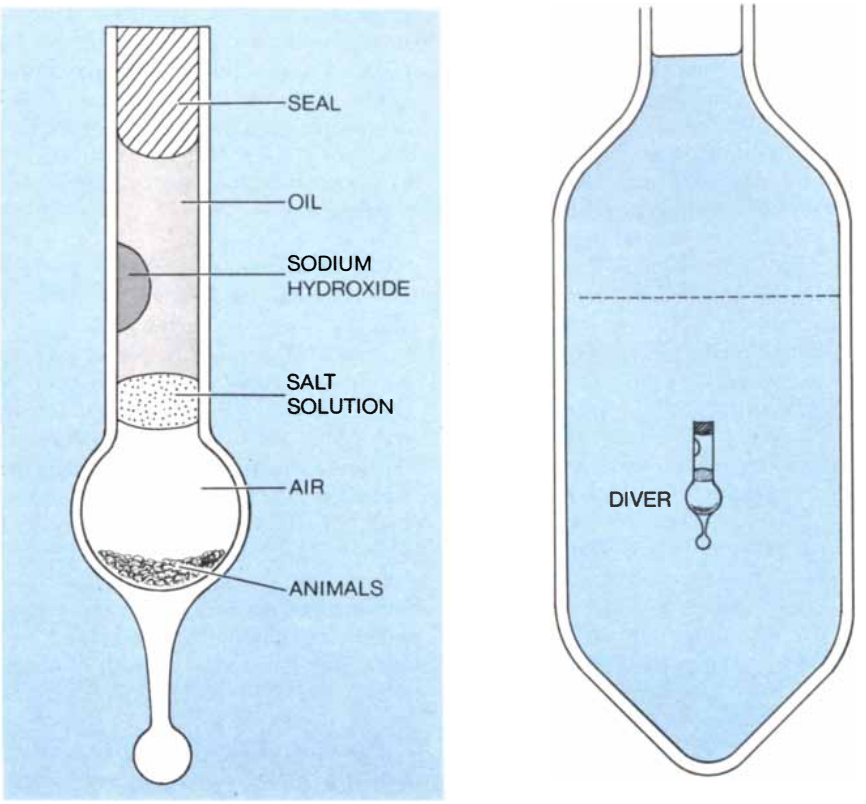
the storage period; evidently the unrevivable crustaceans had not starved to death. Clegg's observations suggest that the presence of oxygen, far from being necessary to the survival of cryptobiotic animals, may actually be detrimental.

There is a hint as to how oxygen may harm the inanimate organisms. Robert J. Heckly of the University of California at Berkeley and Harold M. Swartz of the Walter Reed Army Institute of Research have studied the fatal effect of oxygen on freeze-dried bacteria. They found that reactive molecular fragments—free radicals—accumulate in the bacteria when they are stored in the open air but are absent from bacteria stored in an oxygen-free atmosphere. They believe the production of free radicals is a result of the direct oxidation of the bacteria's constituent molecules. In this view death is a consequence of the accumulation of free radicals. A reference to Becquerel's studies is appropriate here. His cryptobiotes could be revived after exposure to a temperature close to absolute zero; at this temperature metabolic processes, if they proceed at all, must be extremely slow and the destructive effects of oxygen must be minimal. We strongly suspect that metabolism is halted altogether.

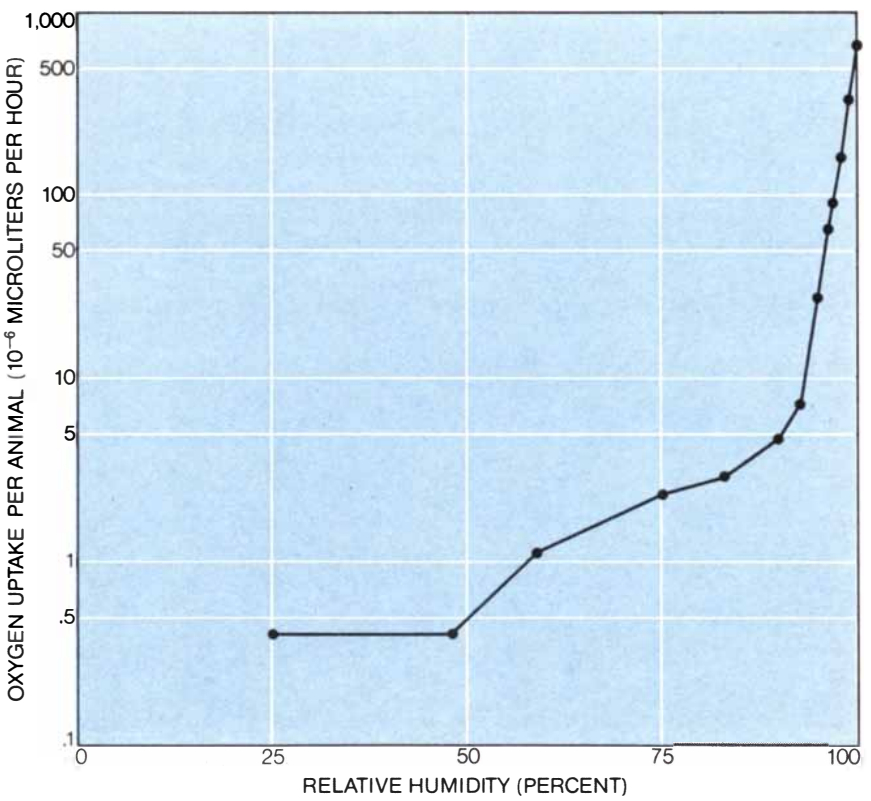
Cryptobiosis demands reexamination of another common belief: that water is essential to life. For example, it is widely believed that water is essential to the maintenance of three-dimensional structure in many large biological molecules, including certain proteins and lipoproteins and several kinds of RNA. If these molecules are dehydrated, some of them are irreversibly damaged. As another example, hydrophobic binding is important in maintaining the structure of cell membranes. One would expect that dehydration, by destroying the integrity of membrane-bound enzyme systems, would do irreversible damage to these structures. Can cryptobiotes nonetheless lose so much water that structural damage seems inevitable and still be revived? The answer is an unequivocal yes.

C. Ellenby of the University of Newcastle has demonstrated that nematodes can lose their body water entirely and still be revived. Ellenby examined the water content of dried nematodes by means of a technique developed from interference microscopy. What he measured were the refractive indexes of various body tissues; the readings reflect the water content of the tissue. He could detect no water, either free or bound, in the nematode tissues.

Our work has shown us that as far as



CARTESIAN DIVER, an extremely sensitive means of detecting small changes in gas volume, was used to determine if cryptobiotic animals continue to metabolize oxygen. Dried specimens were placed in a bubble of air at the bottom of the diver. Any carbon dioxide they might evolve in the course of oxygen metabolism would be absorbed by a droplet of sodium hydroxide. The relative humidity of the air could be varied by altering the strength of a droplet of salt solution. Uptake of oxygen by the animals makes the diver sink.



DIVER EXPERIMENT, conducted by Andrew Pigoń and Barbara Weglarska with dried tardigrades, proved that the higher the humidity, the higher the metabolism. Even at very low humidity, however, the seemingly inert animals continued to take up some oxygen.

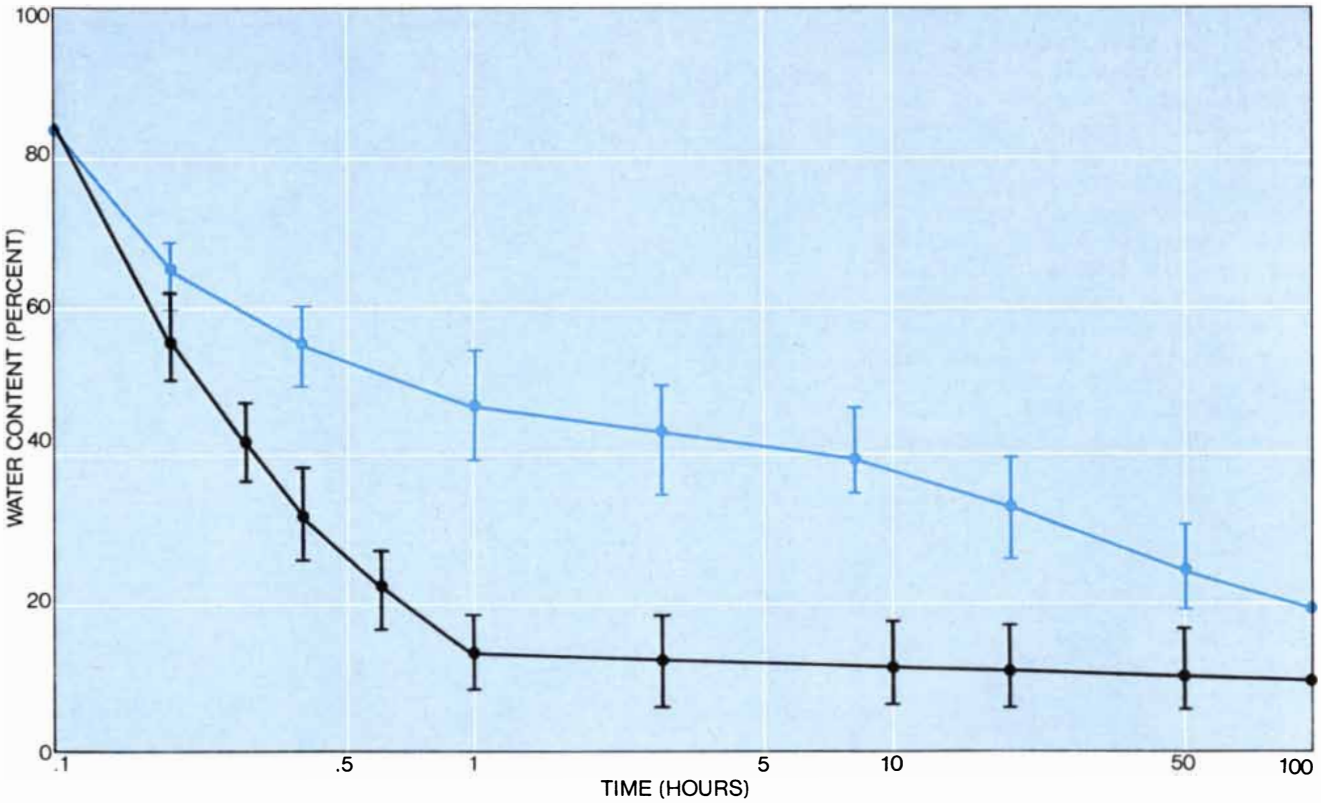
tardigrades are concerned all but a tiny percentage of body water can be lost without affecting the animals' revivability. We demonstrated this by placing dried specimens on an extremely sensitive electrobalance under conditions of zero humidity and recording their weight. The animals were then transferred to dry air at a temperature of 105 degrees C. and kept in this desiccating atmosphere for several hours. When it was apparent that any water they might still have contained had been evaporated, we reweighed the specimens. The difference between the two weights indicated that the fraction of total body weight represented by water at the time of first weighing could not have exceeded 3 percent, compared with a water content that represents 85 percent of the body weight of an active tardigrade.

When rotifers and tardigrades begin to dry out, they contract into a barrel-shaped configuration called a tun (the traditional name for a large cask of wine); nematodes under the same circumstances coil into a tight spiral. What is the significance of these contractions? Earlier investigators speculated that their purpose was to achieve an ordered close packing of organ systems and cellular components in order to minimize gross mechanical damage from desiccation. Electron micrographs of the tissues of dried and active rotifers and tardigrades made by us and by M. R. Dickson and E. H. Mercer at the Australian National University give strong support to the speculation; the tun is indeed a tight package.

We now know that formation of the tun has additional significance. When a tardigrade contracts, parts of its surface that are highly permeable are withdrawn from contact with the air, thereby lowering the rate of evaporative water loss. We tested the usefulness of the tun configuration by measuring the water lost during desiccation from normal tardigrades and from specimens that had been anesthetized and could not contract. During the initial stages the anesthetized tardigrades lost water some 1,000 times faster than the normal animals [*see illustration below*]. What is more, the rapid drying killed all the anesthetized animals.

Our observations suggest that a low rate of water loss during the early stages of desiccation is somehow important to a cryptobiote's ability to enter a state of suspended animation. Ellenby's observations of nematodes provide some corroborating evidence. He found that when nematodes are undergoing desiccation, they congregate in clumps; the animals in the center of the clump dry more slowly than those on the periphery and also survive desiccation better.

The conclusion that the rate of water loss should be slow at the time the animal enters the cryptobiotic state implies that the organism is in some way preparing itself for the intense desiccation to follow. Just what the preparations are is not yet clear, but hints can be found in studies of desiccation in other organisms. For example, at the University of Saskatchewan, S. J. Webb and his colleagues have studied techniques for air-drying bacterial cells. These cells will not normally survive desiccation. When they are first incubated in a dilute sugar solution, however, a large proportion survive the drying process. Webb suggests that the sugar replaces water that normally surrounds the large molecules of the cell, thereby protecting the molecules from desiccation damage. Support for this conclusion comes from Clegg's discovery that brine-shrimp cysts contain large amounts of glycerol, which also may prevent desiccation damage. Taking these observations into account, we sus-



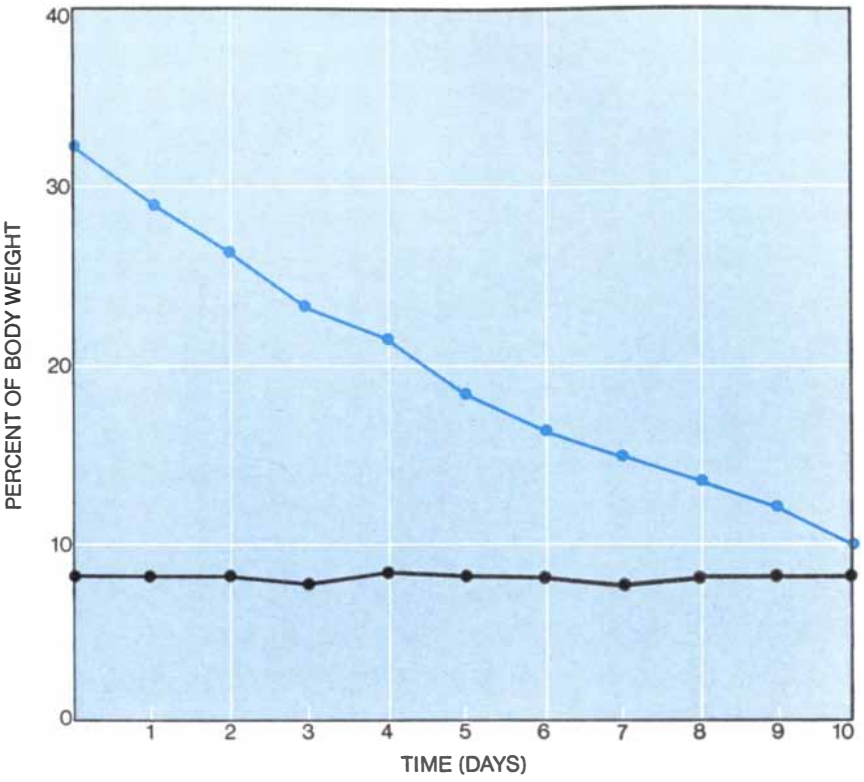
PROCESS OF CONTRACTION retards the rate of evaporative water loss during dehydration. Both normal tardigrades (*color*) and others that had been anesthetized and thus were unable to assume the barrel-like configuration (*black*) were exposed to desiccation. The water loss among the anesthetized animals within an hour was greater than the loss among the control animals after four days.

pect that rotifers, nematodes and tardigrades may synthesize a protective compound—possibly a carbohydrate—at the onset of desiccation. We are now studying the carbohydrate metabolism of the three groups in order to test our hypothesis.

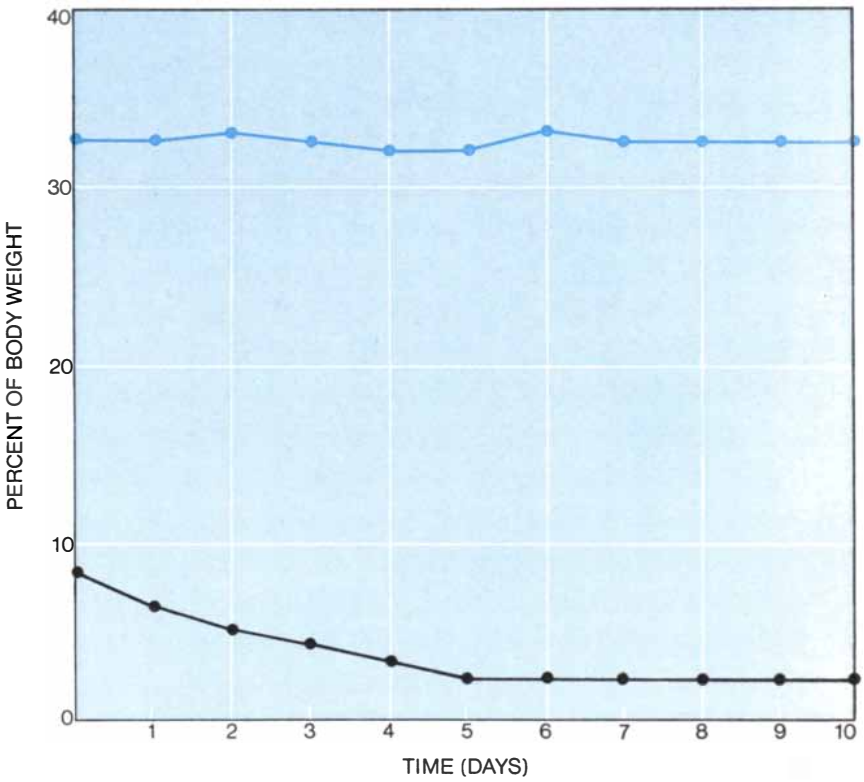
What has been described up to now is only one kind of cryptobiosis: the kind that is brought on by extensive water loss through evaporation and is known technically as anhydrobiosis. Three kinds of cryptobiosis in addition to anhydrobiosis have been recognized. They are osmobiosis, which is induced by removal of water from the organism by an external solution that has high osmotic pressure; cryobiosis, which occurs when the organism is frozen, and finally anoxybiosis, which is induced when the external oxygen concentration falls below the level required to support oxidative metabolism. Since both osmobiosis and cryobiosis are induced by the unavailability of the water needed for normal metabolic reactions, we believe they are essentially similar to anhydrobiosis. Anoxybiosis, however, is clearly a different kind of phenomenon.

Rotifers, nematodes and tardigrades can all be induced to enter the anoxybiotic state by placing them in an oxygen-deficient environment; the animals soon become turgid and cease normal activity. Little is known about the effects of the state insofar as rotifers and tardigrades are concerned, but one of us (Cooper) has recently examined the metabolism of anoxybiotic nematodes. There is one nematode species, for example, whose usual mode of metabolism is oxidative. When individuals of this species are placed in oxygen-deficient water, however, they switch over to an anaerobic, fermentative mode of metabolism. This type of metabolism is common in microorganisms, but it is most unusual in animal tissue; the metabolic end product is ethyl alcohol!

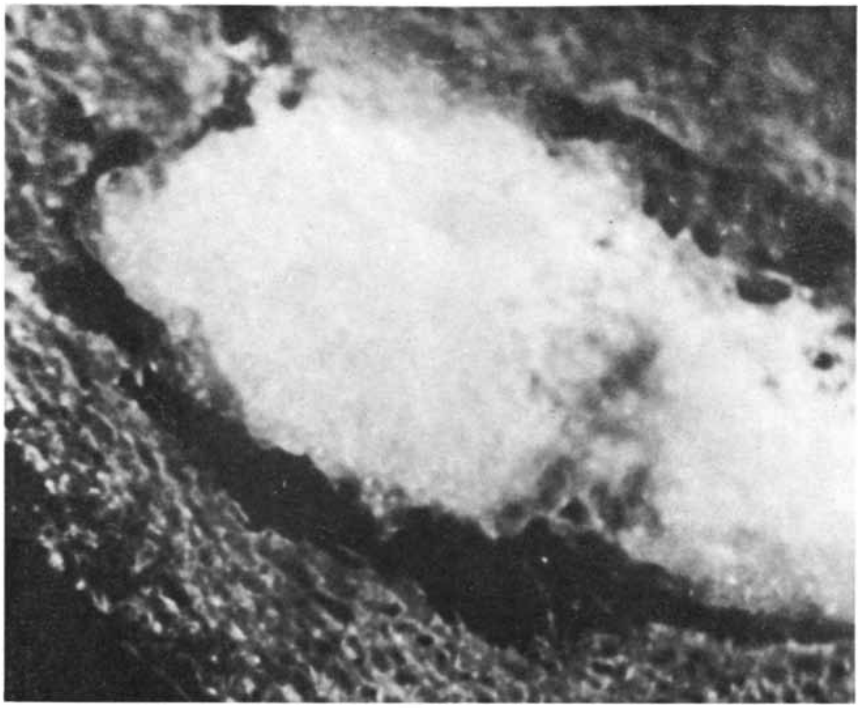
After about six days under anaerobic conditions the nematode ceases even this fermentative activity, and no metabolism of any kind can be detected. Even when the animals are kept in that condition for as long as 100 days, on being returned to aerated water they readily revive and resume normal activity and oxidative metabolism. Other species of nematodes that do not have this ability to enter the anoxybiotic state survive for only a limited time under anaerobic conditions. Their store of the carbohydrate glycogen is depleted within 72 hours. In contrast, the anoxybiotic nematode species still possesses a con-



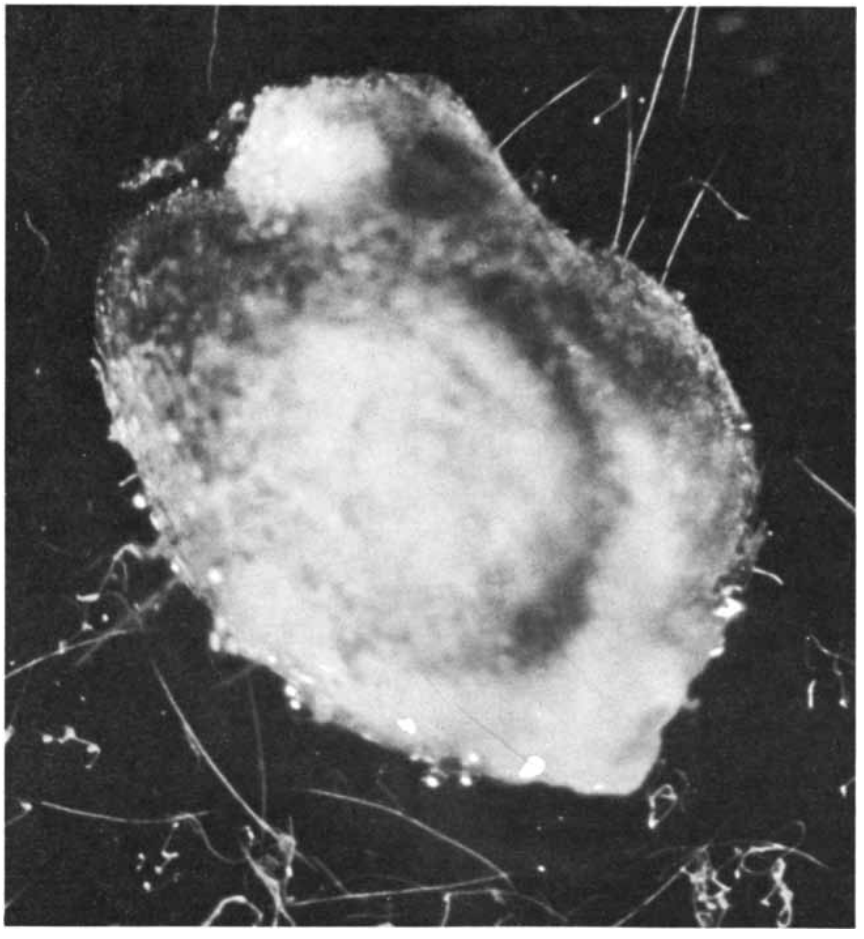
UTILIZATION OF FOOD STORES when oxygen is absent differs in certain nematodes that can live with or without oxygen. In an aerated environment the nematodes' store of glycogen evidently stays at a constant level as their store of lipid (*color*) slowly diminishes.



REVERSE PROCESS operates when the nematodes are shifted to an oxygen-poor environment. The store of lipid (*color*) remains constant; the store of glycogen, however, gradually falls until a state of cryptobiosis is attained and there is no further consumption.



DRYING NEMATODES have entwined to form a clump of "wool." Those in the center dry more gradually and are thus better able to survive. The clump is in a wheat plant.



REVIVED NEMATODES are the threadlike organisms visible along the edge of a mass of newly dampened nematode wool in this micrograph. Dry nematode wool has yielded viable organisms after as long as 39 years. Both of the micrographs on this page were made by S. D. Van Gundy of the Department of Nematology of the University of California at Riverside.

siderable store of glycogen after 100 days of anaerobic suspended animation [*see illustrations on preceding page*]. It should be emphasized that the anoxybiotic species does not stop metabolizing as soon as it encounters anaerobic conditions; it continues to metabolize for as long as six days, even though the new metabolic end product is unusual and potentially harmful. This continued activity in the face of adversity may be a preparatory phase similar to the one we have hypothesized for animals that are undergoing desiccation.

A central issue in the study of cryptobiosis that also has considerable theoretical importance for biology in general is whether or not there is actually a total cessation of metabolism in cryptobiotes. It is normal to think of an organism in which metabolism has ceased as being dead. If we also think of death as an irreversible state, however, it seems to be necessary where cryptobiotes are concerned to define life and death in terms other than the presence or absence of metabolism. We believe that among cryptobiotes life should be defined in terms of the continuity of organized structure. As long as the structural integrity of a cryptobiote remains intact the organism is capable of resuming the active state that is generally deemed to be characteristic of life. If the structural integrity is destroyed, however, the organism is no longer cryptobiotic; it is dead.

The question is more than a semantic one. The structural integrity of any organism, cryptobiotic or not, can be expected to be subject to degradation as a result of environmental influences. Yet in spite of exposure to extremes of heat, cold and ionizing radiation, and even to chemical assault, the structure of a cryptobiote often remains organized and intact. In future studies of cryptobiosis the questions that need to be answered concern the particular morphological, biochemical and physiological properties that enable cryptobiotes to exist under conditions that rapidly destroy the structural integrity of all other living systems.

At least one partial answer is now emerging. The hardiness of the cryptobiote becomes easier to understand when one takes into consideration the fact that degradative reactions in general require the presence of water, oxygen and heat. At least one of the three is usually absent during cryptobiosis. Indeed, the stability of the cryptobiote is even further enhanced when more than one is absent or at least only minimally involved.

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Tentative Data Release P-302 gives further information, including what to do if you really hate to get your fingers wet. Ask for it from Dept. 916, Kodak, Rochester, N.Y. 14650.

An interest in lead

In the poorer parts of town little kids who learned to crawl this summer now nibble sweet chips of ancient lead paint as they stare out the windows at the falling snow.

In food, water, and air the average American adult takes in lead at about the same rate as he can excrete it. A very small amount is retained in the bones. What goes into the bones may not be heard from again. But a Pb concentration above 80 μg/100ml in the blood suggests that intake may have reached a point where Pb is attaining significant levels in other tissues, including the brain. There it may be far from silent, though that is a bad metaphor because the patient may very well turn silent and cost the taxpayers a third of a million dollars to support him for the rest of his life in a state hospital. Before this happens, a conscientious physician noting a Pb blood level above 100 μg/100ml in a child may purge out the lead in 10 days at $120 a day in hospital costs. It is a better deal for the taxpayers, most of whom also have consciences and prefer to think of themselves as decent, sympathetic human beings.

Therefore there are state requirements for clinical evaluation of a child when 50 μg/100ml or higher is indicated by technique capable of distinguishing between 40 and 60 μg/100ml.

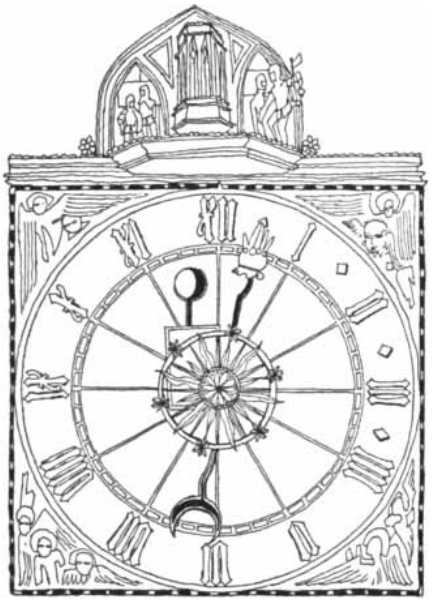
For us in the huge plant that must be kept very clean for the manufacture of photographic film, to detect as little as 5 μg/100ml of Pb in a blood sample is no extraordinary feat. We do it by photographic emission spectrography. Other laboratories use a variety of other methods, of which atomic absorption is probably the most efficient when only Pb is being measured. In a cross-comparison of results on the same straight and Pb-spiked bloods by 66 participating laboratories, our determinations came gratifyingly close to the means of alarmingly broad spans of values reported. When asked by local pediatric and social service people to donate our analytical services, emission spectroscopy is the method we have been using. And the volume of testing we do on this project soars.

As other communities proceed to check Pb levels of blood by atomic absorption technique, they may buy Ammonium-1-pyrrolidenedithiocarbamate (EASTMAN 9279) for complexing Pb and extraction into an organic solvent to feed the atomic absorption flame. Organizations owning emission spectrographs and joining the cause may buy EASTMAN X259, a special grade of trichloroacetic acid low in heavy metals, to extract the lead from the blood and precipitate the blood proteins. They may also buy KODAK Spectrum Analysis Plates or Film, No. 1, to record the spectra.

The resulting profit won't cover our donation. Strict-constructionists who object can be told that while we are chartered for merely economic activity, we are not forbidden from stretching our technical facilities to improve the quality of life a little in our home town.

Details of the emission method will be published in Applied Spectroscopy *for Jan./Feb. 1972.*

SCIENCE AND THE CITIZEN



The Nobel Prizes

The 1971 Nobel prizes in science have been awarded to four individual investigators; it is the first time since 1948 that none of the prizes has been shared. The prize in physiology or medicine went to Earl W. Sutherland, Jr., for his "discoveries concerning the mechanisms of the action of hormones." The prize in chemistry went to Gerhard Herzberg "for his contributions to the knowledge of electronic structure and geometry of molecules, particularly free radicals." The prize in physics went to Dennis Gabor for conceiving the image-making process known as holography, which the Nobel prize committee observed "can be referred to [as] both discovery and invention." The prize in economics went to Simon Kuznets for his "empirically founded interpretation of economic growth, which has led to new and deepened insight into the economic and social structure and process of development." Each prize was accompanied by a cash award equivalent to about $90,000.

Sutherland is professor of physiology at the Vanderbilt University School of Medicine. Before going to Vanderbilt in 1963, Sutherland worked at Washington University in the laboratory of Carl F. Cori (who shared a Nobel prize with his wife Gerty and Bernardo A. Houssay in 1947) and at the Western Reserve University School of Medicine. It was at Western Reserve in 1957 that Sutherland discovered a biological molecule of unusual importance: 3′,5′-adenosine monophosphate, or cyclic AMP.

Sutherland and a colleague, Theodore W. Rall, were trying to learn how the hormone epinephrine, released into the blood in response to anger or fear, immediately increases the amount of glucose in the bloodstream. An obvious hypothesis is that epinephrine simply splits large molecules of glycogen (animal starch) stored in the liver into the sugar glucose. Sutherland and Rall discovered that the actual sequence of events was much more complex.

In response to an alarm of some kind, epinephrine enters the bloodstream and bathes the cells in the liver. Epinephrine triggers the release into the cells of adenyl cyclase, an enzyme, that is evidently attached to the cell membrane. Once inside the cell adenyl cyclase converts adenosine triphosphate (ATP), which plays a ubiquitous role in cell metabolism, into cyclic AMP. The cyclic AMP then sets in motion a sequence of enzymatic reactions that splits glycogen and finally makes glucose available for release into the bloodstream. In summary, cyclic AMP behaves as a "second messenger" within the cell to expedite the production of glucose following the arrival at the cell wall of epinephrine, the "first messenger."

Subsequently Sutherland and other workers demonstrated that more than a dozen mammalian hormones function with cyclic AMP as a second messenger. These hormones include glucagon and insulin, which help to set blood-sugar levels, three hormones of the anterior pituitary and one of the posterior pituitary. Cyclic AMP is also involved in the activity of nerve cells. In bacteria and higher organisms cyclic AMP is associated with the expression of genes. In certain amoebae it acts as a signal for individual cells to come together in reproductive aggregates.

Herzberg, the winner of the chemistry prize, received his doctorate at the Technical University at Darmstadt. He left Germany in 1935 to teach at the University of Saskatchewan, where he remained until 1945. He then spent three years at the Yerkes Observatory of the University of Chicago before joining the National Research Council of Canada, where he was director of the division of pure physics until his retirement in 1969. The Nobel committee's citation states that Herzberg's "laboratory attained a unique position as the foremost center for molecular spectroscopy in the world."

When a molecule falls from an "excited" energetic state to the "ground" state or to some state in between, it emits radiation at many distinct wavelengths ranging from the ultraviolet through the visible region of the spectrum to the infrared region and beyond. The spectrum of a molecule not only provides a means of identification but also yields precise information about the molecule's electronic structure, the geometric disposition of its atoms and how they vibrate and rotate. Herzberg became a master at recording and interpreting spectra and published his results in more than 200 papers. His several books, including a three-volume work, *Molecular Spectra and Molecular Structure,* are classics in their field.

Beginning in the 1950's Herzberg adopted the technique of flash photolysis to study extremely short-lived molecular fragments referred to as free radicals. Chemists had long hypothesized their existence as intermediates in chemical reactions, but little was known of their nature. Herzberg and his co-workers produced high-resolution spectra of many molecular fragments, most of which have a lifetime of between 10^{-5} and 10^{-6} second, and established their properties. They showed, for example, that many radicals with three atoms (such as CH_2) flip from a bent structure to a linear one when they are in a highly excited state. Herzberg's "ideas and discoveries," says the Nobel committee, "have stimulated the whole modern development [of chemistry] from chemical kinetics to cosmochemistry."

Gabor, the Nobel prizewinner in physics, was born in Budapest and received his education there and in Germany. Like Herzberg, he left Germany after Hitler came to power. During most of the period between 1934 and 1948 Gabor worked in the research department of the British Thomson-Houston Company, one of Britain's largest electrical manufacturers. In 1948 he joined the faculty of the Imperial College of Science and Technology, and since 1960 he has spent part of each year in the U.S. at CBS Laboratories.

Gabor had worked for many years on the theory of electron optics and had

conceived of holography in an effort to improve the resolving power of electron microscopes. Gabor visualized a two-stage process. In the first stage electron waves diffracted and scattered by the object were to create an interference pattern by crossing the path of the primary electron beam that illuminated the object. Gabor called the interference pattern a hologram, from the Greek *holos*, meaning "whole." The term signifies that an image recorded by Gabor's method incorporates all the information one can possibly obtain by shining radiation, whether electron waves or other kinds of waves, on an object. A hologram made with light waves is a meaningless pattern of light and dark areas to the unaided eye. The second stage in Gabor's scheme was to reconstruct, or unscramble, the image by illuminating it with waves of the same character. Gabor described holography in a brief letter to *Nature* in 1948. Because of technical difficulties the technique was never applied to electron microscopy.

The key to successful holography is an illuminating beam whose waves are coherent, or all in step. One can obtain a weak beam of coherent light by passing monochromatic light through a pinhole. The first really satisfactory coherent light source became available with the development of the laser in 1960. The first laser holograms were made a year later by Emmett N. Leith and Juris Upatnieks of the University of Michigan (see "Photography by Laser," by Emmett N. Leith and Juris Upatnieks; SCIENTIFIC AMERICAN, June, 1965). When a laser hologram is reconstructed, it reproduces the original scene in three dimensions.

In the past 10 years holography has been used to study how objects change shape under strain, to record high-speed events in gas dynamics and to store information with high density. Because holograms are insensitive to dust and scratches they are being used in one scheme for producing television cassettes.

Kuznets, winner of the Nobel prize in economics, was born in Russia, came to the U.S. at the age of 20 and earned his Ph.D. from Columbia University five years later. In 1927 he joined the staff of the National Bureau of Economic Research, where he helped to refine the statistical methods used to measure economic behavior. He taught at the University of Pennsylvania from 1930 to 1954 and at Johns Hopkins University from 1954 to 1960; since then he has been at Harvard University.

Kuznets is credited with establishing

the techniques of measuring the gross national product. After publishing estimates of the U.S. national income and its composition for the years from 1919 to 1938, Kuznets and his co-workers extended the estimates back to 1869. He also analyzed the economic growth of every country for which reliable statistics were available, publishing his results in a series of 10 monographs under the general title "Quantitative Aspects of the Economic Growth of Nations." Over the years Kuznets has also made important studies of business cycles, movements in production and prices, income distribution and the economic status of minority groups. "More than any other scientist," says the Nobel committee, "he has illuminated with facts—and explained through analysis—the economic growth from the middle of the last century."

The Role of the AEC

The companies that build and operate nuclear power plants must expect stricter regulation from the U.S. Atomic Energy Commission, particularly in guarding against environmental hazards and ensuring plant safety, according to James R. Schlesinger, who became chairman of the AEC in August. In his first public address to leaders of the industry he set out the policy as follows: "From its inception the Atomic Energy Commission has fostered and protected the nuclear industry. Looking back one can, I think, say that this was the right policy for that historical epoch. That policy permitted a new and vital technology to be exploited; it created an industry and then protected the industry as it grew to relative maturity. But that industry ... should now be on a self-sustaining basis.... You should not expect the AEC to fight the industry's political, social and commercial battles."

As an example Schlesinger cited the commission's acceptance of a decision by the U.S. Court of Appeals that the AEC had failed to meet the intent of the National Environmental Policy Act in issuing permits for a nuclear power plant at Calvert Cliffs, Md. The decision and the action of the AEC in issuing new safety regulations as a result were widely criticized in the nuclear power industry. Schlesinger said: "It is not the AEC's responsibility to ignore in your behalf an indication of Congressional intent, or to ignore the courts. We have had a fair amount of advice on how to evade the clear mandate of the Federal courts. It is advice that we did not think proper to accept." Moreover, even though a number of environmentalists "have bad manners," issuing "broadside diatribes" against environmentalists is both in poor taste and wrong. "I believe that we shall receive from the responsible environmentalists considerable assistance in resolving our present difficulties."

Schlesinger also warned the representatives of the nuclear power industry not to be surprised if the AEC lays stress on good engineering and plant quality. "We will need to be assured that piping is of the highest quality, that pumps work, that valves are properly designed and operate reliably, that welding has been done in accordance with specifications and that radiography confirms this fact," he said. "The focus of concern should be the likelihood of small accidents, small spills, unplanned shutdowns, power interruptions and associated higher construction and maintenance costs. Potentially these could be the source of far more trouble over the long run than the possibility of hypothetical disasters."

Rabbit Blood from a Frog

Although it is now widely accepted that all organisms translate the genetic code the same way, most of the evidence has come from cell-free systems. For example, when the messenger RNA bearing the coded instructions for making hemoglobin is removed from rabbit red blood cells and added to a cell-free extract of mouse cells, one finds that the synthetic machinery of the mouse cell will make rabbit hemoglobin. There was evidence, however, that specific initiation factors had to be present in the cell-free system for the synthesis to take place. Moreover, there was no assurance that the intact mouse cell would accept a foreign message; conceivably the cell might have a defense against intrusion by a stray piece of RNA.

The capacity of an intact cell to translate the messenger RNA of another kind of organism has now been demonstrated by C. D. Lane and J. B. Gurdon of the University of Oxford and G. Marbaix of the University of Brussels. The receptor cells were living oöcytes (immature egg cells) of the frog *Xenopus laevis,* with which Gurdon and his colleagues have long been working. Because *Xenopus* oöcytes are unusually large it is feasible to inject into them microscopic amounts of experimental substances.

Gurdon and his co-workers separated the messenger RNA from rabbit red cells into a number of fractions by centrifugation; depending on their sedimentation rate, the fractions are designated 4*S*, 5*S*, 9*S*, 18*S* and 28*S*. When these fractions were separately injected into frog oöcytes, along with a small amount of the iron-containing substance hemin, the 9*S* fraction stimulated the synthesis of a protein that met all the tests for rabbit hemoglobin. The experiment demonstrated that no specific initiation factors in addition to RNA must be supplied from the rabbit cells for the synthesis of rabbit hemoglobin to take place. Moreover, the frog oöcytes translated the hemoglobin messenger RNA with several hundred times the efficiency previously observed when 9*S* RNA was added to cell-free systems. Gurdon and his colleagues conclude that if special initiating factors are required for the synthesis of rabbit hemoglobin, they are present in the cells of a species as remote from the rabbit as the frog. The work is reported in *Journal of Molecular Biology*.

Definitions of Death

The Kansas legislature has passed a law defining death, precipitating an argument over whether it is wise to do so. In *The New England Journal of Medicine* Ian McColl Kennedy, a British lawyer, asserts that the desirability of the law is questionable and that as worded the law sets "an unfortunate example." In the same issue of the journal Don Harper Mills, who holds degrees in both medicine and law, hails the Kansas statute as "bold and innovative."

The Kansas statute, which is the first of its kind, says that a person is dead "if in the opinion of a physician ... there is the absence of spontaneous respiratory and cardiac function" or "the absence of spontaneous brain function." It adds that "death is to be pronounced before artificial means of supporting respiratory and circulatory function are terminated and before any vital organ is removed for purpose of transplantation." Kennedy argues that the statute "seems to be drafted only with transplantation surgery in mind." Since "there is considerable evidence of public disquiet over transplant operations," he says, every effort should be made to persuade the general public that the common law "is not being rewritten in favor of the potential recipient and against the interests of the moribund donor." He cites a body of medical opinion that death in such cases should be certified by at least two physicians who are not involved in the transplant procedure. In any case, Kennedy argues, definitions of death should be reached "through recognition by the courts, in cases before them, of the pre-

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vailing medical opinion as the law" rather than through statutory law, which makes for inflexibility.

Mills argues that the framers of the statute had much more in mind than transplants and were trying, with encouragement from the medical profession, to resolve such issues as when a physician can avoid attempting resuscitation, when he can terminate resuscitative efforts and when he can terminate artificial maintenance. Moreover, Mills says, Kansas has set a constructive legislative precedent in allowing physicians to follow the concept of brain death. "Nowhere else in the common-law world do doctors have knowledge of this right prospectively," he writes, "and in this age of medicolegal uncertainty, this statute stands as quite an accomplishment."

Oldest Frenchman

The prehistory of France begins well over a million years ago with the appearance of crude pebble tools; it continues with the slow evolution of tools flaked on both sides, the introduction of fire some 500,000 years ago and the building of the earliest known human shelters some 200,000 years ago. In all this long record of human activity, however, there has been no trace of man himself.

The picture has now changed. Beginning in 1964 a group under the direction of Henry de Lumley of the University of Aix-Marseilles undertook to excavate a cave site in the eastern Pyrenees near Perpignan. The excavators soon identified 20 superposed habitation levels that contained animal bones and plant pollen characteristic of a period of cold, dry climate. The fauna indicates that the strata were deposited some 200,000 years ago at the beginning of the Riss period: the next-to-last major glacial period in Europe. In 1969 and 1970 the investigators found two fragmentary human lower jaws and in July, 1971, they uncovered the front half of a human skull, including the forehead, brow ridge, eye sockets and upper jaw.

De Lumley and his colleagues believe all three specimens probably represent a single human strain. This strain they tentatively describe as being much more primitive than the Neanderthal stock of 90,000 or so years ago. The Pyrenees people had a heavier lower jaw and their upper jaw projected farther forward. In both of these respects, and also in a heavy brow ridge and a low forehead, the Pyrenees fossils more closely resemble *Homo erectus*, the 500,000-year-old fossil man of Java and China.

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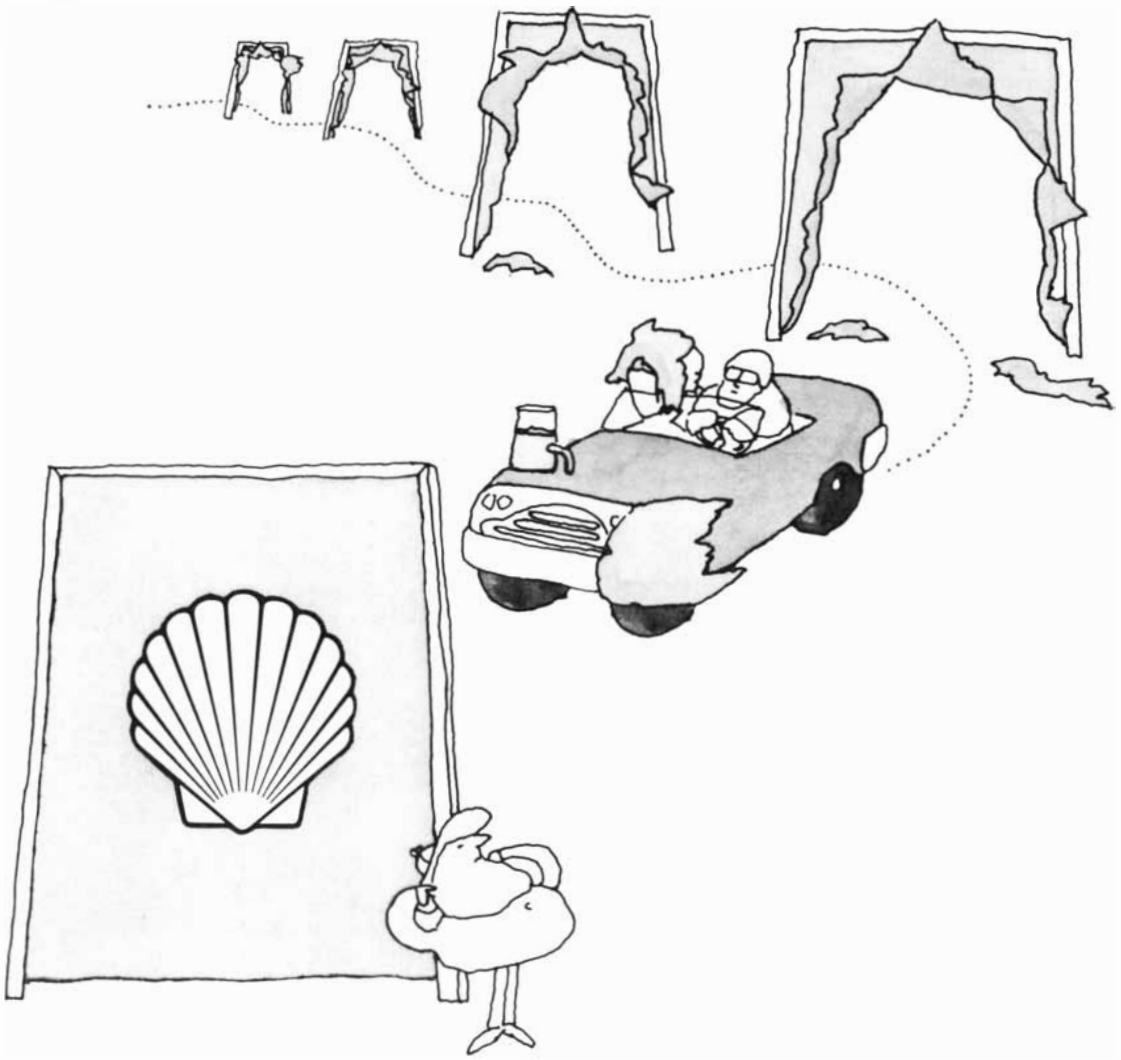

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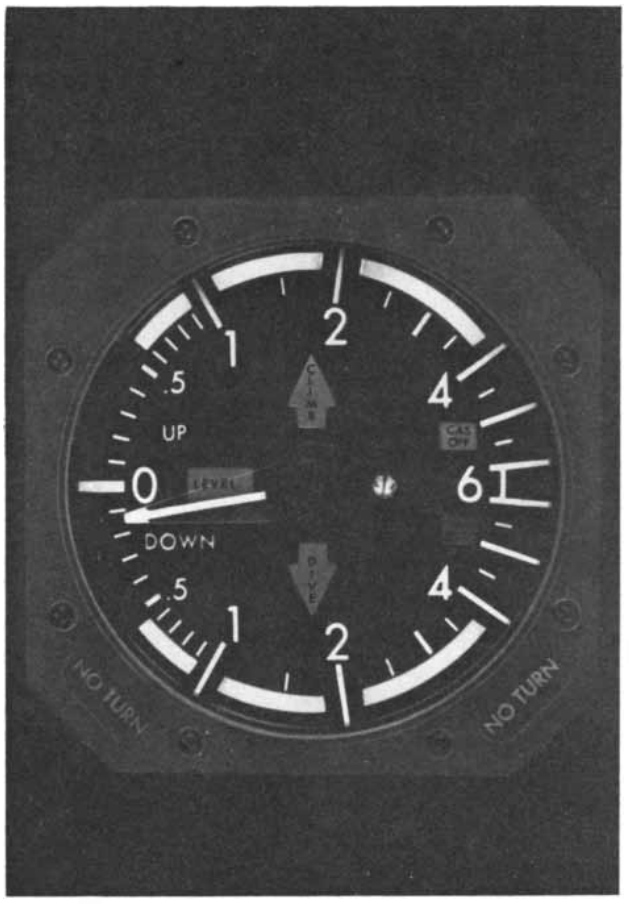

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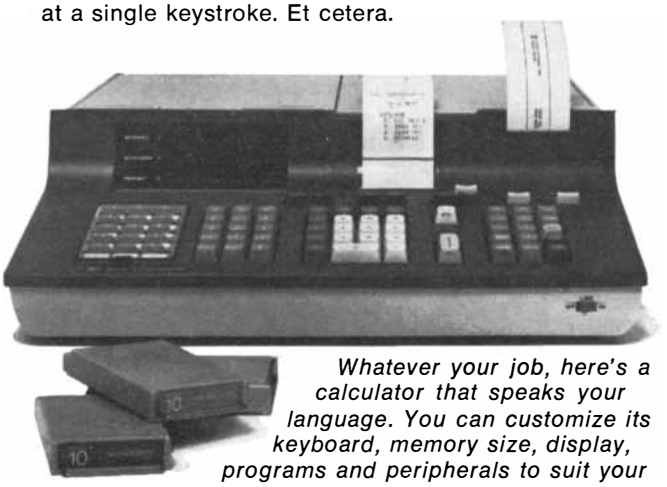

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CATALYSIS

Substances that accelerate chemical reactions without being used up play a major role in producing goods worth more than $100 billion a year. Various techniques help to reveal how a catalyst functions

by Vladimir Haensel and Robert L. Burwell, Jr.

When a chemist considers a chemical reaction, he generally asks himself three questions: How fast is it? How complete is it? How selective is it? Some reactions are very fast and go to completion to yield a single product. A familiar example is the reaction of sodium and chlorine to form sodium chloride. Other reactions, for instance the reaction of hydrogen and oxygen to form water, go very slowly at room temperature but are extremely fast at higher temperatures. They eventually go to completion to yield a single product. Most reactions are very slow indeed. The chemist has to find ways to speed them up. If he is lucky, he can do that simply by raising the temperature (as in the reaction of hydrogen with oxygen). Unfortunately increasing the temperature frequently produces undesirable side effects.

Two major reasons for seeking alternative means of speeding up chemical reactions can be illustrated by the following examples. One is the reaction of nitrogen and hydrogen to form ammonia (NH_3). The other is a hypothetical reaction between methane (CH_4) and oxygen to form dimethyl ether (CH_3OCH_3) and water. Both reactions are alike in that at room temperature their rate is essentially zero. The laws of thermodynamics tell us, however, that both reactions should go a long way toward completion at room temperature.

Let us see what happens as we raise the temperature with each of these reactions. In the reaction forming ammonia there is a composition (some specific proportion of H_2, N_2 and NH_3) that is in chemical equilibrium at a given temperature and pressure. Other compositions, if they react, must tend toward the equilibrium composition. Suppose one raises the temperature in an attempt to get a reasonably good yield of ammonia in a reasonable period of time. Before the rate of formation of ammonia becomes fast, the position of equilibrium has shifted to increase the proportion of hydrogen and nitrogen at the expense of ammonia [*see top illustration on page 48*]. For practical purposes, then, one cannot cause nitrogen and hydrogen to combine directly to form ammonia.

In the second reaction other oxidation reactions of methane become fast as the temperature is raised and destroy the methane before detectable amounts of dimethyl ether are formed. In general most possible reactions proceed slowly at room temperature, and the great majority of reactions in this class cannot be practically effected by raising the temperature. For such reactions what one lacks is selectivity.

If nature provided no way to accelerate chemical reactions selectively, our modern technological society could not have arisen, but one must quickly add that its absence would not be noticed because no form of life could exist either. In fact, nature long ago discovered how to effect many reactions of the type that cannot be effected merely by raising the temperature. Man has acquired the knack only recently.

If the mixture of hydrogen and oxygen is exposed to platinum powder at room temperature, a rapid reaction forming water occurs on the surface of the metal particles. A few atoms of platinum can lead to the formation of many molecules of water. This is catalysis, defined as the phenomenon in which a relatively small amount of foreign material, called a catalyst, augments the rate of a chemical reaction without itself being consumed. The chemist now has an alternate means at his disposal for speeding up reactions. How do these catalysts work?

Suppose one knows that two chemical substances, A and B, react to form C but that the reaction is extremely slow at room temperature. One can demonstrate that no combination of elementary processes involving A, B and C will result in rapid formation of C. Now add a catalyst, designated Cat. It provides the possibility of new elementary processes. If processes such as the following are fast, C will be formed rapidly:

$$A + Cat \rightarrow ACat$$
$$ACat + B \rightarrow C + Cat$$

The combining tendency of A and Cat must be adequate to yield the complex $ACat$, yet it must be not so strong as to make $ACat$ unreactive. After all, unless $ACat$ reacts rapidly with B to form C and then regenerate Cat, we do not have catalysis.

Chemists must by now have discovered the great majority of reactions that proceed without catalysts. Clearly the future of preparative chemistry will heavily involve catalysis. We already have a catalyst (iron) that enables us to manufacture ammonia, but we know of no catalyst that leads to the formation of dimethyl ether from methane and oxygen. There are almost innumerable other reactions that have favorable positions of equilibrium but for which no catalysts are known.

Catalytic reactions can be classified into three principal types. The most common is heterogeneous catalysis, in which the catalyst is a solid and the reactants and products are either gases or liquids. Platinum is a heterogeneous catalyst for the reaction between hydrogen and oxygen. The second type is homogeneous catalysis, in which the reactants, products and catalyst are molecularly dispersed in a single phase, usually the liquid phase. The third type is enzyme catalysis, which is found in living

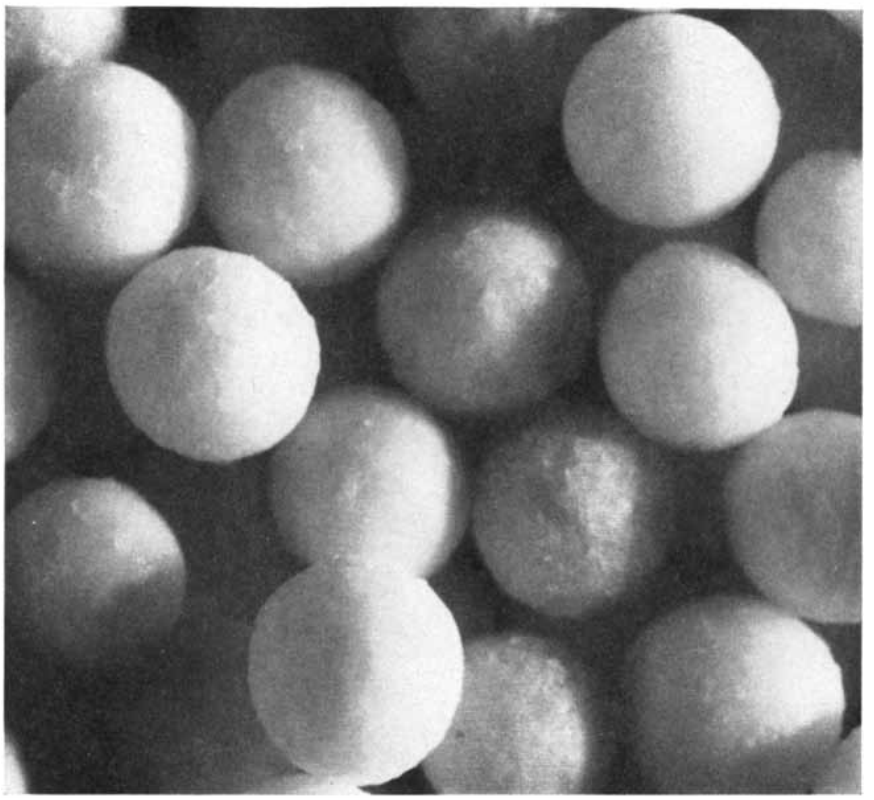
systems. There the catalyst is a complex protein molecule (an enzyme) consisting of scores or hundreds of atoms. Connections between enzyme catalysis and other types are beginning to appear, but at the moment enzyme catalysis forms a separate subject. We shall not take it up here.

The Economic Value of Catalysis

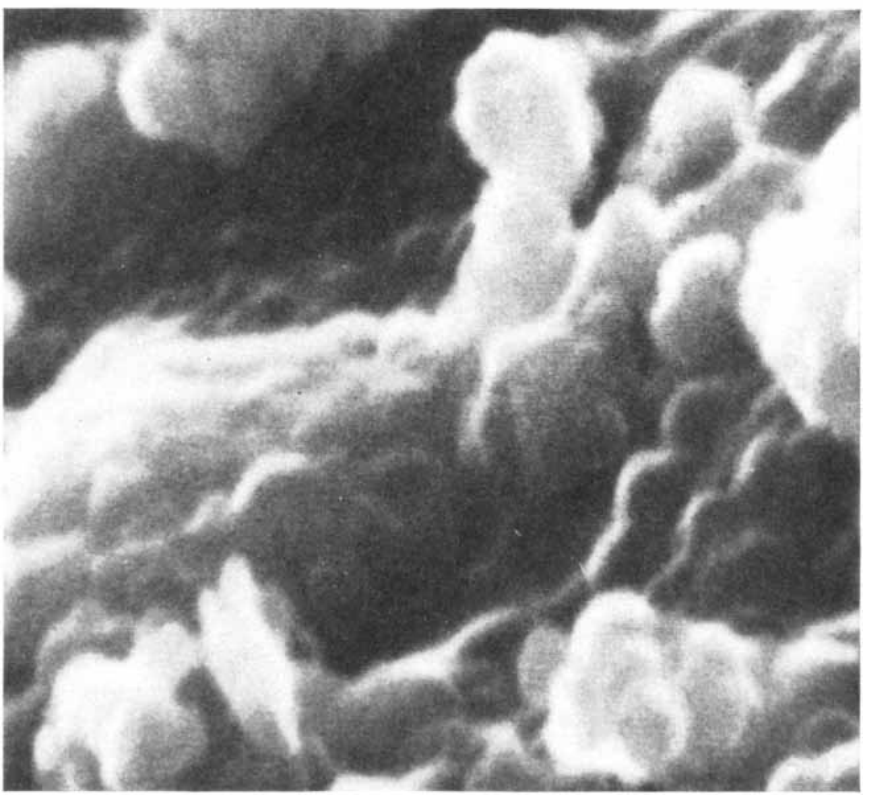
Catalysis has grown at a phenomenal rate because it has made possible the production of new chemicals and the mass production of established chemicals. Today it is an indispensable industrial tool. Catalysis contributes directly and indirectly to products accounting for a sixth of the value of all goods manufactured in the U.S.; therefore it participates in economic activities involving the exchange of more than $100 billion per year. The average consumer has little realization that the synthetics he uses every day have been made possible largely through the use of catalysis. They include plastics and fibers, detergents, hydrogenated fats and synthetic rubber.

The petroleum industry provides an outstanding example of the importance of catalysis. Crude oil contains millions of different hydrocarbon molecules of all shapes and sizes. Those with only one to four carbon atoms in the molecule (for instance methane, ethane, propane and butane) are gases at room temperature. Those with five to ten carbon atoms in the molecule boil in the gasoline range (between 20 and 200 degrees Celsius). This fraction of the crude oil ("virgin naphtha") amounts to less than 20 percent of the total; if it were simply separated by fractionation, it would make a very inferior gasoline. Its properties can be improved by subjecting it to a catalytic process called reforming, which we shall describe below. The bulk of the crude oil (about 80 percent) boils in the range between 200 and 600 degrees C. A part of this material serves as heating fuel; another part, after suitable refining, serves as jet fuel and diesel fuel; a small fraction serves as lubricating oil. By far the major part of the oil boiling in the 200-to-600-degree range is converted into gasoline by one or another type of cracking process.

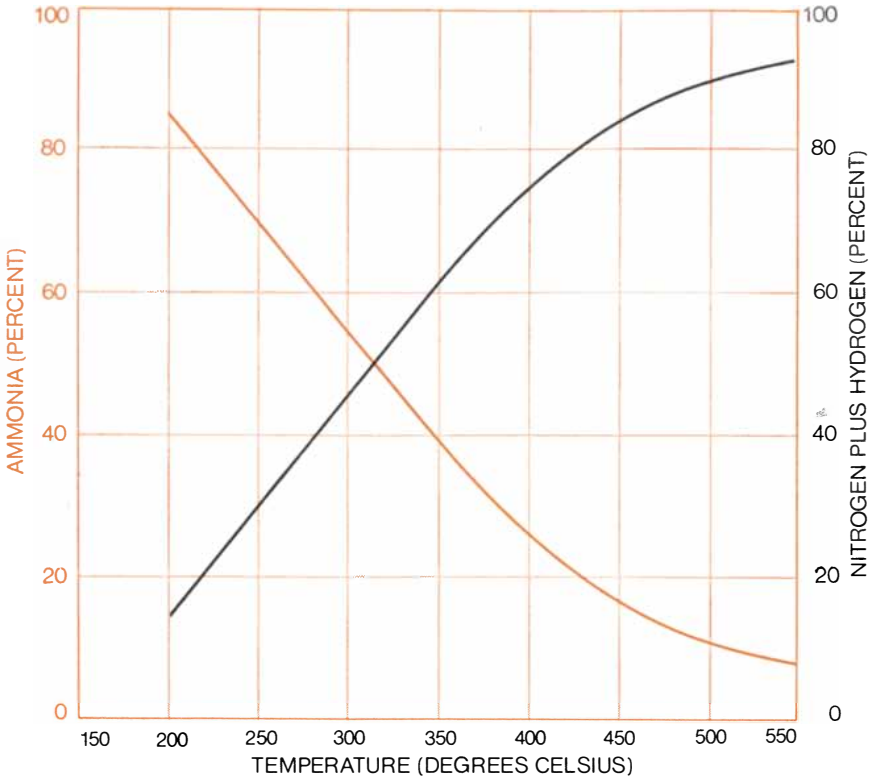
Cracking can be achieved simply by heating the oil to a temperature of about 500 degrees C. under pressure. A much better gasoline and a higher yield can be obtained by doing the cracking in the presence of a catalyst. Thermal cracking, which involves heating the oil to the decomposition point, can be considered



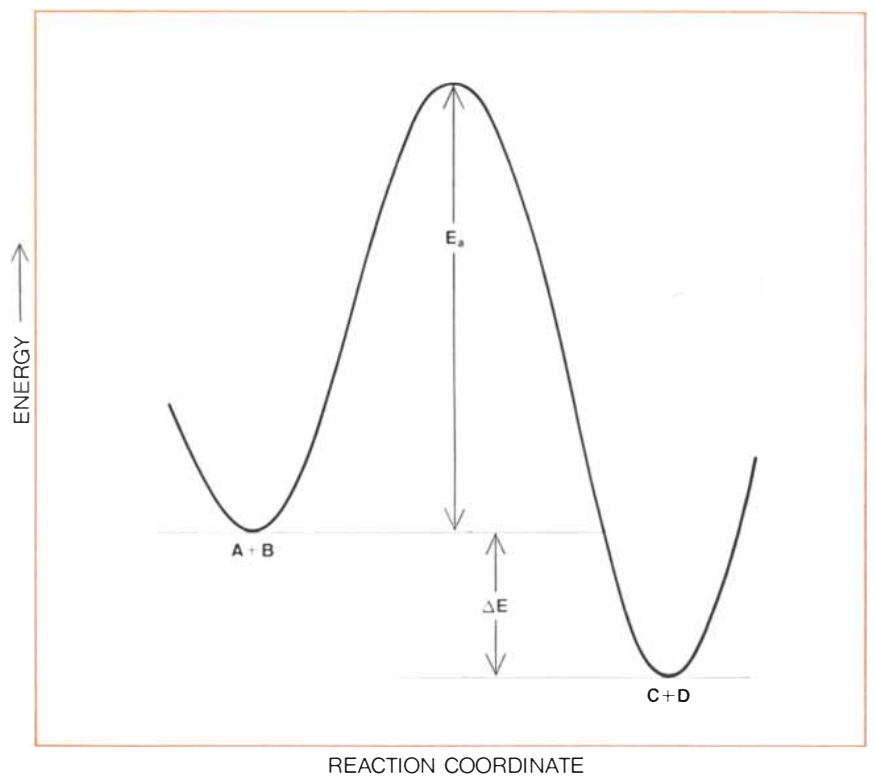
REFORMING CATALYST converts "virgin naphtha," a naturally occurring fraction of crude oil with a low octane number, into high-octane motor fuel. Known as a dual-function catalyst, it alters the structure of hydrocarbon molecules from less favorable (low octane) to more favorable (high octane) configurations. The sample shown here, magnified about 20 diameters, contains .5 percent platinum and 1 percent chlorine on spheres of alumina.



SURFACE OF DUAL-FUNCTION CATALYST is shown at a magnification of 55,000 diameters in this scanning electron micrograph. One can see the enormous surface area that such a catalyst presents. The catalyst is made by the Universal Oil Products Company.



EFFECT OF INCREASING TEMPERATURE on an equilibrium mixture of nitrogen (N_2) and hydrogen (H_2) is to shift the equilibrium to yield increasingly less ammonia (NH_3). Without a catalyst ammonia is formed too slowly even at 550 degrees Celsius to provide a useful process. The equilibrium is shown here for a pressure of 100 atmospheres.



IDEALIZED CHEMICAL REACTION, $A + B = C + D$, requires an activation energy E_a. The potential energy of $A + B$ is at the bottom of the valley at the left, that of $C + D$ is in the valley at the right. A and B can surmount the energy barrier only if they collide with a kinetic energy at least equal to E_a. The barrier is many times greater than the average energy of collision. A catalyst can provide new elementary processes with lower values of E_a.

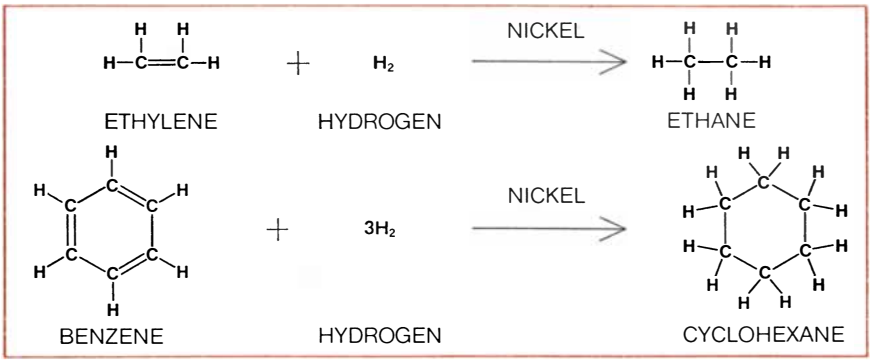
a sledgehammer approach. Heating in the presence of a catalyst is more sophisticated. Heavy molecules are broken in places dictated by the nature of the catalyst; hence there is a more selective cracking and more pieces boil in the gasoline range. Furthermore, many of the pieces no longer resemble the parts of the original molecule in shape. During catalytic cracking they undergo an isomerization reaction (a molecular rearrangement without change in molecular weight). This change in molecular structure fortunately leads to a better gasoline. If the energy in the fuel is released too quickly, the piston in an automobile engine cannot respond and the energy is expended against the walls of the cylinder, causing a pinging sound ("knock"). Isomerization increases the compactness of gasoline molecules, thereby improving the fuel's antiknock quality [*see illustration on page 50*].

Catalytic cracking is thus a more selective tool in the fragmentation reaction and the fragments are reassembled into more valuable pieces. Since very few reactions are perfect, a catalyzed reaction is no exception and some pieces are too small to be included in the gasoline. Some of these pieces do not have a full complement of hydrogen, so that two of the adjacent carbon atoms are double-bonded. It has been found that the unsaturated molecule (known as an olefin if it has a single double bond and an open structure) can react with another unsaturated molecule to produce a dimer or a trimer in the presence of a catalyst such as phosphoric acid, so that the resulting larger molecules boil in the gasoline range. It has also been found that the unsaturated molecules can be catalytically condensed with the more compact type of saturated hydrocarbons in the presence of sulfuric acid or hydrofluoric acid, but not with the straight-chain saturated hydrocarbons. On the other hand, the straight-chain saturated hydrocarbons can be catalytically isomerized to more compact structures and then reacted with the unsaturated molecules [*see top illustration on page 51*]. Thus a good share of the smaller pieces are reconverted into larger molecules and used as gasoline components. In this manner the original large molecules, by a sequence of a number of catalytic steps, are converted into the desired product.

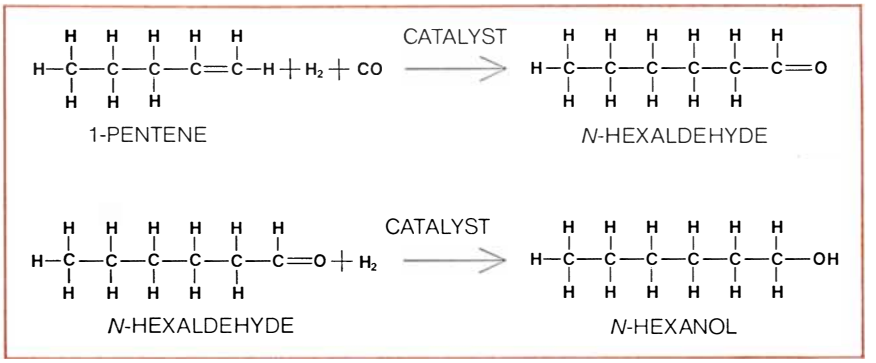
The above discussion has identified only a part of the catalytic participation in the refining of petroleum, but it is clear that if one could tag a few carbon atoms in the original crude oil, they would be seen to go through a complex

series of catalytic steps before winding up in a motorist's gas tank. In the U.S. alone some 12 million barrels of crude oil are processed daily, virtually all of it being consumed as an energy source. A small part of this amount, particularly the largest molecular sizes, is used as asphalt and petroleum coke. The smaller fragments from the various cracking steps are gathered, and some, as indicated above, serve to make gasoline. The smallest reactive fragment, ethylene, is used for the production of ethyl alcohol and polyethylene. Much of the polyethylene is made catalytically; it consists of from about 1,500 to 15,000 ethylene molecules strung together in a long chain.

A challenging and timely problem is how to apply catalysis in air-pollution control. At the moment it appears that catalysis will be heavily involved in the treatment of exhaust gas from internal-combustion engines. This will represent the first instance of the direct application by the general public of prepared catalysts, as distinguished from natural catalysts such as yeast.



CATALYTIC HYDROGENATION was discovered by Paul Sabatier in the 1890's. He found that in the presence of nickel, ethylene, the simplest olefin, reacts rapidly with hydrogen to form ethane (*top*). Benzene reacts with hydrogen to form the saturated ring compound cyclohexane (*bottom*). Many industrial hydrogenation processes use nickel as a catalyst.



OXO PROCESS, developed in Germany in the 1930's, involves the addition of carbon monoxide and hydrogen to olefins (here 1-pentene) to produce long-chain alcohols. The reaction is now used to produce intermediates for synthetic lubricating oils and plasticizers.

Early Developments

Having established the substantial contributions of catalysis to the economy, let us briefly trace the history of catalysis. After some 20 years of observing a number of "notable discoveries," Jöns Jakob Berzelius named and defined catalysis in 1836. The contemporary investigator of catalysis is frequently awed by the keen insights of early workers. After defining catalysis Berzelius proposed, among other suggestions, that it involves the development of a force of affinity coming from the catalyst and having an effect on the chemical activity of the reagents.

The "notable discoveries" described by Berzelius included the work of Johann Wolfgang Döbereiner, who in 1823 found that a stream of hydrogen mixed with air would ignite on contact with platinum sponge. In fact, this discovery led to a lamp in which hydrogen was produced from zinc and sulfuric acid, then catalytically ignited to serve as a replacement for the tinderbox for lighting lamps and candles. It is too bad that such an ingenious device had to be replaced with the match. Other evidence of the catalytic properties of platinum were discovered independently by Humphry Davy and Michael Faraday. All these workers recognized that there was something special, an action through touch or contact, that caused a reaction to occur.

Catalysis received little academic attention during the 60 years following the definition by Berzelius. There were, however, a few technological developments. The heterogeneous catalytic oxidation by air of hydrogen chloride to chlorine ($4HCl + O_2 = 2H_2O + 2Cl_2$) was developed by Henry Deacon in 1868. The direct oxidation of sulfur dioxide with air using a platinum catalyst was observed by Teregrine Phillips in 1831 and restudied by Clemens Winkler in 1875. There was no successful commercial installation of a direct oxidation process, however, until 1901.

As the 19th century ended, the rising importance of the chemical industry stimulated a few chemists to devote their full time to catalysis. Two of the most prominent were Paul Sabatier and Vladimir N. Ipatieff. It is perhaps fair to say that they did more than anyone else to bring catalytic science and technology together.

Sabatier's investigations of catalysis stem from the work of Ludwig Mond, a German-born British chemist, who in 1890 prepared volatile nickel carbonyl: $Ni(CO)_4$. Lord Kelvin remarked that "Mond and his colleagues have given wings to a heavy metal." Sabatier thought it should be possible to synthesize an analogous compound of nickel and ethylene: $Ni(C_2H_4)_4$. Instead of obtaining the desired compound Sabatier found that in the presence of nickel some of the ethylene (C_2H_4) was converted into its fully hydrogenated analogue, ethane (C_2H_6).

Sabatier quickly recognized that if he deliberately introduced hydrogen into the reaction, his nickel catalyst should convert ethylene into ethane with a high yield. Before long Sabatier demonstrated that nickel acted as a general catalyst for the hydrogenation of a variety of unsaturated (hydrogen-deficient) hydrocarbons [*see upper illustration above*].

Ipatieff, who was only 13 years younger than Sabatier, worked in Russia from 1890 to 1929 and in the U.S. from 1930 to 1952. Ipatieff reported the catalytic dehydrogenation of alcohol in 1901. Subsequently he devised industrial processes for the high-pressure hydrogenation of a wide variety of organic compounds. To design the high-pressure autoclaves required by his process, Ipatieff drew on a knowledge of gun barrels he had acquired as a young officer in the

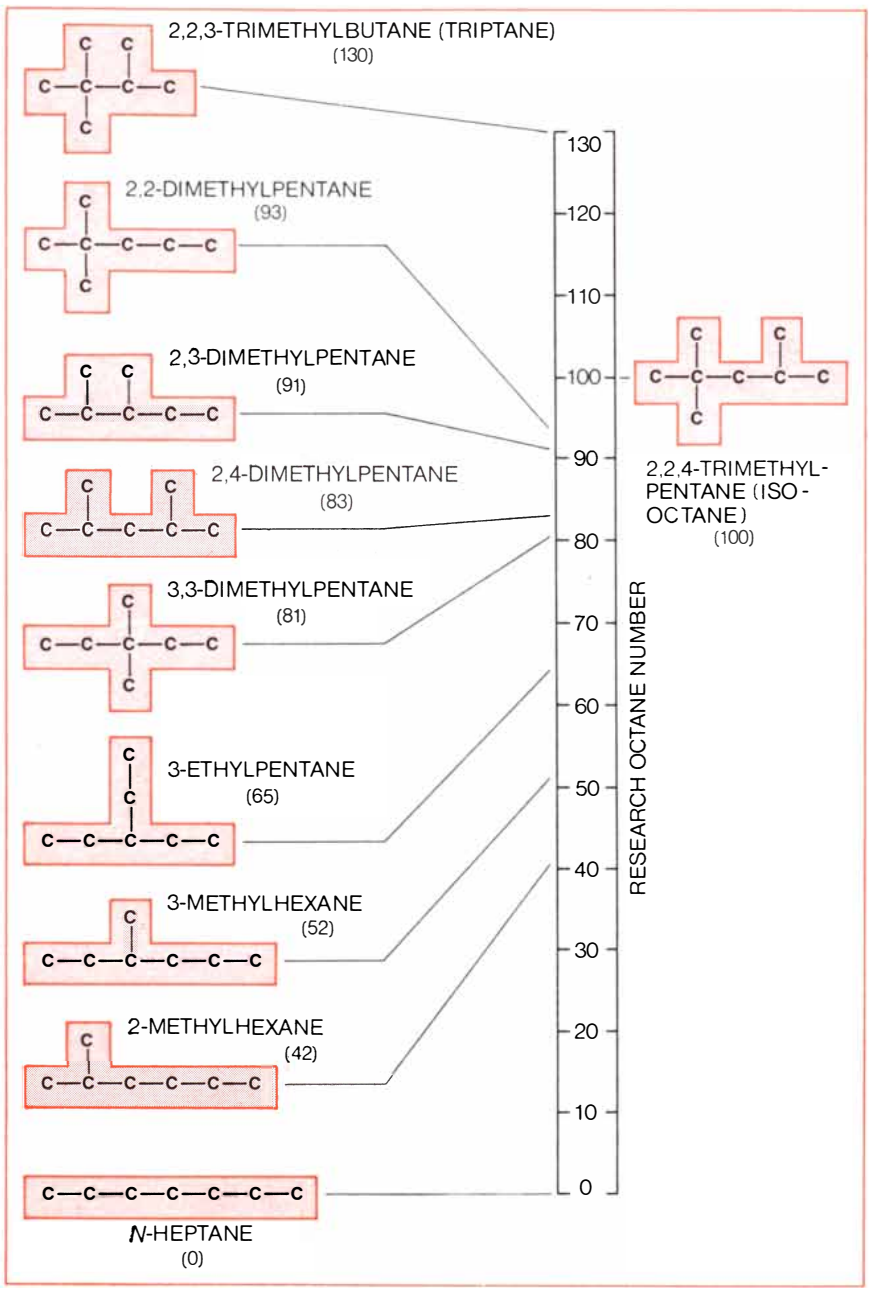
Russian artillery. Building on the foundations laid by Sabatier and Ipatieff, Friedrich Bergius developed the coal hydrogenation process, which supplied Germany with an important part of its motor fuel during World War II.

A goal of many chemists around 1900 was the synthesis of ammonia from hydrogen and nitrogen. The man who first succeeded was Fritz Haber. He worked out a process in the years between 1905 and 1908, testing thousands of potential catalysts at various temperatures and pressures. The first industrial unit incorporating his process was built in 1913. The conversion of ammonia into nitric acid was already commercial in 1906, so that by the start of World War I, Germany was no longer dependent on Chilean saltpeter as a source of nitrates for explosives. Haber's motivation—to make Germany independent of foreign supplies of a crucial industrial material—was a far cry from the innate curiosity that motivated the first workers in the field of catalysis barely 80 years earlier.

The year 1915 marks the entry of physical chemists into the field of catalysis, which had previously been dominated by inorganic and organic chemists. The elegant and precise measurements made by Irving Langmuir of the adsorption strength of various simple molecules on metals gave rise to concepts of chemisorption, and this was further developed by H. S. Taylor, Eric Rideal, P. H. Emmett and a number of other brilliant workers. Their investigations provided further impetus to technological progress.

The 1930's saw a marked spurt in the technological applications of catalysis both in Europe and in the U.S. Significant advances were made by Ipatieff and his co-workers in the use of catalysis for the production of high-octane gasoline. In Europe one of the most interesting new catalytic processes was the Oxo reaction, which involves the addition of carbon monoxide and hydrogen to olefins to produce primary alcohols [*see lower illustration on preceding page*]. The Oxo catalytic reaction is homogeneous, since a soluble cobalt-carbon monoxide catalyst [$Co_2(CO)_8$] is employed. It was also the first industrial catalytic process to use complexes of transition metals rather than the metal itself. The transition metals (such as vanadium, cobalt, titanium, manganese, chromium and copper) are unusual in that they can either lend or borrow electrons with equal ease. The Oxo reaction is now used on a substantial scale to produce intermediates for synthetic lubricating oils and plasticizers.

One striking example of the ability of catalysts to perform highly selective molecular alterations is the stereoregular polymerization of olefins pioneered by Karl Ziegler and Giulio Natta, who were awarded the Nobel prize in chemistry in 1963 for their work. Propylene can be converted to three distinct head-to-tail polymers that differ only in the relative placement of their appended methyl groups. By using suitable complexes involving ions of transition metals, one can produce either "isotactic" or "syndiotactic" polypropylene [*see top illustration on page 54*]. If the starting material is 1,3-butadiene, four different stereotactic polymers can be generated, each requiring a different transition-metal catalyst [*see bottom illustration on pages 54 and 55*]. It is likely that the future will provide many additional examples of the unique capabilities of such catalysts.



OCTANE-RATING SCALE assigns to normal heptane a value of zero and to iso-octane a value of 100. Hydrocarbons with side chains burn more slowly than straight-chain hydrocarbons and thus tend to "knock" less in automobile engines. The nine possible isomers (structural variants) of heptane are shown; hydrogen atoms are omitted for clarity.

The Mechanism of Catalysis

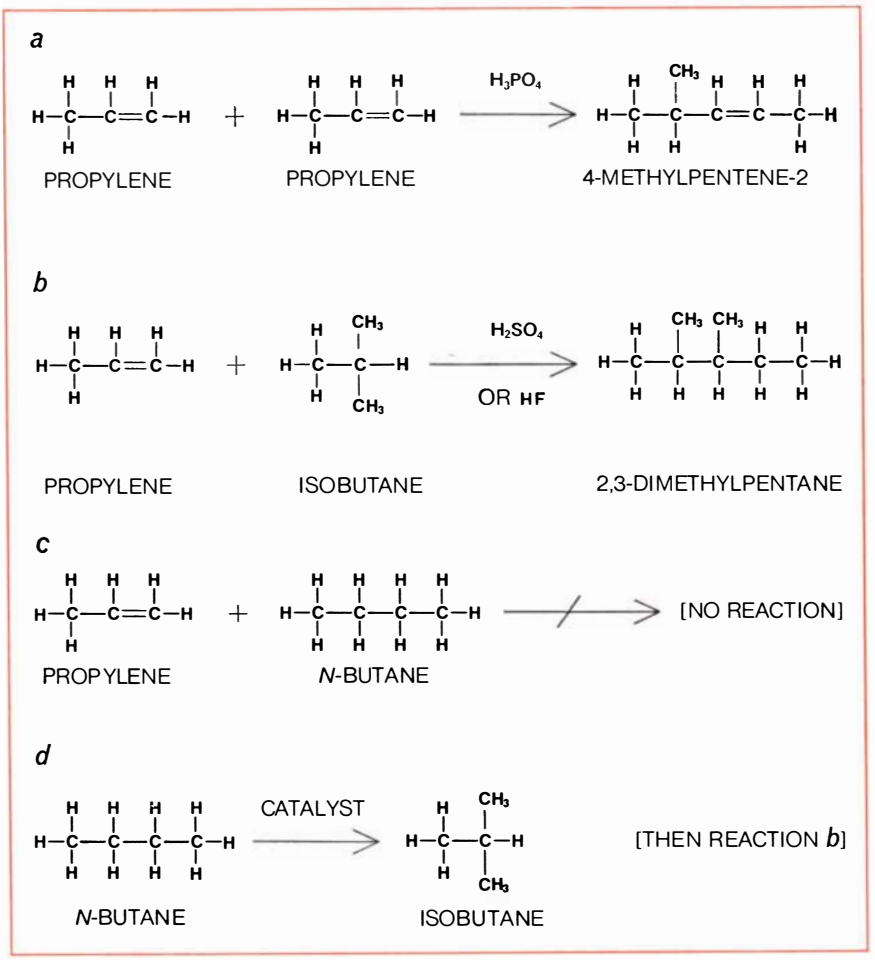
What makes catalytic reactions go? Like chemical reactions in general, catalytic reactions proceed by a more or less

complicated combination of elementary steps. Each step is elementary in that it takes place without intervening intermediates of significant lifetime. Few chemical reactions involve just a single elementary process. Catalytic reactions, then, proceed by means of a set of one or more intermediates. A simple hypothetical example of this was given at the beginning of the article: the reaction $A + B = C$ by way of the intermediate *ACat*. If a foreign substance is to act as a catalyst, it must provide new elementary processes leading to an overall reaction that is faster than the reaction that would take place if only the pure reactants were present.

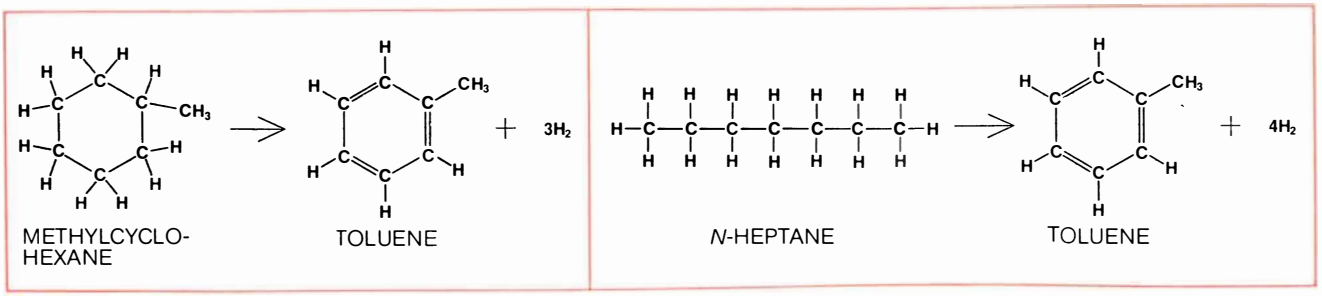
A detailed description of a chemical reaction is referred to as its mechanism. The chemist's views concerning the precise nature of the elementary processes that comprise a mechanism are constantly changing as new facts emerge from studies of catalytic systems. It is usual to recognize five stages in a heterogeneous catalytic reaction: (1) diffusion of reactants to the surface of the catalyst, (2) chemisorption of reactants, (3) surface reactions among chemisorbed species, (4) desorption of products, (5) diffusion of products from the surface.

The diffusion steps can limit the overall rate. In laboratory work one usually tries to make steps 1 and 5 faster than the other steps, but it is often impracticable to translate the laboratory techniques into engineering practice in industrial reactors.

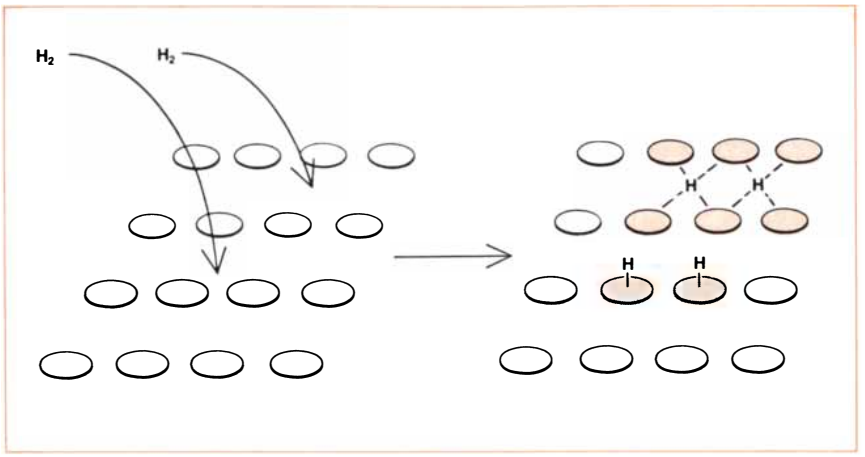
The division of adsorption into physisorption and chemisorption follows the usual division of phenomena into physical and chemical. A physisorbed species retains substantially its original structure. Thus its infrared spectrum will be reasonably related to that of the unadsorbed molecule. The heat of adsorption is small, but not much greater than the heat of liquefaction. A chemisorbed species is a surface chemical compound. The heat of adsorption can be very small or very large, as with the heat of chemical reactions in general. There may be substantial changes in structure between desorbed and adsorbed species; frequently the adsorbed species is only a fragment of the original molecule. Molecular hydrogen (H_2), for example, often adsorbs to form a surface hydride [*see top illustration on next page*]. Chemisorption of this type is called dissociative adsorption. At least one of the reactants must be chemisorbed, but it is difficult to decide when chemisorption is an elementary process and when it



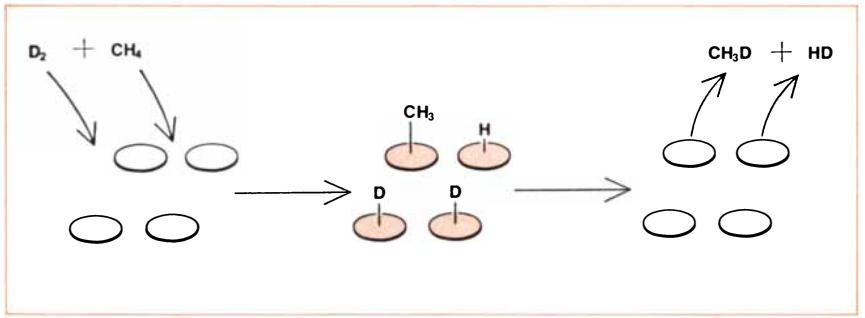
ONE ROUTE TO HIGH-OCTANE FUEL is to assemble small, volatile molecules into larger ones that boil in the gasoline range. Using phosphoric acid as a catalyst (*a*), light olefins such as propylene can be condensed into branched-chain olefins useful as a motor fuel. Either sulfuric acid, $H_2(SO)_4$, or hydrofluoric acid, HF, will join a light olefin to a saturated branched-chain compound (*b*), yielding a product with a high octane number. If the saturated molecule has a straight chain (*c*), no reaction takes place. By isomerization, however, the straight-chain molecule can be rearranged into a molecule that will react (*d*).



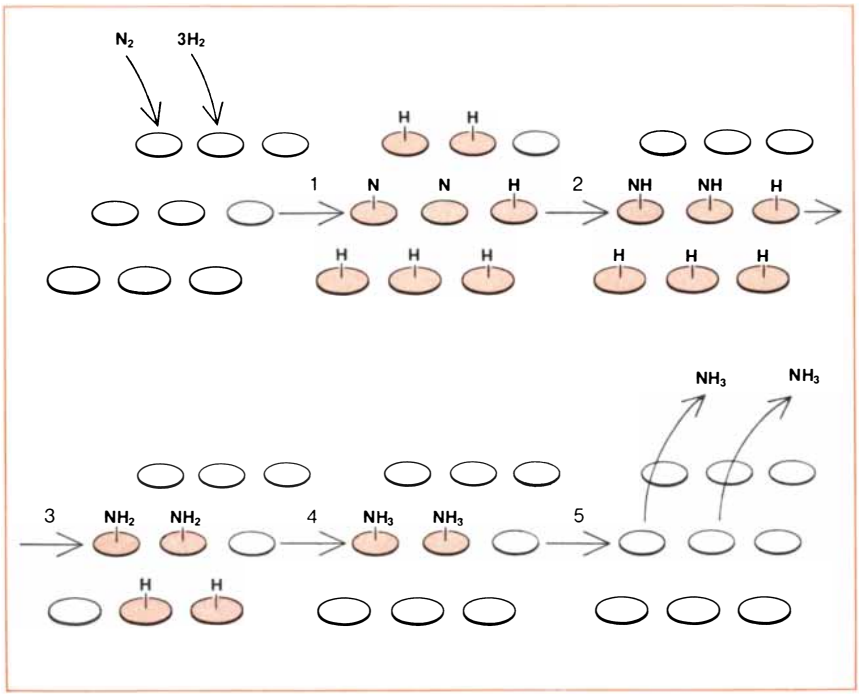
OTHER ROUTES TO HIGH-OCTANE FUEL make use of reforming catalysts that dehydrogenate saturated ring compounds (*left*) or simultaneously dehydrogenate and cyclize straight-chain hydrocarbons (*right*). In both examples the product is toluene, which has an octane number of more than 100. The octane number of methylcyclohexane is between 70 and 80. The octane number of *n*-heptane is zero. Reforming catalysts can also isomerize straight-chain hydrocarbons and crack large molecules into smaller ones.



FIRST STEP IN CATALYTIC DEHYDROGENATION is exemplified by the dissociative adsorption of molecular hydrogen on a catalytic surface. Each adsorbed hydrogen atom (H) may be bound to a single atom on the surface or it may be bound to two or more atoms.



ISOTOPIC EXCHANGE demonstrates that reacting species become dissociated on a catalytic surface. Here deuterium (D) and hydrogen (H) atoms trade places in methane (CH_4).



CATALYTIC SYNTHESIS OF AMMONIA is thought to involve dissociation of nitrogen and hydrogen (*1*) followed by addition of hydrogen to a complex consisting of nitrogen bound to atoms on the surface of the catalyst (*2, 3, 4*). Finally, ammonia (NH_3) is desorbed.

proceeds by means of the intermediate formation of a physisorbed species.

Step 3 usually involves one or more elementary processes in which chemisorbed species react to form new chemisorbed species. In some cases step 3 may involve reaction between a chemisorbed species and a molecule in the gas or liquid phase to form a new chemisorbed species. In step 4 the chemisorbed species desorbs, often by associative desorption, to give the final product.

Some simple cases may lack a surface-reaction step. Isotopic exchange between deuterium (the hydrogen isotope of mass two) and methane occurs on a number of transition metals (nickel and platinum) and their oxides. The reaction appears to proceed simply by dissociative adsorption followed by associative desorption [*see middle illustration at left*].

As Haber discovered, pure iron catalyzes the reaction of hydrogen with nitrogen to yield ammonia at about 450 degrees C. Presumably the first step in the process is that the hydrogen molecule (H_2) and the nitrogen molecule (N_2) are dissociatively adsorbed on the surface of the catalyst. Experiments with isotopes of nitrogen show that nitrogen does not dissociate at reasonable rates on iron until the temperature has been raised to about 450 degrees C. Hydrogen, on the other hand, dissociates freely even at the temperature of liquid nitrogen (−196 degrees C.).

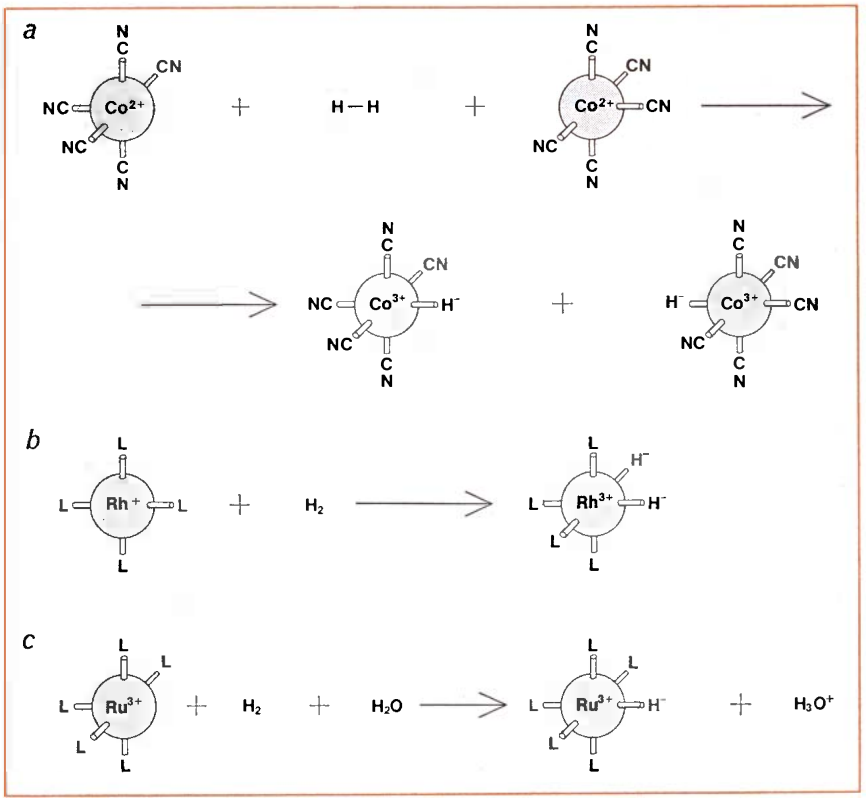
It was suggested as long ago as the 1930's that the rate of ammonia synthesis is limited by the low rate of dissociation of nitrogen. It is hypothesized that once the nitrogen dissociates, forming a surface compound that can be designated N*Cat*, hydrogen atoms are added in three rapid steps forming HN*Cat*, H_2N*Cat* and finally H_3N*Cat*, from which NH_3 is readily released [*see bottom illustration at left*].

Subsequent work has supported and elaborated this mechanism, although many details are unclear and the intermediacy of an adsorbed molecule of nitrogen is favored by some. From the standpoint of industrial importance it has been found that iron plus a few percent of the oxides of potassium and aluminum, which are known as promoters, give a longer-lived catalyst and one with greater resistance to impurities in the feed stream. Catalysts of this type can often be used for several years.

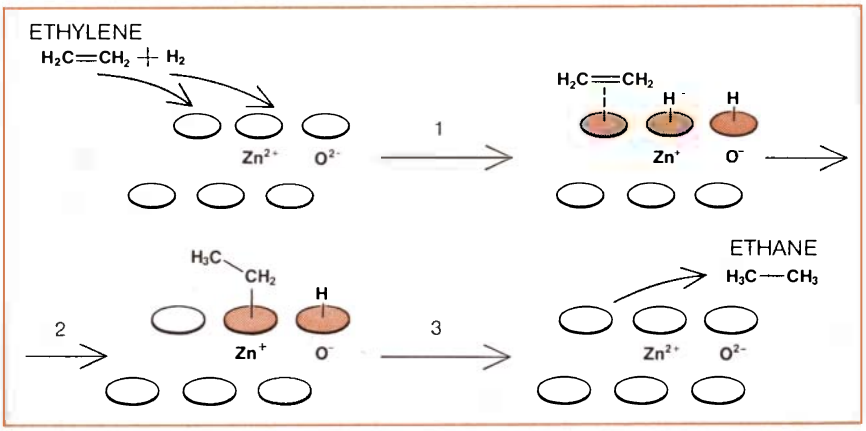
The recently discovered reactions in which coordination complexes of transition elements function as homogeneous catalysts in adding hydrogen to various unsaturated compounds present close

similarities to reactions effected by previously known heterogeneous hydrogenation catalysts. When transition elements are incorporated in organometallic compounds, they work as homogeneous catalysts capable of adding hydrogen to various unsaturated compounds. These active compounds are often coordination complexes. The complex must be "coordinatively" unsaturated if it is to activate hydrogen, that is, there must be a vacant or partially vacant position in the "coordination sphere" that surrounds the metal ion to which hydrogen can become bound. For example, cobalt pentacyanide $[Co(CN)_5]$ has only five of six potential positions filled and can bind an atom of hydrogen in the empty position. A similar coordination complex can be formed with rhodium, which can hold two atoms of hydrogen in the same state of activation: H^-. The rhodium complex is oxidized by hydrogen to give a product in which the hydrogens are formally hydride ions. The reaction is called oxidative addition, and one can readily imagine an analogous oxidative dissociation adsorption. In coordination complexes incorporating ruthenium the hydrogen molecule is split into a positive state (H^+) and a negative state (H^-); the metal ion is not oxidized [*see upper illustration at right*].

The last process of activation is essentially the same as the one thought to operate on the surface of certain metal oxides that are used for hydrogenating olefins, for example zinc oxide (ZnO). In the case of ZnO the Zn^{2+} and O^{2-} act as coordinatively unsaturated surface species. (The superscripts refer to the number of electrons removed from or added to the dissociated fragment.) The zinc fragment binds hydrogen as H^- and the oxygen fragment binds hydrogen to form OH^-. The olefin is weakly adsorbed on a neighboring site and reacts in turn with the H^- and the hydrogen in the OH^-, thereby acquiring two hydrogen atoms [*see lower illustration at right*]. The process is called heterolytic dissociative adsorption to distinguish it from the homolytic adsorption of hydrogen on metals, in which the hydrogen molecule splits into two equally charged fragments.



COMPLEXES OF TRANSITION METALS, such as cobalt, rhodium and ruthenium, exhibit unusual catalytic properties. The complexes consist of ions of transition metals coordinated to side groups called ligands (*L*). Some complexes of this type are soluble in liquids and act as homogeneous catalysts. Pentacyanocobalt (*a*) is able to activate hydrogen because the "coordination sphere" around the cobalt ion (Co^{2+}) has an empty position that can hold a hydrogen ion that is formally in the negative state (H^-). The coordination sphere around the rhodium ion (*b*) can hold two hydrogen atoms, both H^-. In aqueous solution an organometallic compound of ruthenium (*c*) splits a molecule of hydrogen so that one fragment is negatively charged and one becomes bound to a molecule of water as a proton, forming H_3O^+. Catalysts of this type can produce the polymers shown on the next two pages.

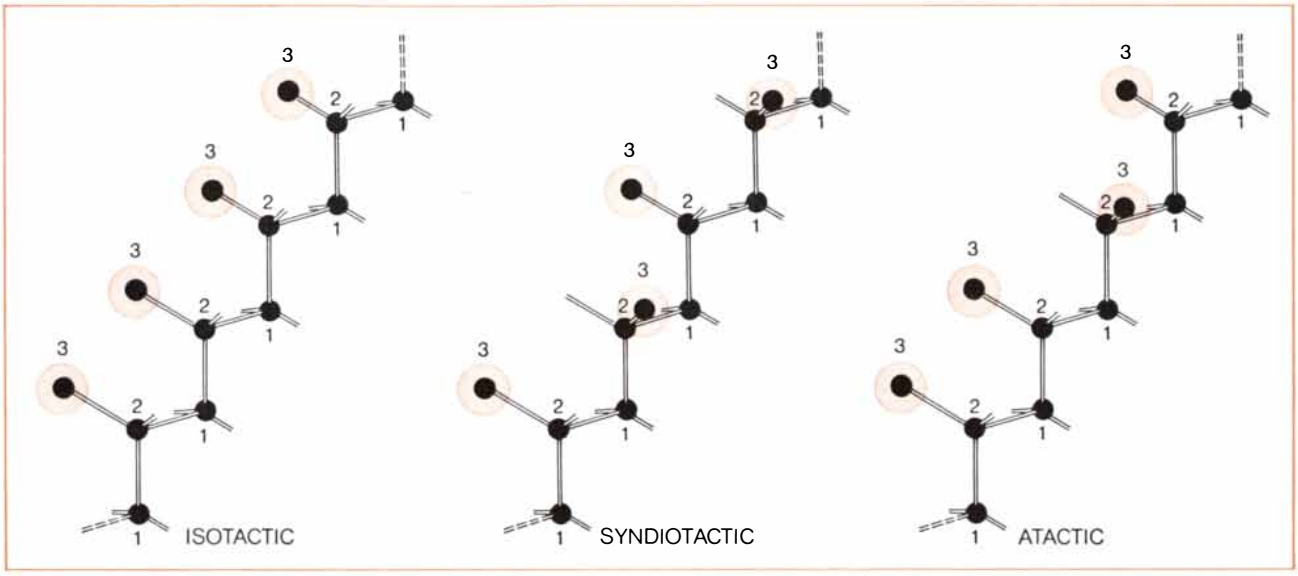


HYDROGENATION OF ETHYLENE, first achieved by Sabatier on a nickel catalyst, takes place readily on zinc oxide. The key sites appear to be coordinatively unsaturated metal ions (Zn^{2+}) and oxide ions (O^{2-}) on the surface. Ethylene ($H_2C : CH_2$) is adsorbed (*1*) and reacts in sequence (*2, 3*) with two hydrogen ions. The product is ethane ($H_3C \cdot CH_3$).

Mechanism of Hydrogenation

We have presented several examples of catalytic reactions and some of the current thinking about how they occur. Generally speaking, the mechanism of homogeneous catalysis is easier to elucidate than that of heterogeneous catalysis. In homogeneous catalysis elementary processes involve simple molecules and intermediates. In heterogeneous catalysis we must also consider the effect of surfaces. One cannot isolate a surface intermediate, recrystallize it and determine its structure by X-ray analysis. If surface reactions provide particularly useful possibilities for combinations of elementary processes, they also present special problems in the study of mechanism. We shall give several examples of the techniques that have proved to be helpful in that study.

Many of the extensively investigated



THREE KINDS OF POLYPROPYLENE can be made from propylene ($H_2C : CHCH_3$) with transition-metal catalysts. At a reaction temperature of 50 degrees C. a catalyst consisting of triethylaluminum and vanadium trichloride yields isotactic polypropylene, in which the methyl (CH_3) groups (*color*) all lie on the same side of the central chain of carbon atoms (*black balls*). Hydrogen atoms have been omitted; their locations are indicated by short bonds projecting from the carbon atoms. At a reaction temperature of −78 degrees C. a catalyst consisting of vanadium tetrachloride and diethyl aluminum chloride yields syndiotactic polypropylene, a molecule in which the methyl groups alternate from side to side. When the methyl groups project at random, the polymer is atactic.

reactions of heterogeneous catalysis are hydrogenations. We have discussed the hydrogenation of nitrogen to ammonia. Hydrogenations of organic compounds such as olefins, acetylenes (hydrocarbons with a triple bond between two adjacent carbon atoms) and ketones (compounds with a terminal oxygen atom doubly bonded to a carbon atom) are usually much easier and occur on a much wider variety of catalysts.

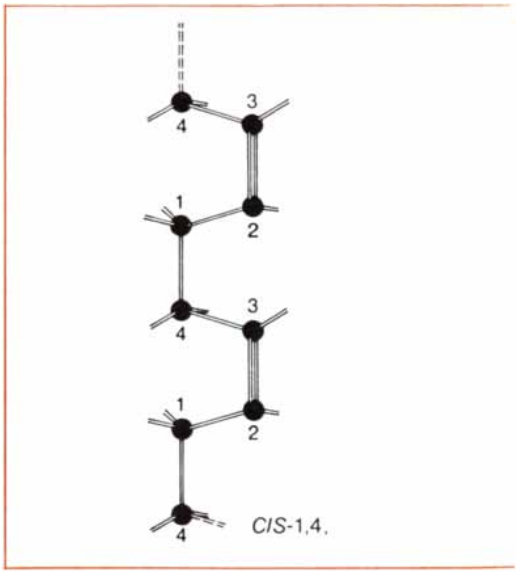
The hydrogenation of dimethylacetylene yields, depending on the catalyst, a number of interesting and useful products [*see top illustration on page 56*]. Dimethylacetylene (CH_3CCCH_3) is a chain of four carbon atoms with the central two carbons joined by a triple bond. If the hydrogenation is carried out at room temperature on nickel or platinum catalysts, the initial products are a mixture of butane (the fully saturated hydrocarbon C_4H_{10}) and two isomers of a four-carbon olefin: *trans*-2-butene and *cis*-2-butene, with *cis*-2-butene predominating. The designation "*trans*" means "located across from each other"; "*cis*" means "located on the same side." Here the terms refer to the location of the two methyl groups with respect to the double bond in the butene molecule.

On a palladium catalyst the initial product is almost exclusively *cis*-2-butene. In studying the mechanism of the reaction, chemists have used deuterium as the hydrogenating agent. By analyzing the product with the mass spectrograph one can separate the product into fractions that differ in the number of deuterium atoms incorporated in each butene molecule. By means of nuclear magnetic-resonance spectroscopy one can then determine the exact location in the molecule of the deuterium atom or atoms.

It turns out that as long as some dimethylacetylene remains unreacted, the initial product consists almost entirely of *cis*-2-butene bearing one deuterium atom on each of its two central carbon atoms. This is what one would expect if dimethylacetylene is chemically adsorbed on the surface of the catalyst by a breaking of one of the bonds between its central carbons [*see second illustration from top on page 56*].

Once all the dimethylacetylene has reacted, *cis*-2-butene begins to be hydrogenated to butane and isomerized to *trans*-2-butene. Actually isomerization is more rapid than hydrogenation. There is considerable evidence that the isomerization involves a mechanism first proposed by Juro Horiuchi and Michael Polanyi. Presumably as the *cis*-2-butene species is held to the catalyst by a single bond one of the two methyl groups rotates to an alternate position, after which a hydrogen replaces the catalytic bond and the molecule—now *trans*-2-butene—leaves the surface [*see third illustration from top on page 56*]. To account for the formation of still another isomer, 1-butene, one can postulate a mechanism that simply shifts the double bond in *cis*-2-butene from its location in the middle of the molecule to a new location between the first and second carbon atoms [*see bottom illustration on page 56*].

Studies with deuterium and a wide variety of hydrocarbons of different



FOUR POLYBUTADIENES, each precisely constructed, can be made from 1,3-butadiene ($H_2C : CHCH : CH_2$). The designation "1,3" indicates that the first and third carbon atoms in the molecule are joined to the next carbon in sequence by a double bond. If both double bonds open up and take part in

structure have led to a rather good understanding of the nature of the intermediates formed in the reactions of hydrocarbons on metallic catalysts. Relatively little is known, however, about the nature of the chemical bond between metal and carbon, about the exact location of the adsorbed species on the surface of the catalyst and about the origin of the differences in behavior of different metals that act as catalysts.

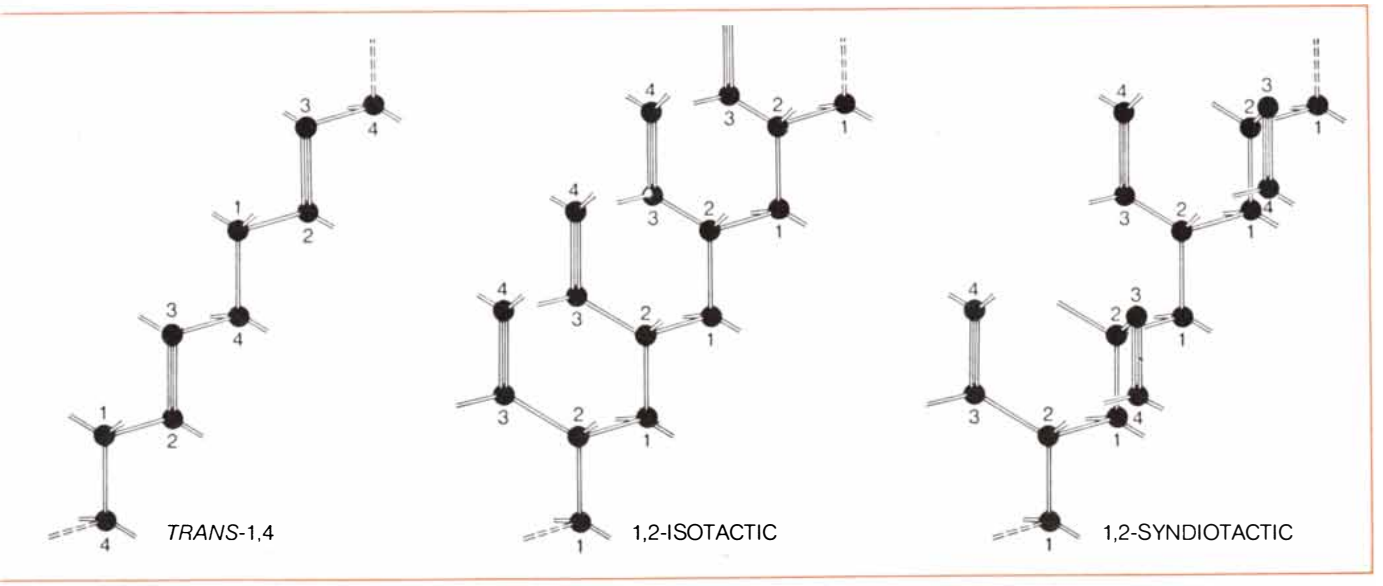
It will have been noted that all the arguments given above for the surface intermediates were inferential. One might hope to examine the catalyst during reaction by infrared spectroscopy and from the observed infrared spectra deduce what species are present on the surface. Some progress has in fact been made in such a program, but there is a difficulty. Much of the surface of most metals is occupied during hydrogenation by relatively slow-reacting species. That is, most of the surface species are not involved in the hydrogenation but the infrared spectroscope responds to the whole set of adsorbed species. It has not been easy to interpret the results.

More clear-cut results have been obtained with infrared spectroscopy of another type of hydrogenation catalyst, such as the zinc oxide catalyst mentioned above. Chromium oxide also acts as a hydrogenation catalyst. It appears that the key sites for activity on these oxides are coordinatively unsaturated metal ions and oxide ions at the surface. Heterolytic dissociative adsorption of hydrogen on these sites can be seen by infrared spectroscopy in the case of zinc oxide. The infrared studies indicate the presence of two kinds of adsorbed olefin. Ethylene is rather weakly adsorbed and then reacts with $Zn^{2+}H^-$ [*see lower illustration on page 53*]. In contrast to the metals, the first reaction has no tendency to reverse. If one starts with ethylene (C_2H_4) and deuterium (D), the product is almost exclusively CH_2DCH_2D. For zinc oxide the deuterium studies provide fairly strong evidence for the illustrated mechanism and the infrared data add additional support. The isotopic distribution over metals is much more complicated.

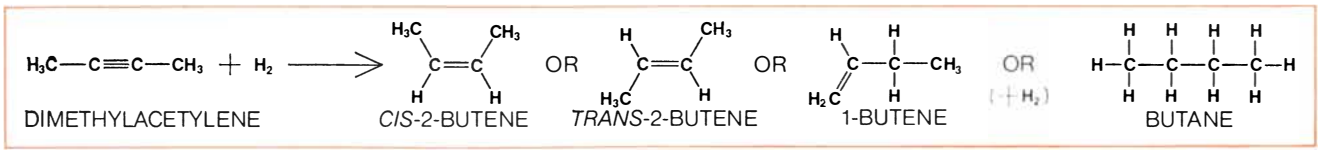
Evidence from infrared spectroscopy and nuclear magnetic-resonance spectroscopy shows that simple olefins such as ethylene and propylene can be adsorbed on active surface sites in just about all the ways one might imagine. In some cases only a single carbon atom is bonded to the surface; in other cases two carbon atoms are bonded. Sometimes the double bond between the carbons is preserved; in other cases the double bond is opened and provides the link to the surface. It is apparent that quite an organometallic zoo can exist on the surface of metallic catalysts.

The practical aspects of catalysis involve the ability to perform a chemical reaction at a profit. In the simplest commercial installation the reagents and a catalyst are simply placed together in a vessel. The vessel is usually equipped with an indirect steam-heating system and a stirrer. When the reaction is completed, the vessel is emptied and the catalyst is separated from the product and may be reused in the next batch operation. In a continuous operation the reagents are preheated and pumped through a reactor containing the catalyst. The continuous type of operation provides for better control of conditions and ease of handling of product; it also allows operation at higher temperatures and pressures.

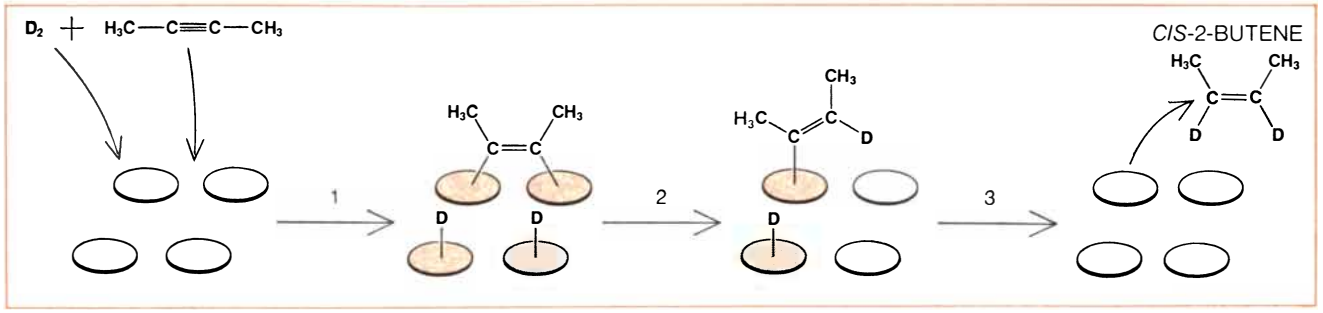
Ideally once the catalyst is placed in the reactor it should last indefinitely. In practice catalysts age, they become poisoned, they deteriorate physically and they accumulate reaction products or intermediates that undergo further reaction and finally deactivate the system. The whole idea in continuous operation is to maintain reasonably constant product quality. Usually as the catalyst deactivates, the temperature is raised to maintain a high yield. When these increases reach a limit, the catalyst may either be replaced or subjected to regeneration. For hydrocarbon reactions the regeneration means the removal of carbonaceous deposits. This is normally accomplished by passing a stream of gas with a controlled content of oxygen through the catalyst bed, thus burning off the deposits. While the catalyst is being regenerated or replaced, it is obvi-



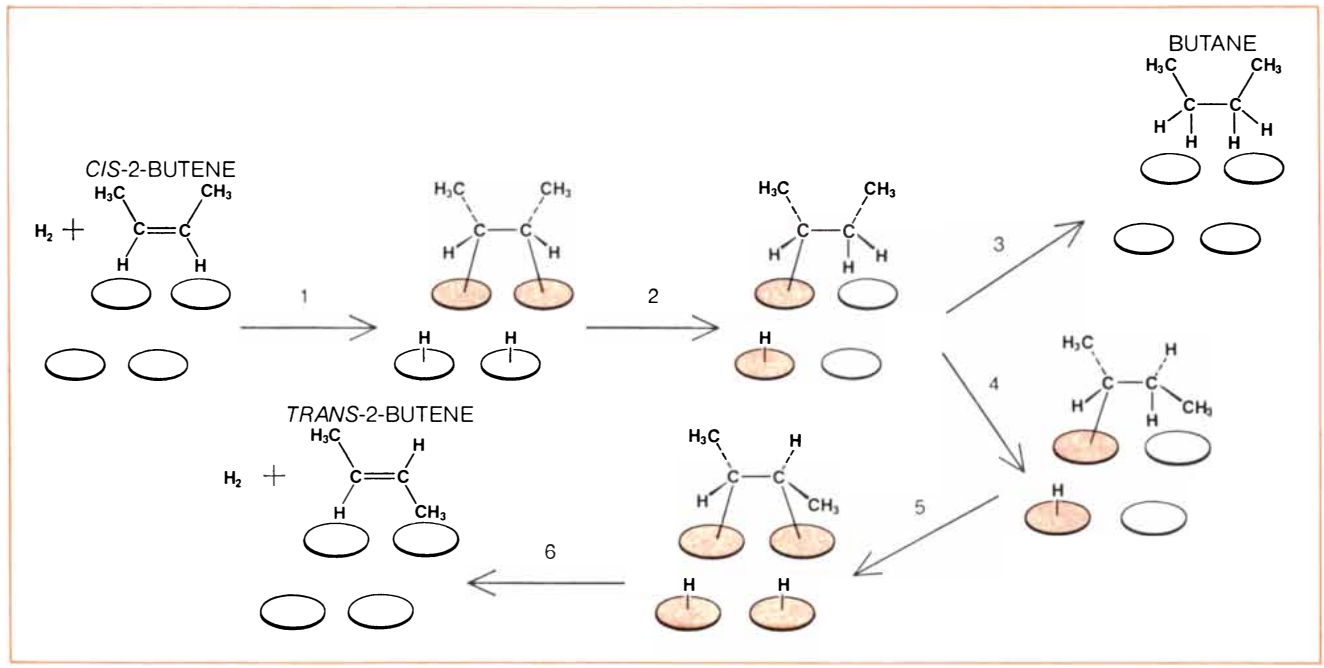
the polymerization, the resulting polymer consists of a continuous chain of carbon atoms with a double bond between every other pair of atoms. If the 1–2 and 3–4 single bonds both lie on the same side of the 2–3 double bond, the polymer is termed *cis*-1,4-polybutadiene. If the single bonds lie on opposite sides, the polymer is *trans*-1,4-polybutadiene. Here "1,4" indicates that the first and fourth carbon atoms in butadiene link up to form the polymer. If the polymerization involves only the double bond between the first and second carbons in each butadiene molecule, the third and fourth carbon atoms project as a side chain. If the side chains are all on one side of the central chain, the polymer is 1,2-isotactic polybutadiene. If the side chains alternate from side to side, the polymer is 1,2-syndiotactic polybutadiene. Each stereospecific configuration is produced by a distinctive transition-metal catalyst.



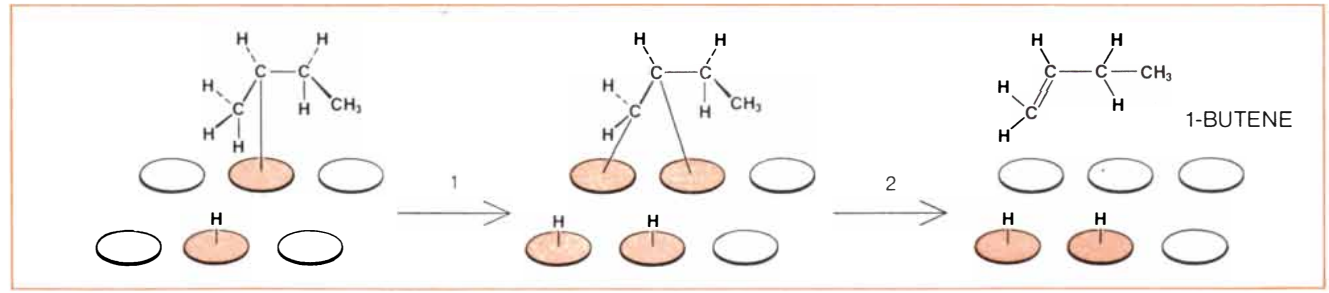
HYDROGENATION OF DIMETHYLACETYLENE can yield three different olefins, *cis*-2-butene, *trans*-2-butene and 1-butene, and the saturated hydrocarbon butane. With a palladium catalyst the initial product is chiefly *cis*-2-butene (*see mechanism below*).



MECHANISM OF HYDROGENATION of dimethylacetylene on palladium has been studied by substituting deuterium (D) for hydrogen. Dimethylacetylene is adsorbed to active sites (*color*) through its central carbon atoms (*1*). Two deuterium atoms are then added in sequence (*2, 3*), yielding *cis*-2-butene. "*Cis*" indicates that the two methyl groups are on the same side of the double bond.



FURTHER HYDROGENATION AND ISOMERIZATION of *cis*-2-butene can occur once all the dimethylacetylene has reacted. *Cis*-2-butene is presumably readsorbed and can acquire two more hydrogens (*2, 3*) to form butane. Alternatively one methyl group can rotate to a new position (*4*). The hydrocarbon again forms a double bond with the palladium (*5*) and emerges as *trans*-2-butene (*6*).



FURTHER ISOMERIZATION converts *trans*-2-butene to 1-butene. The *trans* molecule is evidently readsorbed so that its first and second carbon atoms are linked to active sites (*1*). On desorption (*2*) the double bond appears between the first and the second carbon.

ously not making product; ideally, if one has to regenerate, one would prefer to do it continuously and not interfere with the processing of the raw material.

An excellent example of continuous processing and regeneration is the catalytic cracking of oils [*see illustration on next page*]. The catalyst, in finely divided form, is carried into the reactor by the upward flow of vaporized oil, the catalyst-product mixture is withdrawn from the top of the reactor and the catalyst is inertially removed from the product vapors in a cyclone separator. The catalyst is then stripped with steam to remove entrained product and is fed by gravity into a regeneration vessel where it comes in contact with a countercurrent stream of air that burns off the carbonaceous deposits. The clean, hot catalyst is fed through a standpipe and is picked up by the incoming fresh oil. The circulation of catalyst through the reactor and regenerator is very large with respect to the oil processed. Currently more than 6.9 million barrels of oil per day are subjected to catalytic cracking. The catalyst circulation on a daily basis amounts to eight million tons. About .15 pound of catalyst per barrel of oil is added to the unit in order to compensate for loss and withdrawal, thus allowing for the maintenance of equilibrium activity.

Catalysts are prepared in many different ways. A catalyst widely used in catalytic cracking is a composite of silica (SiO_2) and alumina (Al_2O_3), which can be prepared by neutralizing a solution of water glass (Na_2SiO_3) with sulfuric acid to form a gelatinous precipitate that is a polymerized silicic acid [$(H_2SiO_3 \times H_2O)_n$]. This is next treated with aluminum sulfate solution [$Al_2(SO_4)_3$] and ammonia to precipitate aluminum hydroxide [$Al(OH)_3$] on the silicic acid precipitate. The composite is filtered and thoroughly washed to remove all soluble salts. It is then dried in air and calcined at about 500 degrees C. The resulting material contains about 75 percent SiO_2 and 25 percent Al_2O_3 by weight and is believed to have a structure wherein trivalent aluminum atoms are incorporated within a tetrahedral matrix of polymeric silicic acid. Each trivalent aluminum atom thus has to carry a net positive charge to compensate for its enforced tetrahedral coordination.

These positive, or electron-deficient, sites serve as the locus of acidity; in fact, the strength of the acidity thereby created is comparable to the strength of mineral acids such as sulfuric acid. Unlike most mineral acids, the acids created are very stable at high temperatures. The total number of sites is limited and is related to the surface area of the composite. The usual surface area for fresh silica-alumina is about 600 square meters per gram of catalyst. This remarkable surface area is due to a multitude of extremely small channels ranging from five to 100 angstroms in diameter. In service some of the smaller channels collapse, and there is a substantial loss in surface area: down to about 150 square meters per gram. The larger channels survive, however, and the acidity function in these channels is retained.

In general at a given temperature the reaction rate on a heterogeneous catalyst is dependent on two factors: the number of active sites available to the reactant and the turnover rate. The number of active sites is related to the surface area, whereas the turnover rate is a function of the chemistry of the site in relation to the reactant. If the chemistry of the site is such that a reactant stays too long on a site, and during that time is not available to another reactant molecule, the turnover number is low.

Catalytic Reforming

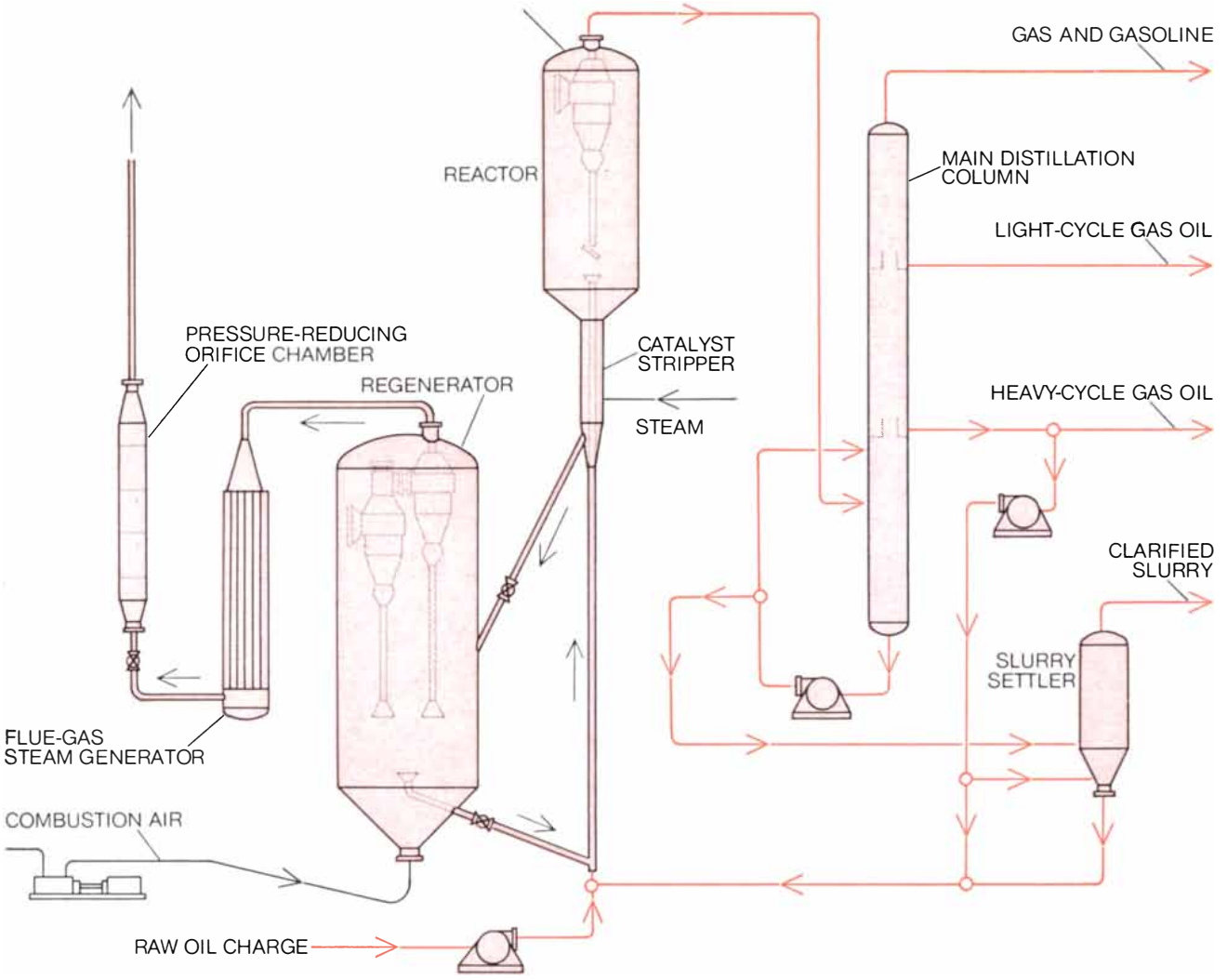
We have pointed out that the gasoline fraction, or virgin naphtha, obtained from crude oil by fractionation needs upgrading to be useful as a motor fuel. Since about 1930 there has been a continuing need to increase the octane number of gasoline. In 1930 the average gasoline had an octane number of about 65; today the average is about 100. To meet this demand new catalytic processes have had to be developed and widely employed.

During the 1950's new platinum-alumina-halogen catalysts were introduced to carry out the catalytic reforming of low-octane oil fractions. The new catalysts performed a dual function by maintaining a proper balance between two catalytic requirements. In general the reactions of catalytic reforming require two types of sites: hydrogenation-dehydrogenation sites (provided by platinum) and acidic sites; catalytic reforming does not occur in the absence of either. The main advantages of the use of this type of catalyst are considerably higher selectivity (higher yield), higher octane number and the ability to run continuously without frequent regeneration.

The chemistry of catalytic reforming using platinum catalysts involves four major reactions. The first is the dehydrogenation of cyclic hydrocarbons, for example converting methylcyclohexane into toluene. The second is dehydrocyclization of paraffins (saturated open-chain hydrocarbons), for example converting normal heptane into toluene [*see bottom illustration on page 51*]. The third is hydrocracking, which means breaking long-chain paraffins into two smaller molecules and adding hydrogen at the sites where the original chain has been broken. The fourth is isomerization, which means converting a straight-chain hydrocarbon into a branched-chain molecule.

All these reactions lead to an octane-number enhancement. For example, the second reaction converts normal heptane, with an octane number of zero, to toluene, which has an octane number in excess of 100. The third reaction can convert decane, for example, with an octane rating of less than zero, into two molecules of isopentane with an octane number of 90. The first and second reactions are strongly endothermic; the third is exothermic; the fourth is essentially thermoneutral. To maintain an overall heat balance one must use multiple reactors with intermediate reheating. Although the overall system produces hydrogen, the process is carried out in the presence of excess hydrogen (recycled from the first and second reactions) at pressures ranging from 150 to 500 pounds per square inch. The excess hydrogen holds down the deposition of carbonaceous material on the catalyst. By this expedient a catalyst can be used continuously for as long as three years. Reaction temperatures are held between 475 and 550 degrees C. Between one volume and three volumes of gasoline are processed per volume of catalyst per hour. The catalyst contains between .3 and .8 percent platinum and up to about 1 percent chlorine or fluorine on a base of highly porous alumina. During the lifetime of the catalyst each platinum atom leads to the reaction of some 20 million molecules of gasoline, a truly catalytic act. The function of the halogen is to induce acid reactions, which convert saturated hydrocarbon rings into benzene (unsaturated) rings.

The formation of benzene-ring, or aromatic, compounds from paraffins (dehydrocyclization) is extremely complex. Some 10 to 15 intermediate steps are postulated. They require the presence of both platinum and acid sites, and adsorbed hydrocarbons evidently migrate from one site to another. In spite of this complexity the efficiency of conversion from the paraffin to an equilibrium mixture of aromatics is of the order of 90 percent. Even higher efficiencies are obtained with the newly developed platinum-rhenium-halogen-alumina catalysts. Since its introduction in 1949, catalytic reforming, using dual-function plati-



FLUID CATALYTIC CRACKING PROCESS was developed in the late 1930's. The catalyst is in the form of fine grains that behave in the reactor much like a fluid when agitated from below by vaporized oil. The large object depicted in gray inside the reactor is a cyclone separator that removes the catalyst from the reactor product. The reactor product passes to a distillation column where fractions of different volatility are separated. Part of the heaviest fraction is recycled to the reactor. A portion of the catalyst is continuously transferred by gravity from the reactor to the regenerator, where it again behaves like a fluid when it is subjected to a flow of air that burns off carbonaceous deposits. The reactivated catalyst is returned continuously to the reactor. The hot air leaving the regenerator is used to make steam. The catalytic cracker illustrated here was designed by the Universal Oil Products Company.

num-containing catalysts, has grown in importance. Today some 6.8 million barrels per day are processed by this catalytic system in the U.S., western Europe and Japan.

The Future of Catalysis

Although it has attained tremendous practical importance, heterogeneous catalysis has attracted few workers in the chemistry departments of American universities. One may suspect that the need for new areas of research will one day lead organic chemists to extend their interest to heterogeneous catalysis, but only a handful have taken the step so far. In recent years, however, a number of aspects of heterogeneous catalysis have received increased attention in American departments of chemical engineering. There are several other countries where the number of university chemists interested in heterogeneous catalysis is relatively large: Japan, the Netherlands and the U.S.S.R. in particular. It will be interesting to see if this university activity is followed by important technological developments.

One must admit that in spite of the considerable progress in the technological and scientific aspects of catalysis, only experiment can establish whether or not a specific chemical material will make a suitable catalyst for a particular reaction. For many thermodynamically possible reactions no catalysts are known, and many of the catalysts we know were discovered by accident or by a very extensive screening program. The discovery of new promoters has been little helped by theory. The added complexity of the surface makes heterogeneous catalysis an interdisciplinary subject. Both surface chemistry and surface physics must, so to speak, precede heterogeneous catalysis. Therefore a better understanding of many aspects of heterogeneous catalysis must await further advances in the chemistry and physics of surfaces.

New tools are being developed that will enable us to look more closely at the surface of the catalyst and thus possibly gain some additional understanding. The interdisciplinary nature of the study of catalysis, involving as it does both surface chemistry and surface physics, will also require close cooperation with other sciences.

Taller skyscrapers to save space.
Lower buildings for a view of the sky.

More parking spaces.
No more parking lots.

Respect for civic law.
Freedom to do exactly what I want.

Varied neighborhoods.
Neighbors who are just like me.

Better garbage collection.
Lower sanitation costs.

A place to walk my dog.
Dogs prohibited.

Living space to raise my family.
No noisy kids for neighbors.

A city that's easy to walk around.
A city that's easy to drive around.

Better school systems for everybody.
Lower school taxes.

Immediate end to air pollution.
More power stations.

More jobs for city dwellers.
No commercial zoning near dwellings.

A place I want to come home to.
A place that's easy to get out of.

Lower rents.
A fair break for landlords.

Visually varied street planning.
Practical grid systems for streets.

Cleaner, faster subways and buses.
Lower bus and subway fares.

No parades disrupting traffic flow.
More parades promoting civic pride.

More and better sewage treatment.
No treatment plants in my neighborhood.

Solutions in ten years.
Solutions now!

The ideal

The ideal city will happen when people with different—even opposing—ideas can work together to build an environment that balances human diversity.

The real

Our cities are threatened with chaos to the degree that groups and individuals ignore their interdependence on one another.

There are no simple solutions to urban problems. Because modern cities aren't simple places. They're concentrations of diversity—different people with different attitudes, backgrounds, skills. Their interaction makes a city stimulating; their interdependence on one another makes the city workable. We must find solutions that respect human diversity and balance it in a mutually supportive environment. Not a simple problem. But the solutions are worth working for.
Because the city is the future.
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Model 420.

Uses Focused Flash system. Automatic exposure control for all other shots. Dual-image coupled rangefinder-viewfinder. Detachable cover and adjustable carrying strap.

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Square Shooter.

Square format (3⅜″ x 3¼″) reduces instant color film cost up to 25%.* Built-in Focused Flash system. Automatic electric eye, electronic shutter exposure control for all other shots. New distance finder uses triangulation principle for easy, precise focusing. (Line up pointer on feet of subject, raise camera to eye level and shoot.) For color only.

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The finest camera we make. The Focused Flash system automatically controls the brilliance of the flash as you focus the camera (a cam adjusts louvers to precisely meter the light according to the distance of the subject from the camera). Soft flattering light for 3½′ close-ups. Perfect illumination for group shots as far as 10′ back. Completely automatic exposure system (transistorized electronic shutter and highly sensitive electric eye) for all other shots. Electronic development timer "beeps" when the picture is perfectly developed. Single-window Zeiss Ikon rangefinder-viewfinder for precise focusing at any distance. Black all-metal body with brushed-chrome finish. Uses all optional accessories: for portraits from 19″ to 3½′; for close-ups from 9″ to 19″; self-timer; cable release; ultraviolet filter; cloud filter.

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did not exist. There's something for everybody. Even one that's under $20.

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Uses Focused Flash system. Automatic exposure control for all other shots. Built-in mechanical development timer. Dual-image, coupled rangefinder-viewfinder. Same sharp triplet lens as expensive cameras. Lightweight, high-impact plastic body.

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Designed to produce distortion-free color portraits and close-ups only. Split-image single-window rangefinder-viewfinder has 5½" base for extreme accuracy. Focus is fixed at approximately 39" (move the camera back and forth until images coincide, then shoot). Fresnel lens concentrates light from self-energizing Magicube on the subject with controlled, even softness. Built-in timer signals when your picture's ready.

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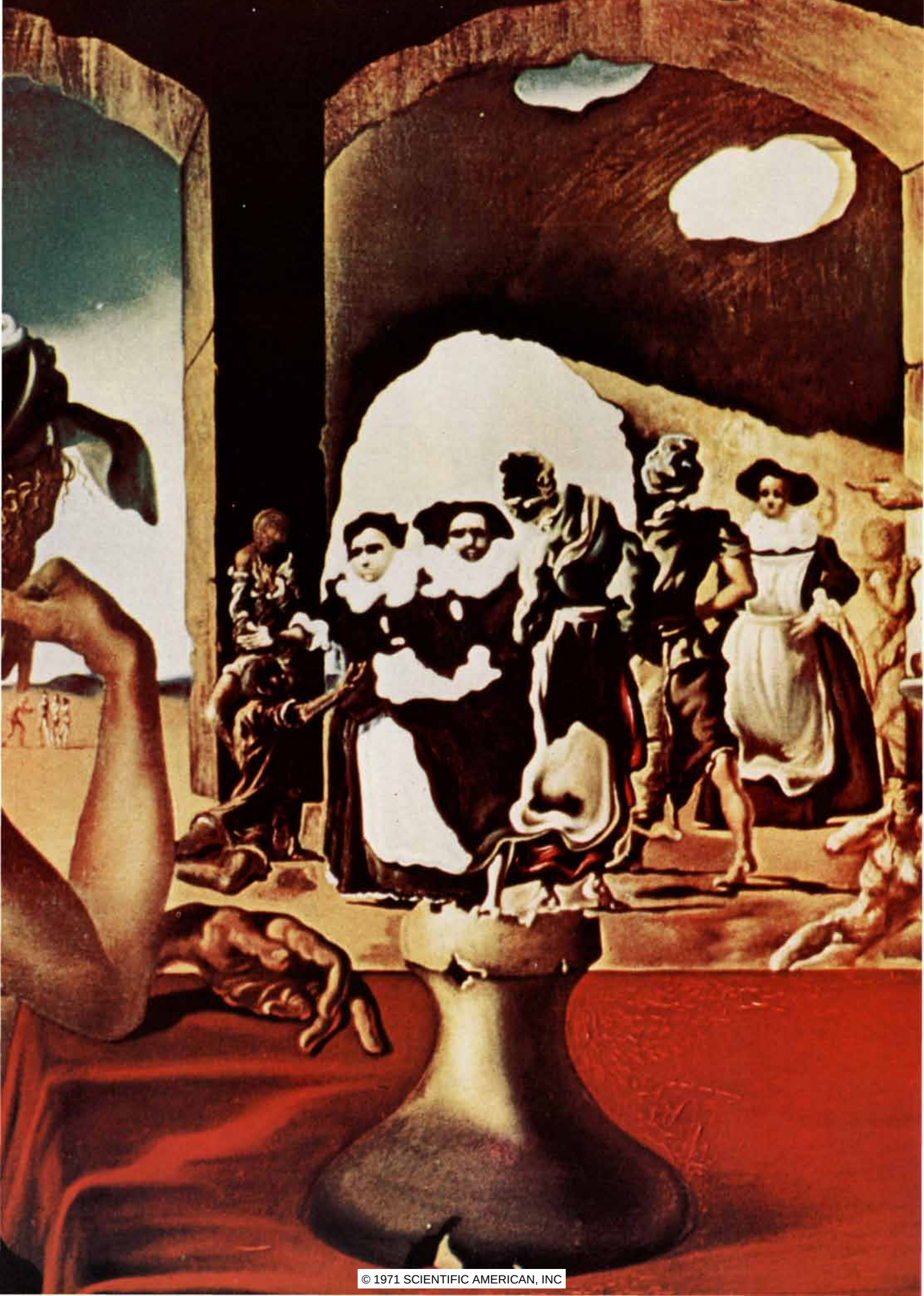
*Comparison based on T88/T108 film at suggested list prices. Polaroid®



MULTISTABILITY IN PERCEPTION

Some kinds of pictures and geometric forms spontaneously shift in their principal aspect when they are looked at steadily. The reason probably lies in the physical organization of the perceptual system

by Fred Attneave

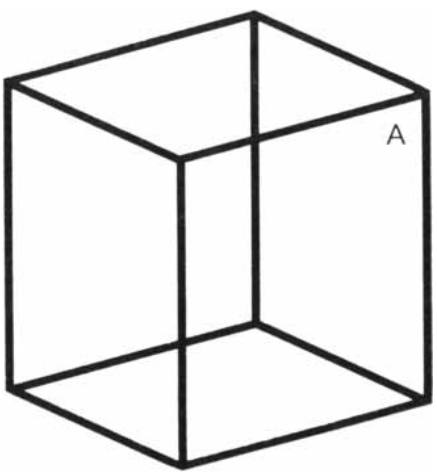
Pictures and geometric figures that spontaneously change in appearance have a peculiar fascination. A classic example is the line drawing of a transparent cube on this page. When you first look at the cube, one of its faces seems to be at the front and the other at the back. Then if you look steadily at the drawing for a while, it will suddenly reverse in depth and what was the back face now is the front one. The two orientations will alternate spontaneously; sometimes one is seen, sometimes the other, but never both at once.

When we look steadily at a picture or a geometric figure, the information received by the retina of the eye is relatively constant and what the brain perceives usually does not change. If the figure we are viewing happens to be an ambiguous figure, what the brain perceives may change swiftly without any change in the message it is receiving from the eye. The psychologist is interested in these perceptual alternations not as a curiosity but for what they can tell us about the nature of the perceptual system.

It is the business of the brain to represent the outside world. Perceiving is not just sensing but rather an effect of sensory input on the representational system. An ambiguous figure provides the viewer with an input for which there are two or more possible representations that are quite different and about equally good, by whatever criteria the perceptual system employs. When alternative representations or descriptions of the input are equally good, the perceptual system will sometimes adopt one and sometimes another. In other words, the perception is multistable. There are a number of physical systems that have the same kind of multistable characteristics, and a comparison of multistability in physical and perceptual situations may yield some significant clues to the basic processes of perception. First, however, let us consider several kinds of situations that produce perceptual multistability.

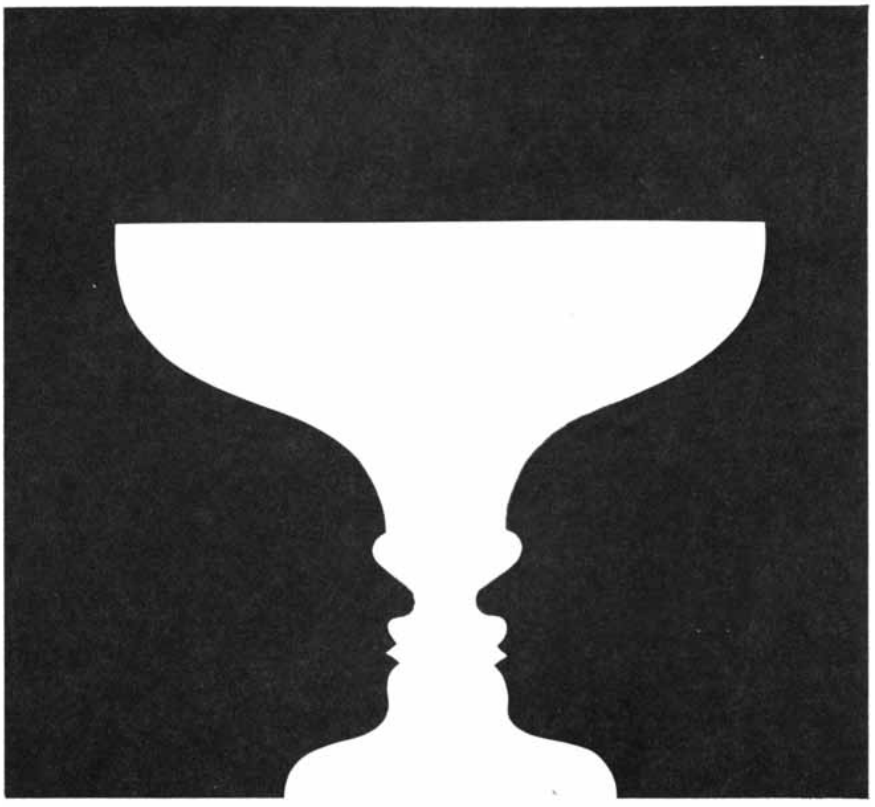
Figure-ground reversal has long been used in puzzle pictures. It is often illustrated by a drawing that can be seen as either a goblet or a pair of faces [*see top illustration on next page*]. This figure was introduced by the Danish psychologist Edgar Rubin. Many of the drawings and etchings of the Dutch artist Maurits C. Escher are particularly elegant examples of figure-ground reversal [*see bottom illustration on next page*]. These examples are somewhat misleading because they suggest that the components of a figure-ground reversal must be familiar objects. Actually you can make a perfectly good reversing figure by scribbling a meaningless line down the middle of a circle. The line will be seen as a contour or a boundary, and its appearance is quite different depending on which side of the contour is seen as the inside and which as the outside [*see top illustration on page 65*]. The difference is so fundamental that if a person first sees one side of the contour as the object or figure, the probability of his recognizing the same contour when it is shown as part of the other half of the field is little better than if he had never seen it at all; this was demonstrated by Rubin in a classic study of the figure-ground dichotomy.

Note that it is quite impossible to see both sides of the contour as figures at the same time. Trying to think of the halves as two pieces of a jigsaw puzzle that fit together does not help; the pieces are still seen alternately and not simultaneously. What seems to be involved here is an attribution of surface properties to some parts of a field but not to others. This kind of distinction is of central importance in the problem of scene analysis that Marvin Lee Minsky of the Massachusetts Institute of Technology and other investigators of computer simulation have been grappling with lately. The figure made by drawing a line through a circle is actually tristable rather than bistable; the third possibility is being able to see the line as a thing in itself, as a twisted wire rather than the boundary of a figure.



NECKER CUBE, a classic example of perspective reversal, is named after Louis Albert Necker, who in 1832 reported that line drawings of crystals appeared to reverse in depth spontaneously. Corner *A* alternates from front to back when gazed at steadily.

PAINTING BY SALVADOR DALI on the opposite page is an example of the use of ambiguous figures by a serious artist. The illustration is a portion of "Slave Market with Apparition of the Invisible Bust of Voltaire." It is reproduced with the permission of the Dali Museum in Cleveland. When viewed at close range, the figures of people predominate; when viewed at a distance, bust of Voltaire becomes apparent.



REVERSIBLE GOBLET was introduced by Edgar Rubin in 1915 and is still a favorite demonstration of figure-ground reversal. Either a goblet or a pair of silhouetted faces is seen.

WOODCUT by Maurits C. Escher titled "Circle Limit IV (Heaven and Hell)" is a striking example of both figure-ground reversal and competition between rival-object schemata. Devils and angels alternate repeatedly but neither seems to be able to overpower the other.

The point of basic interest in figure-ground reversal is that one line can have two shapes. Since an artist's line drawing is readily identifiable with the object it is supposed to portray, and since a shape has much the same appearance whether it is white on black, black on white or otherwise colored, many workers have suggested that the visual system represents or encodes objects primarily in terms of their contours. As we have seen, however, a contour can be part of two shapes. The perceptual representation of a contour is specific to which side is regarded as the figure and which as the ground. Shape may be invariant over a black-white reversal, but it is not invariant over an inside-outside reversal.

Under natural conditions many factors cooperate to determine the figure-ground relationship, and ambiguity is rare. For example, if one area encloses another, the enclosed area is likely to be seen as the figure. If a figure is divided into two areas, the smaller of the areas is favored as the figure [*see middle illustration on opposite page*].

The visual field usually consists of many objects that overlap and occlude one another. The perceptual system has an impressive ability to segregate and sort such objects from one another. Along with distinguishing figure from ground, the system must group the fragments of visual information it receives into separate sets that correspond to real objects. Elements that are close to one another or alike or homogeneous in certain respects tend to be grouped together. When alternative groupings are about equally good, ambiguity results.

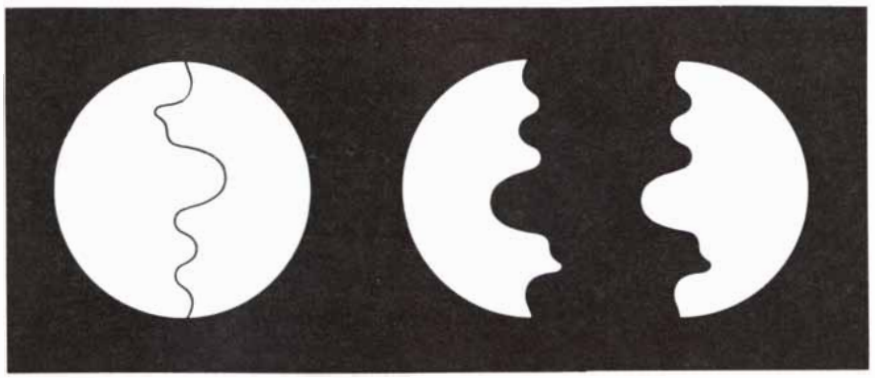
For example, if a set of dots are aligned, the perceptual system tends to group them on the basis of this regularity. When the dots are in regular rows and columns, they will be seen as rows if the vertical distance between the dots is greater than the horizontal distance, and they will seem to be in columns if the horizontal distance is greater than the vertical distance. When the spacing both ways is the same, the two groupings—rows and columns—tend to alternate. What is interesting and rather puzzling about the situation is that vertical and horizontal groupings are competitive at all. Geometrically the dots form both rows and columns; why, then, does seeing them in rows preclude seeing them in columns at the same moment? Whatever the reason is in terms of perceptual mechanisms, the principle involved appears to be a general one: When elements are grouped percep-

tually, they are partitioned; they are not simultaneously cross-classified.

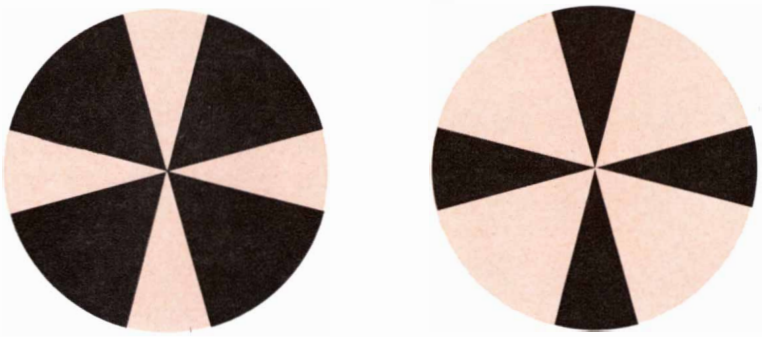
A related case of multistability involves apparent movement. Four lights are arranged in a square so that the diagonally opposite pairs of lights flash simultaneously. If the two diagonal pairs of lights are flashed alternately, it will appear to an observer as if the lights are moving. The apparent motion can take either of two forms: the observer will see motion along the vertical sides of the square, with two pairs of lights, one on the left and the other on the right, moving in opposite directions up and down, or he will see two sets of lights moving back and forth horizontally in opposite directions. If he continues to watch for a while, the motion will switch from vertical to horizontal and vice versa. When one apparent motion gives way to the other, the two perceptions are subjectively so different that the unsuspecting observer is likely to believe there has been some physical change. Apparent movement involves the grouping of events that are separated in both space and time, but the events so grouped are represented as having a common identity; specifically it appears that the same light has moved to a new place. The rivalry between the horizontal and the vertical movement is thus easier to comprehend than the rivalry between rows and columns of dots: if the representational system reflects the laws of the world it represents, the same object cannot traverse two different paths simultaneously or occupy two different places at once.

Ambiguities of grouping are also evident in fields of repetitive elements such as a floor with hexagonal tiles or even a matrix of squares drawn on paper [*see top illustration on page 69*]. If one stares at the matrix for a while, certain subsets of the squares will spontaneously organize themselves into simple figures. With voluntary effort one can attain fairly stable perceptions of rather complex figures. The most readily seen figures, however, tend to be simple, compact and symmetrical.

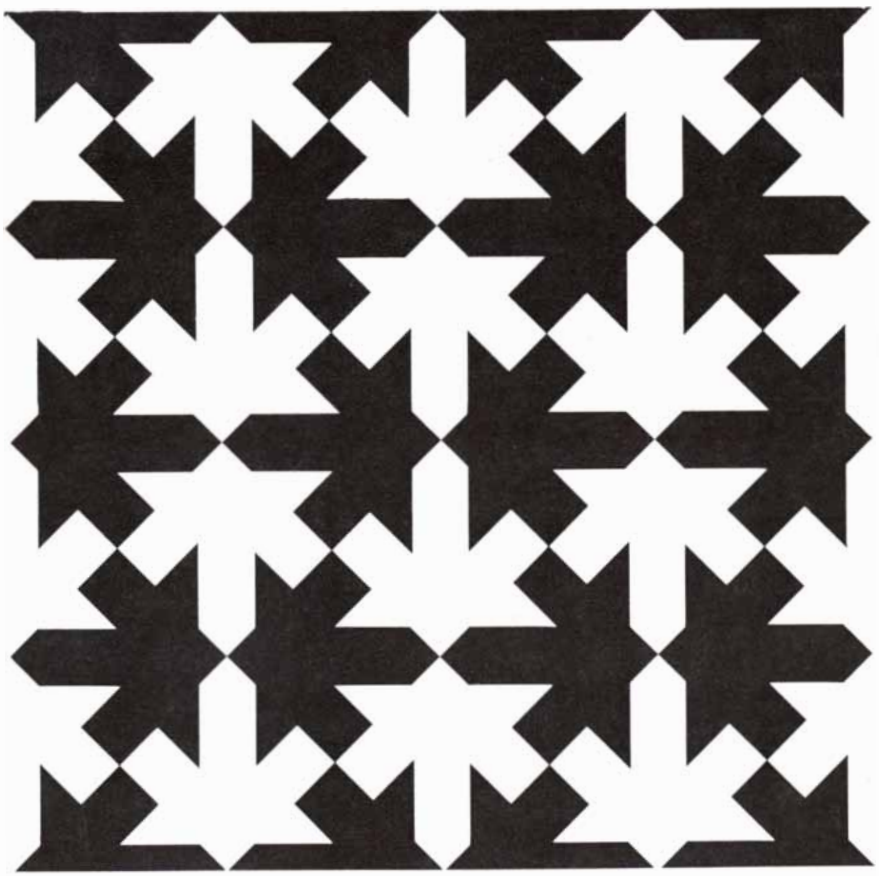
Some of the most striking and amusing ambiguous figures are pictures (which may or may not involve figure-ground reversal) that can be seen as either of two familiar objects, for example a duck or a rabbit, a young girl or an old woman, and a man or a girl [*see illustrations on next two pages*]. What is meant by "familiar" in this context is that the visual inputs can be matched to some acquired or learned schemata of classes of objects. Just what such class



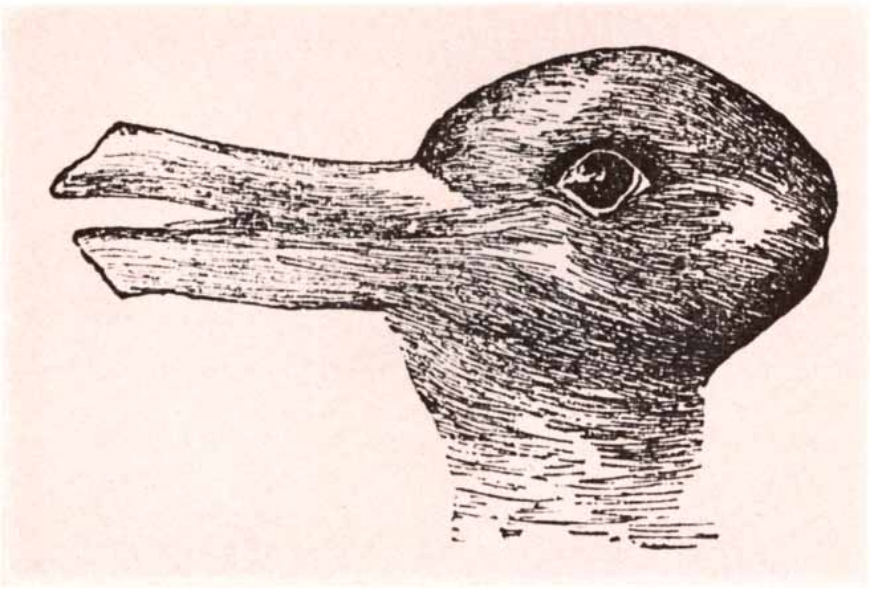
REVERSING FIGURE can be made by scribbling a line through a circle. The shape of the contour formed depends on which side of the line is regarded as part of the figure.



LARGER AREA of a figure is more likely to be seen as the background. Either the large crosses or the small ones may be seen as the figure, but the small crosses have the advantage.



REVERSAL AND ROTATION occur simultaneously in this ingenious design. When the stylized maple-leaf pattern alternates between black and white, it also rotates 90 degrees.



RABBIT-DUCK FIGURE was used in 1900 by psychologist Joseph Jastrow as an example of rival-schemata ambiguity. When it is a rabbit, the face looks to the right; when it is a duck, the face looks to the left. It is difficult to see both duck and rabbit at the same time.

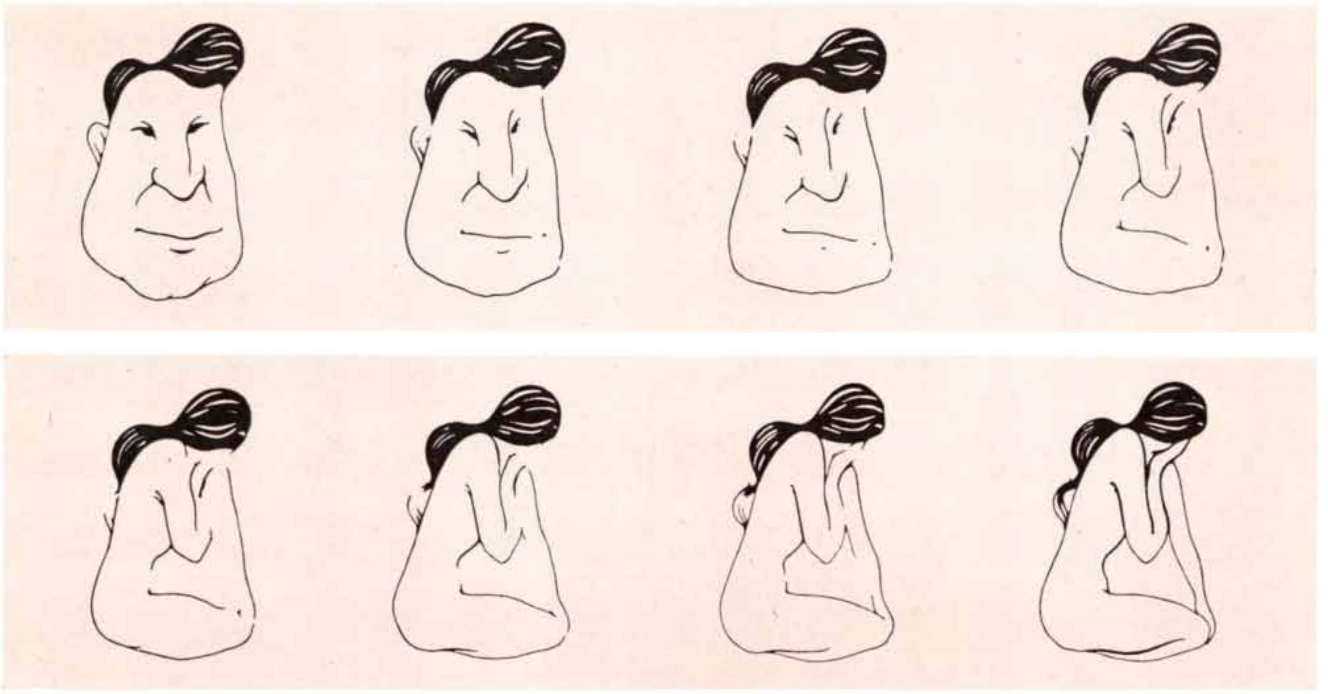
YOUNG GIRL–OLD WOMAN was brought to the attention of psychologists by Edwin G. Boring in 1930. Created by cartoonist W. E. Hill, it was originally published in *Puck* in 1915 as "My Wife and My Mother-in-law." The young woman's chin is the old woman's nose.

schemata consist of—whether they are like composite photographs or like lists of properties—remains a matter of controversy. In any case the process of identification must involve some kind of matching between the visual input and a stored schema. If two schemata match the visual input about equally well, they compete for its perceptual interpretation; sometimes one of the objects is seen and sometimes the other. Therefore one reason ambiguity exists is that a single input can be matched to different schemata.

In certain ambiguous figures we can clearly see the nature of the positive feedback loop that accounts for the "locking in," or stabilization, of one or another aspect of the figure at any given time. For example, if in the young girl–old woman figure a certain line is tentatively identified as a nose, then a line below it must be the mouth and the shapes above must be the eyes. These partial identifications mutually support one another to form a stable perception of an old woman. If, however, the line we started with is seen as a chin instead of as a nose, then the perception formed is that of a young woman. The identification of wholes and of parts will likewise be reciprocally supportive, contributing further to the locking-in process.

Why one aspect of an ambiguous figure, once it is locked in, should ever give way to the other is a fundamental question. Indeed, a person can look for quite a long time at an ambiguous figure and see only one aspect of it. Robert Leeper of the University of Oregon showed that if a subject was first exposed to a version of the figure that was biased in favor of one of the interpretations, he would almost always see only that aspect in the ambiguous version. Not until the other aspect was pointed out would the figure spontaneously alternate. It is only after the input has made contact with both schemata that they become competitive. Making the initial contact and the associated organization must entail a type of learning.

Ambiguities of depth characterize a large class of multistable figures, of which the cube on page 63 is the most familiar. In 1832 a Swiss geologist, Louis Albert Necker, pointed out that a drawing of a transparent rhomboid crystal could be seen in either of two different ways, that the viewer often experiences "a sudden and involuntary change in the apparent position of a crystal or solid represented by an engraved figure." Necker concluded that the aspect seen depends entirely on the point of

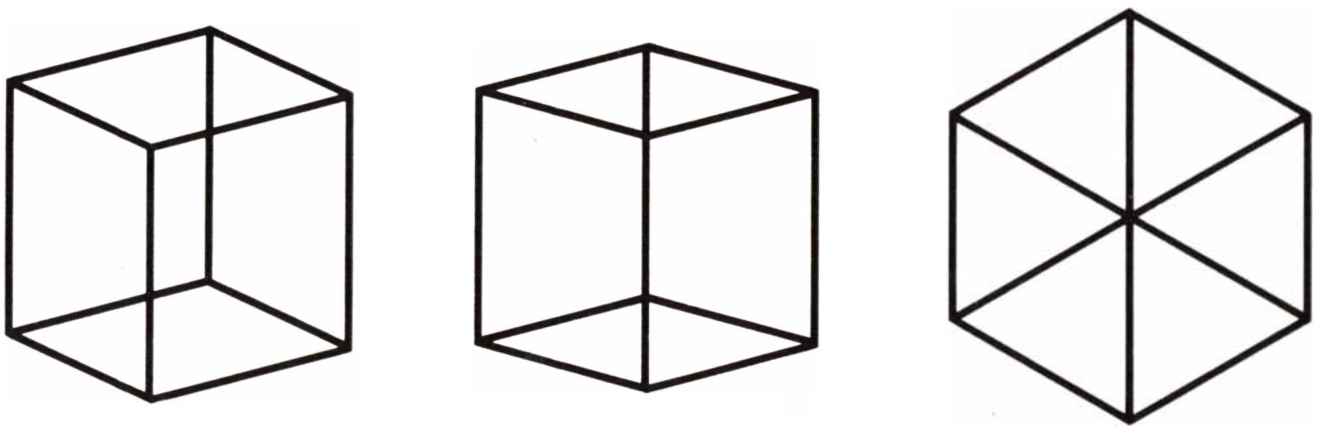


MAN-GIRL FIGURES are part of a series of progressively modified drawings devised by Gerald Fisher in 1967. He found that the last drawing in the top row has equal probability of being seen as a man or as a girl. Perception of middle pictures can be biased toward the man by viewing series in sequence beginning from top left and can be biased toward the girl by starting from bottom right.

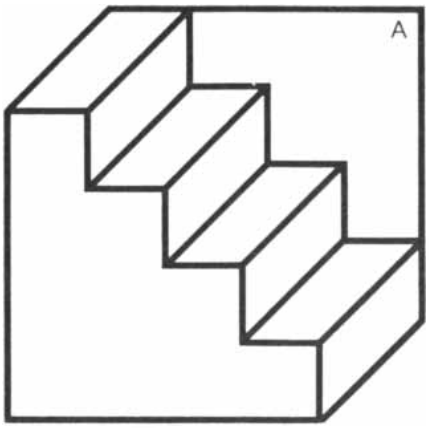
fixation, "the point of distinct vision" being perceived as the closer. Although the fixation point is indeed important, it has been shown that depth reversal will readily occur without eye movement.

If we want to understand how depth relationships can be multistable, we must first consider the more general question of how the perceptual system can derive a three-dimensional representation from a two-dimensional drawing. A straight line in the outside world casts a straight line on the retina. A given straight line on the retina, however, could be the image of any one of an infinite number of external lines, and not necessarily straight lines, that lie in a common plane with one another and the eye. The image on a single retina is always two-dimensional, exactly as a photograph is. We should not be surprised, therefore, that depth is sometimes ambiguous; it is far more remarkable that the perceptual system is able to select a particular orientation for a line segment (or at worst to vacillate between two or three orientations) out of the infinite number of legitimate possibilities that exist.

On what basis does the system perform this feat? According to the Gestalt psychologists the answer is to be found in a principle of *Prägnanz:* one perceives the "best" figure that is consistent with a given image. For most practical purposes "best" may be taken to mean "simplest." The advantage of this interpretation is that it is easier to find objective standards for complexity than for such qualities as being "best." One observes a particular configuration of lines on paper, such as the Necker cube, and assigns a three-dimensional orientation to the lines such that the whole becomes a cube (although an infinite number of noncubical forms could project the same form) because a cube is the simplest of the possibilities. In a cube the lines (edges) are all the same length; they take only three directions, and the angles they form are all equal and right



PROJECTIONS OF A CUBE onto a two-dimensional surface are nearly always seen in depth when they resemble the Necker cube (*left*). As the projection becomes simpler and more regular it is more likely to be seen as a flat figure, such as a hexagon (*right*).



SCHRÖDER STAIRS line drawing is another classic example of perspective reversal. Corner *A* is part of the rear wall when the staircase goes up to the left; when reversal occurs, corner *A* becomes part of the front wall and the bottom of the stairway is seen.

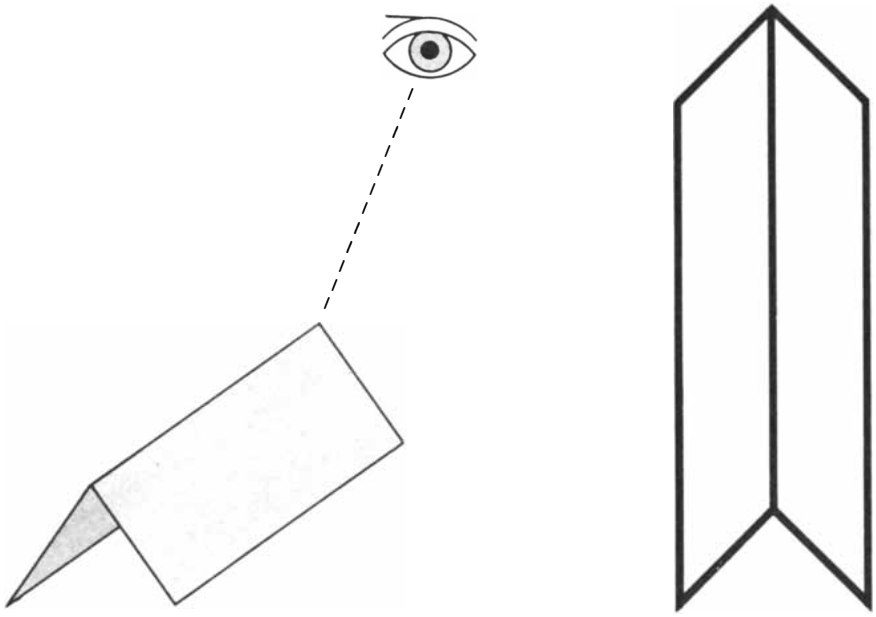
angles. No other interpretation of the figure, including the two-dimensional aspect itself, is as simple and regular. In cases of reversible perspective two maximally simple tridimensional constructions are permissible, each being symmetrical with the other in depth.

If this reasoning is correct, simple projections of a given solid should be perceived as being flat more often than complex projections of the same solid. Julian Hochberg and his colleagues at Cornell University studied various two-dimensional projections of a cube and other regular solids [*see bottom illustration on preceding page*]. Relatively complex projections are nearly always perceived in depth. A figure such as a regular hexagon divided into equilateral triangles, which is simple and regular in two dimensions, stays two-dimensional because seeing it as a cube does not make it any simpler. Intermediate figures become tristable; they are sometimes seen as being flat and sometimes as being one or another aspect of a cube. The measure of complexity devised by Hochberg and Virginia Brooks involved the number of continuous lines in the figure, the number of interior angles and the number of different angles. This measure predicted with considerable accuracy the proportion of the time that a figure was seen in depth rather than as being flat.

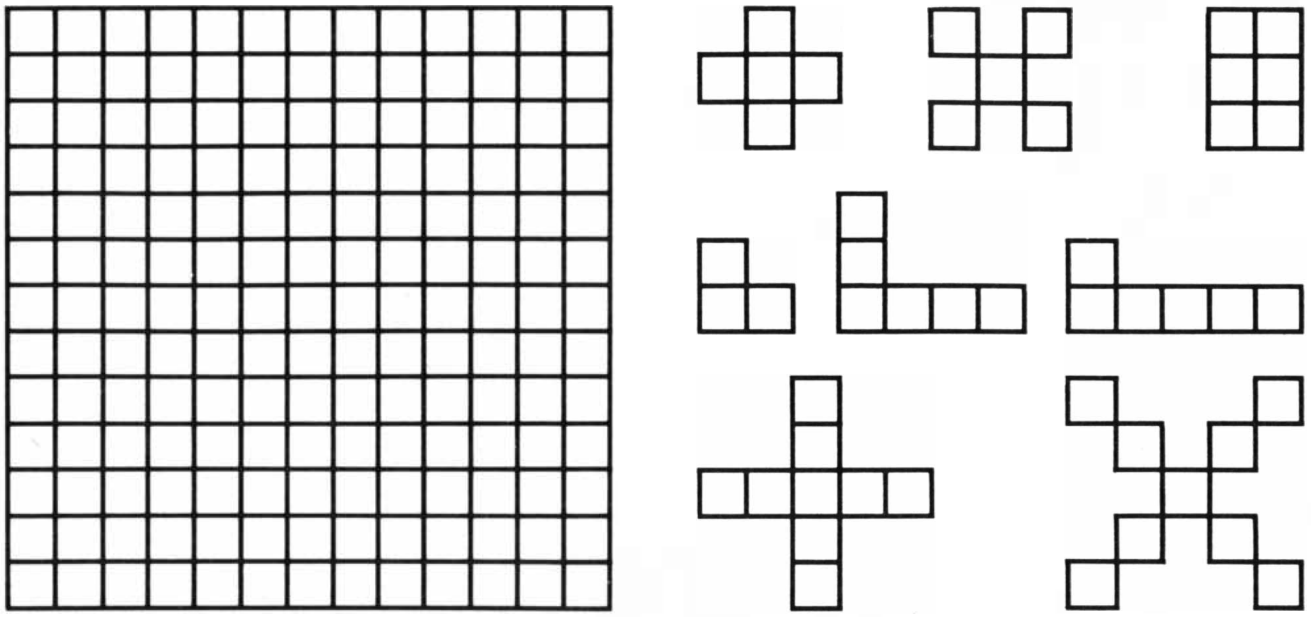
I have been emphasizing the importance of simplicity, but it is obvious that familiarity also plays an important role in instances of ambiguous depth. The two factors are hard to disentangle. Simple structures are experienced with great frequency, particularly in man-made environments. As Alvin G. Goldstein of the University of Missouri has shown by experiment, within limits a nonsense shape is judged to be simpler the more often it is experienced. In my view familiarity and simplicity become functionally equivalent in the perceptual system when a given input corresponds closely to a schema that is already well established by experience and can therefore be encoded or described (in the language of the nervous system) most simply in terms of that schema.

Depth reversal does not occur only with two-dimensional pictures. As the Austrian physicist and philosopher Ernst Mach pointed out, the perspective of many real objects will reverse when the object is viewed steadily with one eye. A transparent glass half-filled with water is a particularly dramatic example, but it requires considerable effort to achieve the reversal and the stability of the reversal is precarious. Mach discovered an easier reversal that is actually more instructive. Take a white card or a small piece of stiff paper and fold it once along its longitudinal axis [*see bottom illustration on this page*]. Place the folded card or paper in front of you on a table so that it makes a rooflike structure. Close one eye and view the card steadily for a while from directly above. It will reverse (or you can make it reverse) so that it appears as if the fold is at the bottom instead of the top. Now view the card with one eye from above at about a 45-degree angle so that the front of the folded card can be seen. After a few seconds the card will reverse and stand up on end like an open book with the inside toward you. If the card is asymmetrically illuminated and is seen in correct perspective, it will appear to be more or less white all over, as it is in reality, in spite of the fact that the illuminated plane reflects more light than the shadowed one. When the reversal occurs, the shadowed plane looks gray instead of white and the illuminated plane may appear luminous. In the perspective reversal the perceptual mechanism that preserves the constancy of reflectance is fooled; in order to maintain the relation between light source and the surfaces the perceptual system makes corrections that are erroneous because they are based on incorrect information.

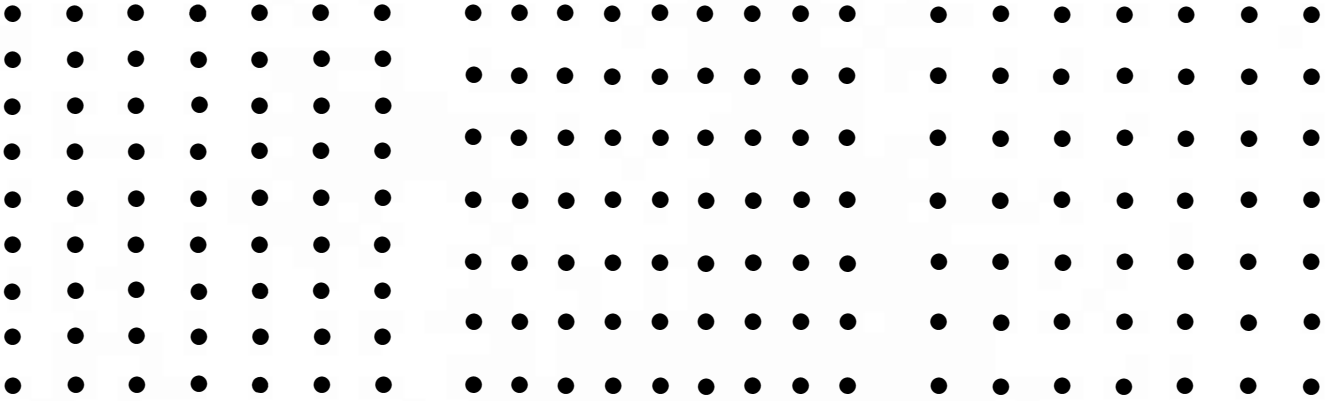
Another remarkable phenomenon involving the folded card seems to have escaped Mach's notice. Recently Murray Eden of the Massachusetts Institute of Technology found that if after you make the folded card reverse you move your head slowly from side to side, the card will appear to rock back and forth quite as convincingly as if it were physically in motion. The explanation, very roughly, is that the mechanism that makes allowance for head movements, so that still objects appear still even though the head moves, is operating properly but on erroneous premises when the perspective is reversed. The perceived rocking of the card is exactly what would



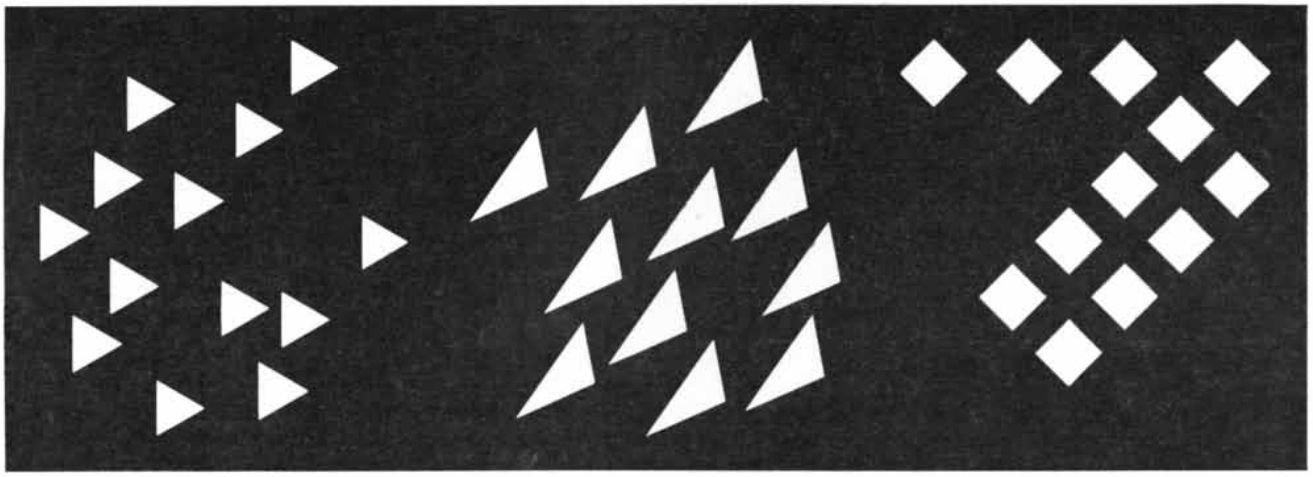
DEPTH REVERSAL OF A REAL OBJECT can occur when it is viewed from above with one eye, an effect discovered by Ernst Mach. When a folded card is viewed from above and the front, it will appear to stand on end like an open book when it reverses. The same kind of depth reversal occurs with a simple line drawing of a folded card (*above right*).



FIGURAL GROUPINGS occur when one stares at a matrix of squares. The simple figures organize themselves spontaneously and with effort more complex figures can be perceived. Some figures, however, are so complex that they are difficult to maintain.



ALIGNED DOTS fall into a regular pattern when viewed. Depending on the spacing, dots can be seen as columns (*left*) or as rows (*middle*). When vertical and horizontal spacing are equal, dots can be seen as rows or columns but not as both at the same time.



EQUILATERAL TRIANGLES appear in one of three orientations depending on the dominant axis of symmetry (*left*). Usually all point in the same direction at one time, although the direction can change spontaneously. The scalene triangles (*middle*) fluctuate in orientation even though they are asymmetrical because they can also appear as isosceles or right triangles that point down or up. The same shape can be seen as either diamonds or tilted squares (*right*) depending on the orientation of the local reference system.

have to happen objectively if the card were really reversed to account for the sequence of retinal images accompanying head movement. What is remarkable about this is not that the mechanism can be wrong but rather that it can function so efficiently as a "lightning calculator" of complex problems in projective geometry and compensate so completely to maintain the perceived orientation. It seems to me that this capacity is a good argument for the existence of some kind of working model of three-dimensional space within the nervous system that solves problems of this type by analogue operations. Indeed, the basic concept of *Prägnanz,* of a system that finds its way to stable states that are simple by tridimensional criteria, is difficult to explain without also postulating a neural analogue model of three-dimensional space. We have no good theory at present of the nature of the neural organization that might subserve such a model.

A few years ago I stumbled on a principle of ambiguity that is different from any we have been considering. While planning an experiment on perceptual grouping I drew a number of equilateral triangles. After looking at them for a time I noticed that they kept changing in their orientation, sometimes pointing one way, sometimes another and sometimes a third way [*see bottom illustration on preceding page*]. The basis for this tristable ambiguity seems to be that the perceptual system can represent symmetry about only one axis at a time, even though an equilateral triangle is objectively symmetrical about three axes. In other words, an equilateral triangle is always perceived as being merely an isosceles triangle in some particular orientation. Compare any two sides or any two angles of an equilateral triangle and you will find that the triangle immediately points in the direction around which the sides and angles are symmetrical. When a group of equilateral triangles points upward, the triangles cease to fluctuate; the perceptual system strongly prefers the vertical axis of symmetry. Indeed, any perceived axis of symmetry seems to have the character of a locally rotated vertical.

When scalene triangles (triangles with three unequal sides) are grouped together with their corresponding sides parallel, they also appear to fluctuate in orientation after a brief inspection [*see bottom illustration on preceding page*]. This is at first puzzling since they have no axes of symmetry at all. The answer to the puzzle involves the third dimension: When the triangles are seen to point in a given direction, they simultaneously go into depth in such a way that they look like isosceles triangles seen at an angle. Perspective reversal doubles the possibilities, so that there are six ways the scalene triangles can be seen as isosceles. The same triangles may also be seen as right triangles in depth, with the obtuse angles most easily becoming the right angles.

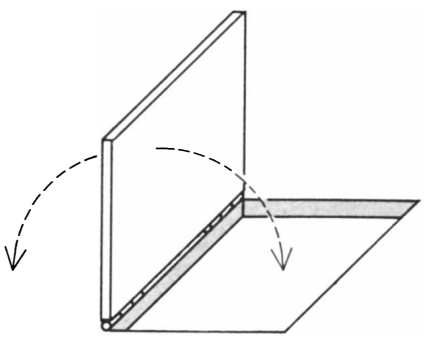
These observations begin to make sense if we suppose the perceptual system employs something quite like a Cartesian coordinate system to locate and describe things in space. (To call the system Cartesian is really putting the issue backward, since Descartes clearly took the primary perceptual directions of up-down, left-right and front-back as his reference axes.) The multistable states of triangles thus appear to involve simple relations between the figure and the reference system. The reference system may be tilted or rotated locally by the perceptual system and produce the apparent depth or orientation of the triangles.

In the same way we can explain how the same shape can appear to be so different when it is seen as a square or as a diamond. The square is perceived as having horizontal and vertical axes along its sides; the diamond is perceived as being symmetrical about a vertical axis running through opposite corners. Yet in certain kinds of grouping the perceptual axes can be locally rotated and the diamond can look like a tilted square [*see bottom illustration on preceding page*].

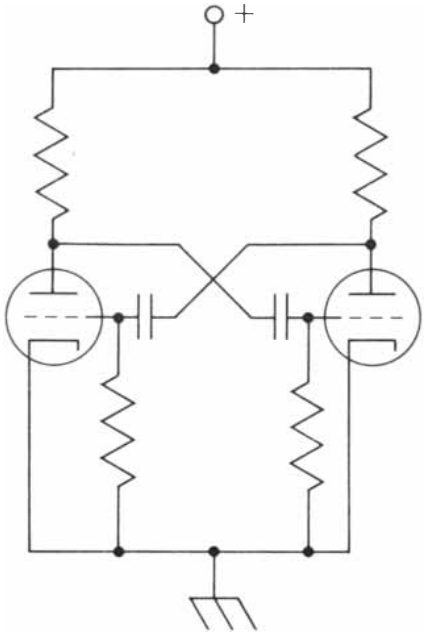
It should be evident by now that some principle of *Prägnanz,* or minimum complexity, runs as a common thread through most of the cases. It seems likely that the perceptual machinery is a teleological system that is "motivated" to represent the outside world as economically as possible, within the constraints of the input received and the limitations of its encoding capabilities.

A good reason for invoking the concept of multistability to characterize figural ambiguity is that we know a great deal about multistable physical and electronic systems and may hope to apply some of this knowledge to the perceptual processes. The multistable behavior of the perceptual system displays two notable characteristics. The first is that at any one moment only one aspect of the ambiguous figure can be seen; mixtures or intermediate states occur fleetingly if at all. The second is that the different percepts alternate periodically. What accounts for this spontaneous alternation? Once the perceptual system locks into one aspect of the figure, why does it not remain in that state? An analogous physical system is a trapdoor that is stable only when it is either open or closed.

As Necker pointed out, changing the point of visual fixation may cause perspective to reverse. In the instances where the input is being matched against more than one schema visual fixation on a feature that is more critical to one representation than the other may lock perception into only one aspect of the ambiguous figure. Since the percepts can alternate without a change in the point of fixation, however, some additional explanation is needed. The most likely is that the alternative aspects of the figure are represented by activity in different neural structures, and that when one such structure becomes "fatigued," or satiated or adapted, it gives way to another that is fresher and more excitable. Several investigators have noted that a reversing figure alternates more rapidly the longer it is looked at, presumably because both alternative neural structures build up some kind of fatigue. In some respects the neural structures behave like a multistable electronic circuit. A common example of multistability in electronic circuitry is the multivibrator flip-flop circuit, which can incorporate either vacuum tubes or transistors. In the vacuum tube version [*see illustration on opposite page*] when one tube is conducting a current, the other tube is prevented from conducting by the low voltage on its grid. The plates and the grids of the two tubes are cross-coupled through capacitors, and one tube continues to conduct until the charge leaks from the coupling capacitor sufficiently for the other tube to start conducting. Once this tube begins to conduct, the positive feedback loop quickly makes it fully conducting and the other tube is cut off and becomes



PHYSICAL SYSTEM that exhibits a simple form of multistability is a trapdoor that is stable only when it is either open or shut.

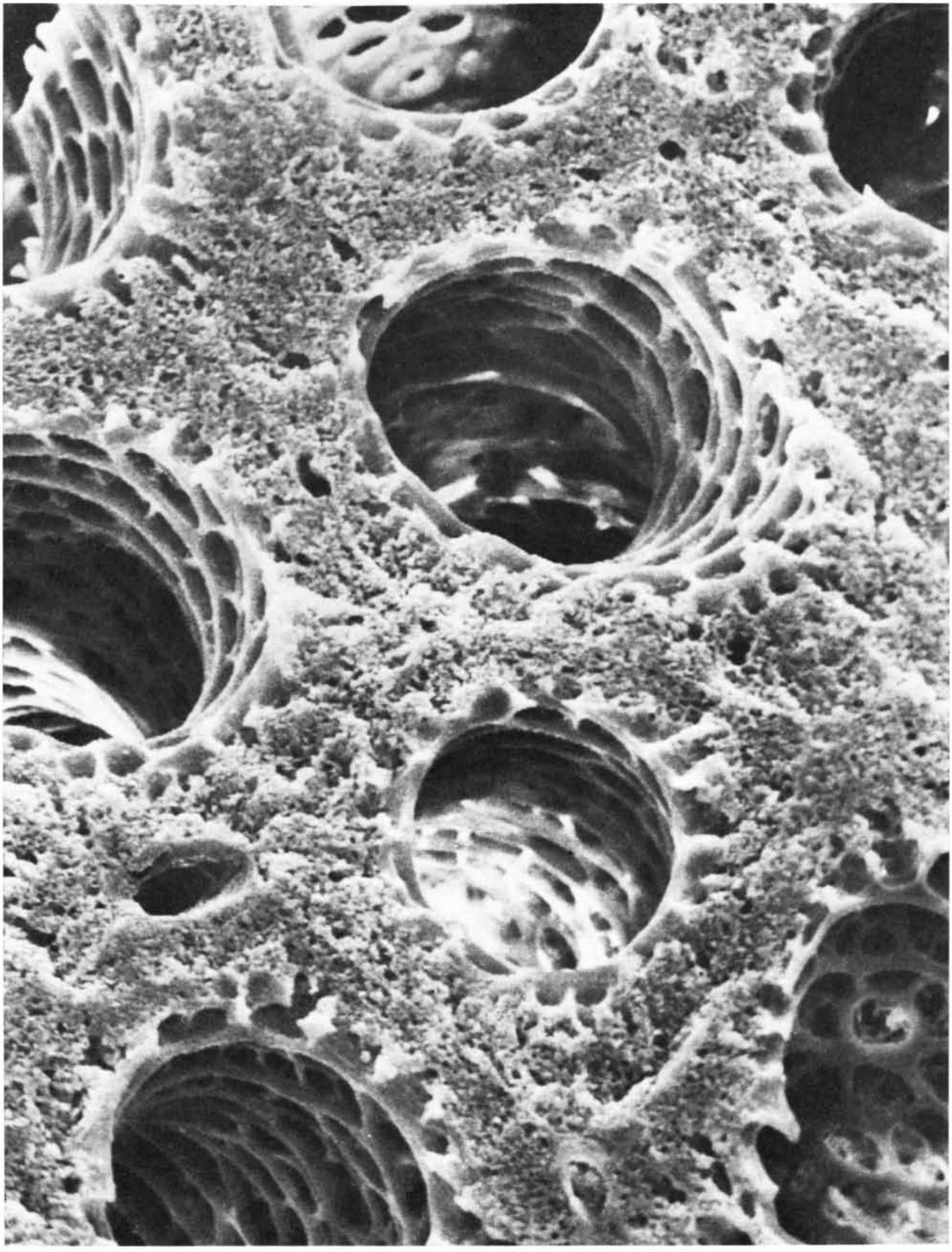


MULTIVIBRATOR CIRCUIT spontaneously alternates between two states. When one vacuum tube is conducting, the other is inhibited. A charge leaking from the coupling capacitor eventually starts the inhibited tube conducting. The positive feedback loop quickly makes it fully conducting and cuts off conduction in the first tube. The entire process is repeated in reverse, and the circuit flops from one state to the other.

nonconducting. The process reverses and the system flip-flops between one state and the other.

What is "fatigued" in the multivibrator is the suppressive linkage. In other words, the inhibition of the nonconducting tube slowly weakens until it is no longer strong enough to prevent conduction. The possibility of an analogous neural process, in which the inhibition of the alternative neural structure progressively weakens, is worth considering.

Brain lesions may affect the perception of ambiguous figures. The finding most generally reported is that in people who have suffered brain damage the rate of alternation is lower, more or less independently of the locus of the lesion. On the other hand, a study of a group of brain-damaged war veterans conducted by Leonard Cohen at New York University indicated that damage to both frontal lobes increases the rate of alternation of a reversible figure, whereas damage to only one frontal lobe decreases the rate. The theoretical implications of these neurological findings are quite obscure and will doubtless remain so until we have some fundamental picture of the way the nervous system represents form and space.



INTERIOR OF BIRD'S LUNG shows the structure that enables air to flow through the lung instead of in and out of it, as in the mammalian lung. This scanning electron micrograph was made by H. R. Duncker of Justus Liebig University at Giessen in West Germany. The circular structures are parabronchi, which are fine branches of the bronchial system, and the surrounding material is lung tissue. Equivalent structures in the mammalian lung are the saclike alveoli. The parabronchi in this micrograph, which are enlarged 180 diameters, are in the lung of a domestic fowl that was 14 days old. The micrograph shows the parabronchi in transverse section.

How Birds Breathe

The avian respiratory system is different from the mammalian one. The lungs do not simply take air in and then expel it; the air also flows through a series of large sacs and even hollow bones

by Knut Schmidt-Nielsen

A bird in flight expends more energy, weight for weight, than a mammal walking or running on the ground. Moreover, the bird's respiratory system can deliver enough oxygen for the animal to fly at altitudes where a mammal can barely function. How do the birds do it? It turns out that the avian respiratory system is quite different from the mammalian one. The remarkable anatomical details of the avian system have been elucidated over a period of three centuries, but precisely how the system operates has been worked out only recently.

One of the first clues to the distinctive nature of the avian respiratory system was the discovery that a bird with a blocked windpipe can still breathe, provided that a connection has been made between one of its bones and the outside air. This phenomenon was demonstrated in 1758 by John Hunter, a fellow of the Royal Society, who wrote: "I next cut the wing through the *os humeri* [the wing bone] in another fowl, and tying up the trachea, as in the cock, found that the air passed to and from the lungs by the canal in this bone. The same experiment was made with the *os femoris* [the leg bone] of a young hawk, and was attended with a similar result."

The bones of birds contain air, not marrow. This is true not only of the larger bones but also often of the smaller ones and of the skull bones, particularly in birds that are good fliers. As Hunter's experiments showed, the air spaces are connected to the respiratory system.

Like mammals, birds have two lungs. They are connected to the outside by the trachea, much as in mammals, but in addition they are connected to several large, thin-walled air sacs that fill much of the chest and the abdominal cavity [*see top illustration on next page*]. The sacs are connected to the air spaces in the bones. The continuation of the air passages into large, membranous air sacs was discovered in 1653 by William Harvey, the British anatomist who became famous for discovering the circulation of blood in mammals.

The presence in birds of these large air spaces, much larger in volume than the lungs, has given rise to considerable speculation. It has often been said that the air sacs make a bird lighter and are therefore an adaptation to flight. Certainly a bone filled with air weighs less than a bone filled with marrow. The large air sacs, however, do not in themselves make a bird any lighter. As a student I heard a professor of zoology assert that the sacs did make a bird lighter and therefore better suited to flight. Somewhat undiplomatically I suggested that if I were to take a poor flier such as a chicken and pump it up with a bicycle pump, the chicken would be neither any lighter nor better able to fly. The simple logic of the argument must have convinced the professor, because we did not hear any more about the function of the air sacs.

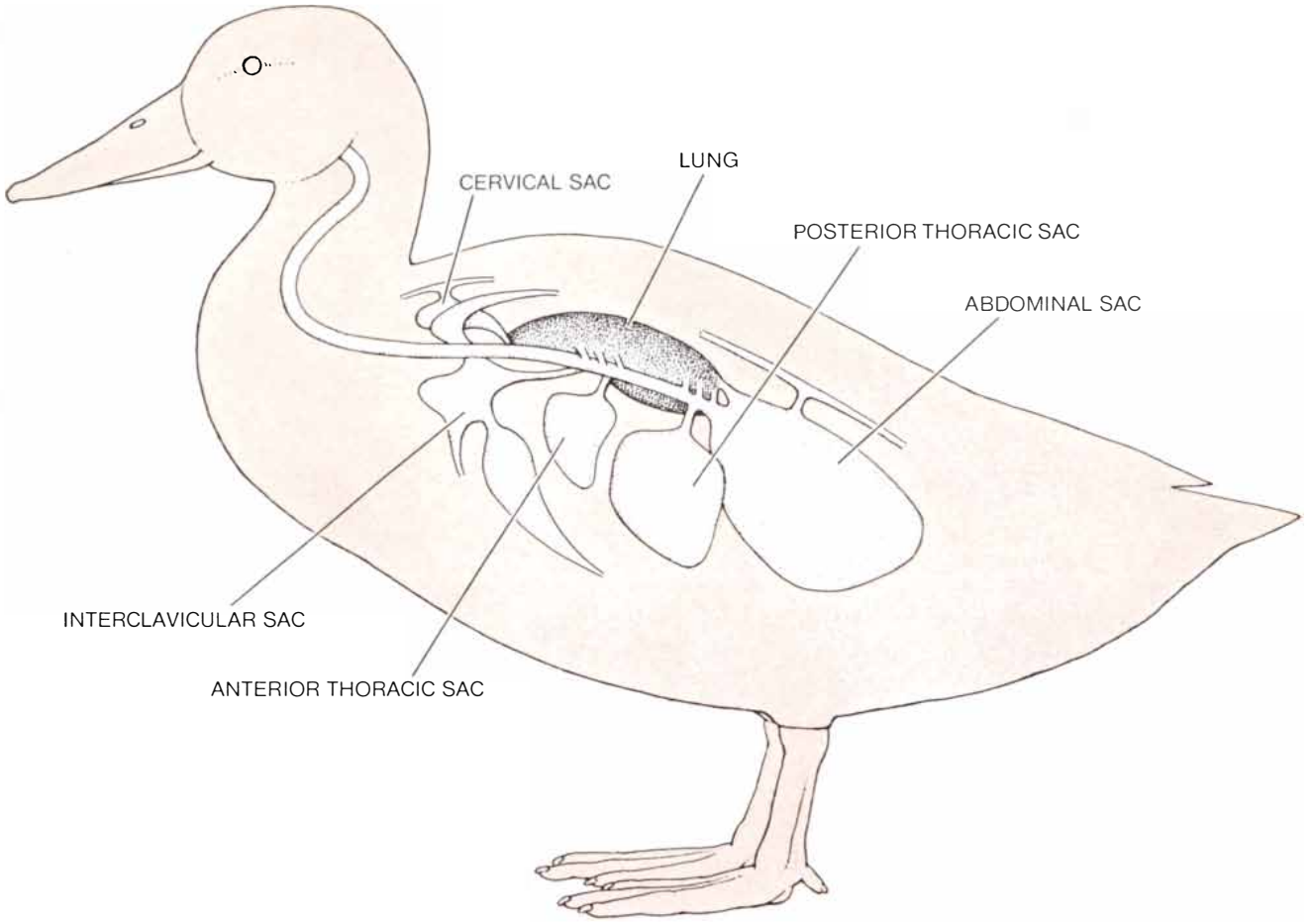
In order to understand the function of the sacs, how air flows in them, how oxygen is taken up by the blood and carbon dioxide is given off and so on it is necessary to consider the main structural features of the system. In this context it is helpful to compare birds with mammals. Birds as a group are much more alike than mammals. In size they range from the hummingbird weighing some three grams to the ostrich weighing about 100 kilograms. In terms of weight the largest bird is roughly 30,000 times bigger than the smallest one.

All birds have two legs and two wings, although the ostrich cannot use its wings for flying and penguins have flipper-like wings modified for swimming. All birds have feathers, and all birds have a similar respiratory system, with lungs, air sacs and pneumatized bones. (Even the ostrich has the larger leg bones filled with air. Air sacs and pneumatized bones are therefore not restricted to birds that can fly.)

Mammals, on the other hand, range in size from the shrew, which weighs about as much as a hummingbird, to the 100-ton blue whale. The largest mammal is therefore 30 million times bigger than the smallest one. Mammals can be four-legged, two-legged or no-legged (whales). They can even have wings, as bats do. Most mammals have fur, but many do not.

It was once argued that birds needed a respiratory system particularly adapted for flight because of the high requirement for energy and oxygen during flight. At rest birds and mammals of similar size have similar rates of oxygen consumption, although in both birds and mammals the oxygen consumption per unit of body weight increases with decreasing size. In recent years the oxygen consumption of birds in flight has been determined in wind-tunnel experiments [see "The Energetics of Bird Flight," by Vance A. Tucker; SCIENTIFIC AMERICAN, May, 1969]. The results show that the oxygen consumption in flight is some 10 to 15 times higher than it is in the bird at rest. This performance is not much different from that of a well-trained human athlete, who can sustain a similar increase in oxygen consumption.

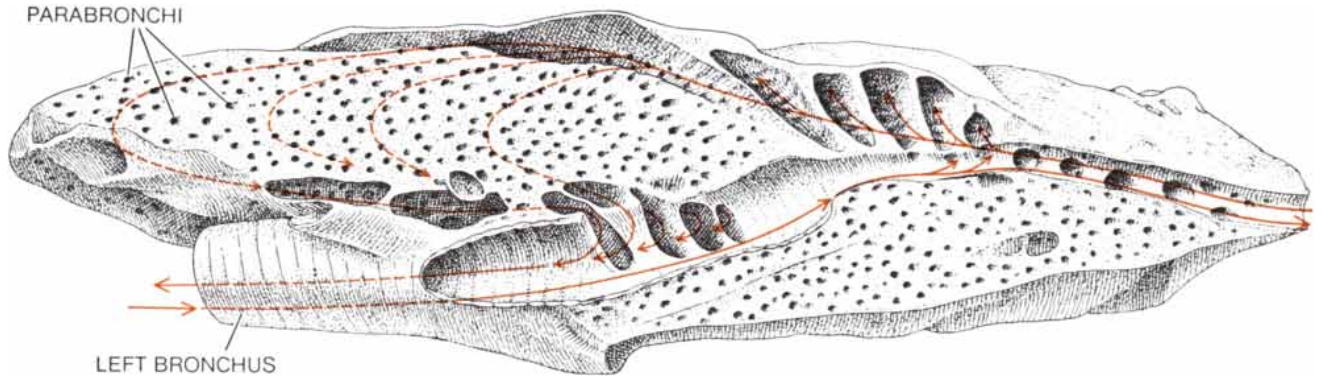
Small mammals such as rats or mice, however, seem unable to increase their oxygen consumption as much as tenfold. Since birds and mammals of the same body size show similar oxygen consumption when they are at rest, is it the special design of the bird's respiratory system that allows the high rates of oxygen consumption during flight?



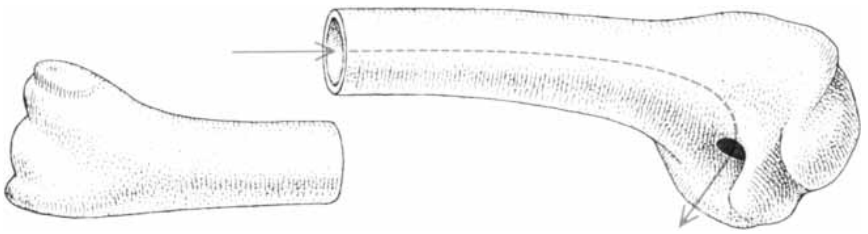
AVIAN RESPIRATORY SYSTEM, here represented by the system of a mallard duck, has as a distinctive feature a number of air sacs that are connected to the bronchial passages and the lungs. Most of the air inhaled on a given breath goes directly into the posterior sacs. As the respiratory cycle continues the air passes through the lungs and into the anterior sacs, from which it is exhaled to the outside in the next cycle. The mechanism provides a continuous flow of air through the lung and also, by means of the holding-chamber function of the anterior sacs, keeps the carbon dioxide content of the air at an appropriate physiological level.

The best argument against considering the unusual features of the avian respiratory system as being necessary for flight is provided by bats. They have typical mammalian lungs and do not have air sacs or pneumatized bones, and yet they are excellent fliers. Moreover, it has recently been shown by Steven Thomas and Roderick A. Suthers at Indiana University that bats in flight consume oxygen at a rate comparable to the rate in flying birds. Clearly an avian respiratory system is not necessary for a high rate of oxygen uptake or for flight.

One highly significant phenomenon is that many birds can fly at high altitudes where mammals suffer seriously from lack of oxygen. This fact points to what is perhaps the most important difference between the avian system and the mammalian one.



AVIAN LUNG is shown in longitudinal section from the left side of the bird. Since the bird has two lungs, one sees here half of the lung system. The orientation is as it would be with the bird's head at left. Air enters the bronchus and for the most part passes through to the posterior sacs. On its return through the lungs, assisted by a bellows-like action of the posterior sacs, it flows into the many parabronchi, where gases are exchanged with the blood. The flow has some similarity to the flow of water through a sponge.



HOLLOW BONE filled with air is characteristic of bird skeleton. Such a structure makes the bird lighter than a bird would be with mammalian bones and so is an aid to flying. The bird's bones are connected to the respiratory system. A bird with a blocked trachea can still breathe if a connection has been made between the wing bone and the outside air.

Let us look more closely at the main features of the avian respiratory system. The trachea of a bird branches into two main bronchi, each leading to one of the lungs. So far the system is similar to the mammalian system. In birds, however, each main bronchus continues through the lung and connects with the most posterior (and usually the largest) air sacs: the abdominal air sacs. On its way through the lung the main bronchus connects to the anterior air sacs and also to the lung [*see bottom illustration on opposite page*]. In the posterior part the main bronchus has another set of openings that connect to the posterior air sacs as well as to the lung. The air sacs also have direct connections to the lung in addition to the connection through the bronchus.

The lung itself has a most peculiar characteristic: it allows air to pass completely through it. In contrast, the mammalian lung terminates in small saclike structures, the alveoli; air can flow only in and out of it. The bird lung is perforated by the finest branches of the bronchial system, which are called parabronchi. Air flows through the lung somewhat the way water can flow through a sponge.

This feature of the bird lung has led to the suggestion that the air sacs act as bellows helping to push air through the lung, which thus could be supplied with air more effectively than the mammalian lung is. Before accepting this hypothesis one must be sure that the air sacs do not have a lunglike function, that is, that they do not serve as places where oxygen is taken up by the blood. Since the air sacs are thin-walled, they could perhaps be important in the exchange of gases between the air and the blood.

The fact is that the sacs are poorly supplied with blood. Moreover, they have smooth walls, which do not provide the immensely enlarged surface that the finely subdivided lung has. A crucial experiment was performed some 80 years ago by the French investigator J. M. Soum, who admitted carbon monoxide into the air sacs of birds in which he had blocked the connections to the rest of the respiratory system. If the air sacs had played any major role in gas exchange, the birds would of course have been rapidly poisoned by the carbon monoxide. They remained completely unaffected. We can therefore conclude that the air sacs have no direct function in gas exchange. Since the volume of the sacs changes considerably during the respiratory cycle, one can accept the hypothesis that they serve as a bellows.

A suggestion made long ago is that the large sacs could be filled with fresh air and, by alternate contraction of the anterior and posterior sets of sacs, air could be passed back and forth through the lung. The hypothesis has proved to be wrong, however, for the reason that the sacs do not contract in alternation. The pressure changes in the anterior and posterior sacs are similar: on inhalation the pressure drops in both sets of sacs, and all the sacs are filled with air; on exhalation the pressure increases simultaneously in the anterior and posterior sacs, and air passes out of both sets of sacs.

It has even been suggested that birds, by filling their air sacs, could take with them a supply of air to last them during a flight. This adventurous suggestion was supported by the speculation that the chest of a flying bird is so rigidly constrained by muscular contractions that breathing is impossible. The reasoning disregards the most elementary considerations of the amount of oxygen needed for flight.

The question of how air flows in the avian lung can be studied in a number of ways. One useful approach is to introduce a foreign gas as a marker. The flow of the gas and its time of arrival at various points in the respiratory system yield much information. Another approach is to use small probes that are sensitive to airflow and to place them in various parts of the elaborate passageways. In this way the flow directions can be determined directly during the phases of the respiratory cycle. My colleagues and I at Duke University have used both of these approaches, and we believe we now know with reasonable certainty the main features of avian respiration.

The use of a tracer gas has been quite successful in clarifying the flow of air. Our first experiments were with ostriches, which have the advantage of rather slow respiration. An ostrich breathes about six times per minute, and changes in the composition of gas in its air sacs can therefore be followed rather easily. If an ostrich is given a single breath of pure oxygen and is then returned to breathing normal air, which has an oxygen content of 21 percent, an increased concentration of oxygen in the respiratory system will indicate how the single marked inhalation is distributed.

We used an oxygen electrode to follow changes in oxygen concentration. In the posterior air sacs we picked up a rapid increase in oxygen near the conclusion of the inhalation that carried pure oxygen. In other words, the marker gas flowed directly to the posterior sacs. In contrast, in the anterior sacs the oxygen did not appear until a full cycle later; the rise was noted as the second inhalation was ending [*see illustration on page 77*]. This finding must mean that the anterior air sacs do not receive inhaled air directly from the outside and that the marker gas that arrived on the second cycle or later must meanwhile have been in some other part of the respiratory system. We concluded that the posterior sacs are filled with air coming from the outside and that air entering the anterior sacs must come from elsewhere, presumably the lungs. Outside air thus enters the anterior sacs only indirectly, through other parts of the respiratory system, and it is delayed by at least one cycle.

It would be tempting to conclude from this experiment that the posterior sacs are well ventilated and that the anterior sacs do not receive much air but contain a rather inert and stagnant mass of air. The composition of the gas in the sacs might seem to support such a conclusion. The posterior air sacs usually contain about 3 or 4 percent carbon dioxide and the anterior sacs 6 or 7 percent, which is comparable to the carbon dioxide content of an air mass that is in equilibrium with venous blood. The conclusion would be wrong.

Whether or not an air sac is well ventilated can be ascertained by introduc-

ing a marker gas directly into the sac and determining how fast the marker disappears on being washed out by other air. In the ostrich we injected 100 milliliters of pure oxygen directly into an air sac and measured the time required to reduce by half the increase in oxygen concentration thereby achieved. We found that all the air sacs in the ostrich are highly ventilated and that they wash out rapidly.

The results showed that none of the air sacs contained a stagnant or relatively inert air mass. Since the anterior sacs have about the same washout time as the posterior sacs, they must be equally well ventilated. Why, then, since the renewal rate of air is high in the anterior sacs, do they contain a high concentration of carbon dioxide? This phenomenon can best be explained by postulating that the anterior sacs receive air that has passed through the lungs, where during passage it has exchanged gases with the blood, taking up carbon dioxide and delivering oxygen.

When we had arrived at this stage, it became essential for us to obtain unequivocal information about the flow of air in the bird lung. For this purpose W. L. Bretz in our laboratory designed and built a small probe that could record the direction of airflow at strategic points in the respiratory system of ducks. The information obtained in these experiments can best be summarized by going through the events of inhalation and then through the events of exhalation.

On inhalation air flows directly to the posterior sacs, which therefore initially receive first the air that remained in the trachea from the previous exhalation and then, immediately afterward, fresh outside air. The posterior sacs thus become filled with a mixture of exhalation air and outside air. Experiments with marker gas showed just this sequence; the marker arrived in the posterior sacs as the first inhalation was ending. The flow probe did not show any flow in the connections to the anterior sacs during inhalation, which was what we had expected from the fact that marker gas never arrived directly in the anterior sacs. Since the anterior sacs do expand during inhalation, the air that fills them can come only from the lung. Another finding is that air flows in the connection from the main bronchus to the posterior part of the lung, indicating that some of the inhaled air goes directly to the lung.

During exhalation the posterior sacs decrease in volume. Since the flow probe shows little or no flow in the main bronchus, the air must flow into the lung. The anterior sacs also decrease in volume. A probe placed in their connection to the main bronchus shows a high flow, consistent with direct emptying of these sacs to the outside.

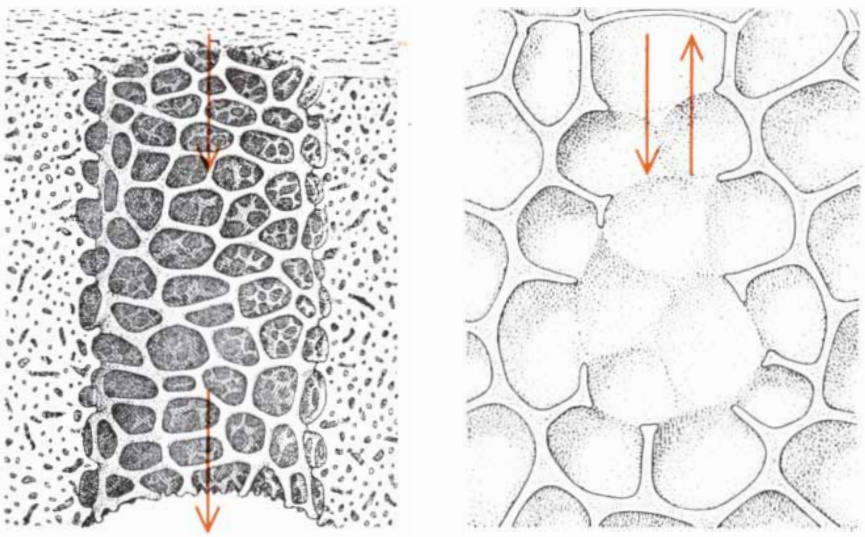
The most interesting conclusion to be drawn from these patterns of flow is that air flows continuously in the same direction through the avian lung during both inhalation and exhalation. This suggestion is not new, but once we are certain that it is correct we can better examine its consequences. The air flowing through the lungs comes mostly from the posterior sacs, where the combination of dead-space air and outside air supplies a mixture that is high in oxygen but also contains a significant amount of carbon dioxide. Here we encounter one of the most elegant features of the system. If completely fresh outside air, which contains only .03 percent carbon dioxide, were passed through the lung, the blood would lose too much carbon dioxide, with serious consequences for the acid-base regulation of the bird's body. Another consequence of excessive loss of carbon dioxide arises from the fact that breathing is regulated primarily by the concentration of carbon dioxide in the blood. An increase in carbon dioxide stimulates breathing; a decrease causes breathing to slow down or even stop for a time.

Hence we see that the avian lung is continuously supplied with a mixture of air that is high in oxygen without being too low in carbon dioxide. The anterior sacs serve as holding chambers for the air coming from the lungs. This air is later discharged to the outside on exhalation, but enough of it remains in the trachea to ensure the right concentration of carbon dioxide in the posterior sacs after the next inhalation.

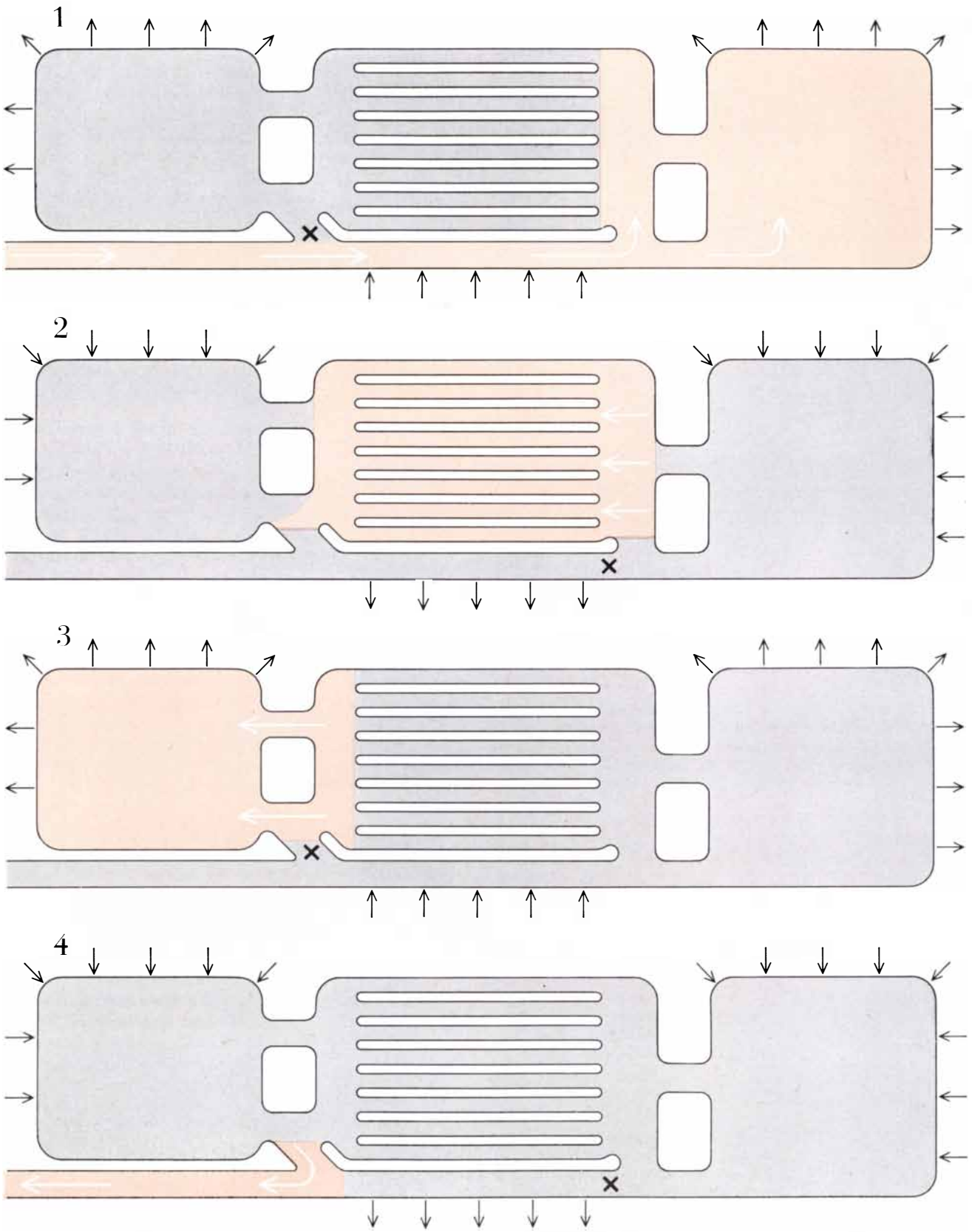
A few disturbing questions remain. One is why, since the pressure in the anterior air sacs falls during inhalation, air from the outside does not enter these sacs. The system has no valves that can open and close to help direct the flow. The answer is probably that the openings from the main bronchus have an aerodynamic shape that tends to lead the air past the openings. The avian respiratory tract is a low-pressure, high-velocity system in which gas flow may be governed by the principles of fluidics without the need for anatomical values [see "Fluid Control Devices," by Stanley W. Angrist; SCIENTIFIC AMERICAN, December, 1964].

Another conceptual difficulty is why air moves from the posterior sacs to the lungs during exhalation and from the lungs to the anterior sacs during inhalation. These movements require both suitable pressure gradients and a change in the volume of the lungs. It has been said that the bird lung changes little in volume because it is much firmer and less distensible than the mammalian lung. A bird's lung removed from the body retains its shape instead of collapsing to a small fraction of its normal volume as a mammal's lung does.

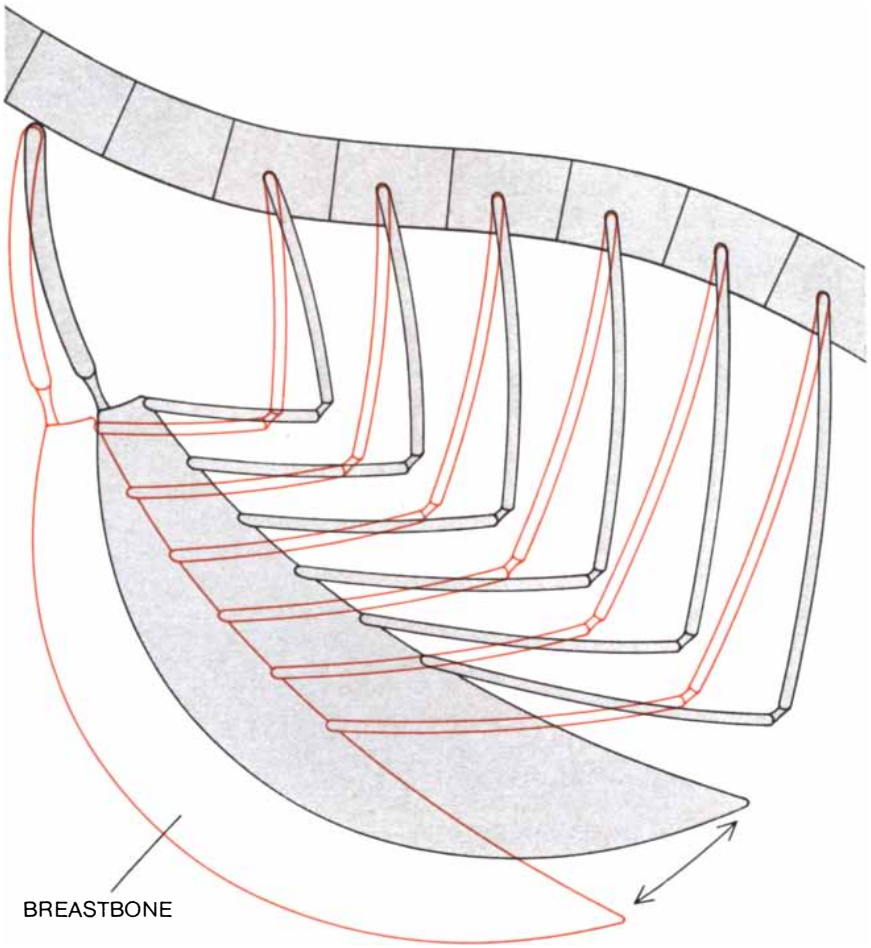
Another anatomical feature that has been misinterpreted is the bird's diaphragm. Birds have no muscular diaphragm, which is a most important feature in mammalian respiration. In its place they have a thin membrane of connective tissue. The membrane is con-



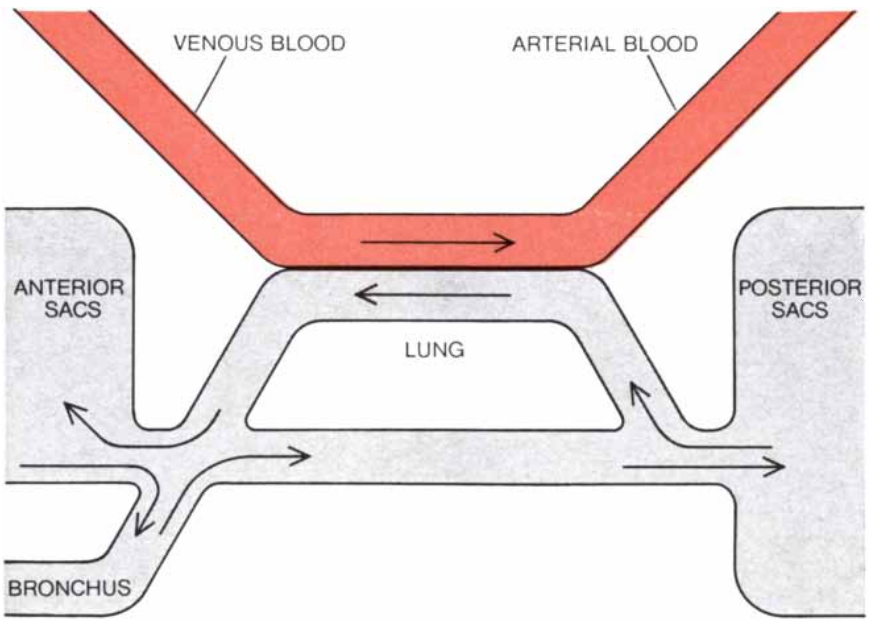
FINE STRUCTURE of an avian lung is also quite different from that of a mammalian lung. In the bird's lung the parabronchi (*left*) enable air to pass through the lung, entering from one side and leaving from the other. In the mammalian lung the baglike alveoli (*right*) are terminals, so that air necessarily flows into and out of the lung rather than through it.



RESPIRATORY CYCLE in a bird is depicted schematically, following a single slug of air through two breaths. On inhalation (*1*) air flows through the bronchus and mainly into the posterior sacs, represented here by a single chamber. Some air also goes into the lung. The first air to reach the posterior sacs is air that was left in the trachea after the previous exhalation, so that it contains more carbon dioxide than fresh air does. The anterior sacs are bypassed, apparently under fluid-dynamical influences since there are no valves. The air sacs expand. On exhalation (*2*) the sacs decrease in volume, and air from the posterior sacs flows into the lung. On the next inhalation (*3*) the slug of air moves from the lungs into the anterior sacs. On the next exhalation (*4*) it is discharged from them into the trachea and thence to the outside. The system thus provides a continuous, unidirectional flow through the bird's lungs.



RIB STRUCTURE of a bird is related to respiration by being hinged in such a way that on inhalation the breastbone is lowered. The chest expands, as do the air sacs, but the lung diminishes in volume. On exhalation the process is reversed. Because the lungs expand on exhalation, air flows into them from the posterior sacs. Similarly, as the lungs decrease in volume on the next inhalation, air flows out of them and into the anterior-sac system.



COUNTERCURRENT FLOW OF BLOOD AND AIR in the lung of the bird is the key to the bird's efficient extraction of oxygen and so to its ability to fly at high altitudes. Air flowing through the lung from the posterior sacs gives up more and more oxygen to the blood, and the blood can continuously take up more and more oxygen. Even as blood enters the lung it can take up oxygen because blood at that point has a low oxygen concentration.

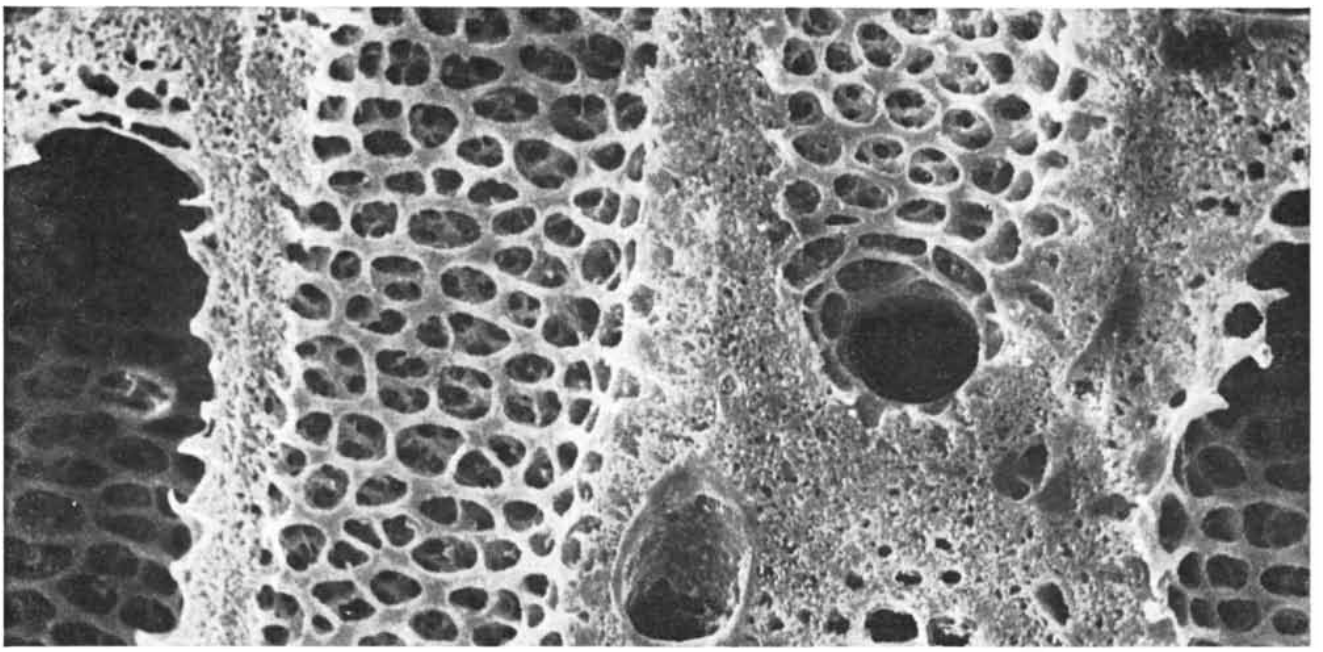
nected to muscles that are attached to the body wall. When the muscles contract, they flatten out the membranous diaphragm, thus pulling on the ventral surface of the lung in a manner that is mechanically similar to the pull of the mammalian diaphragm. The avian diaphragm, however, works on a cycle opposite to that of the mammalian diaphragm: it tends to make the lungs expand on exhalation and the volume of the lungs to diminish on inhalation.

This paradoxical cycle provides the necessary mechanism for the movement of air into the lungs. As the lungs expand on exhalation, air flows from the posterior sacs to fill the lungs. As the lungs diminish in volume on inhalation, air flows from the lungs to the anterior sacs.

Earlier in this article I remarked that the complex lung and air sac system of birds is not a prerequisite for flight, but I suggested that it confers a considerable advantage at high altitude. Man and other mammals begin to show marked symptoms of oxygen deficiency at an altitude of 3,000 to 4,000 meters (10,000 to 13,000 feet). A man moving to such an altitude from sea level finds it difficult to exert himself in physical work, although he gradually acclimatizes and is able to perform normally. At higher altitudes work and acclimatization become increasingly difficult; the limit for moderately active functioning of a man, even after long acclimatization, is about 6,000 meters.

Birds, in contrast, have been observed to move about freely and fly at altitudes above 6,000 meters. Airplanes have collided with flying birds as high as 7,000 meters. Birds might reach these altitudes by riding on strong upcurrents of wind, but this would not explain the fact that they fly actively and without apparent difficulty once they are there.

A few years ago Vance A. Tucker of Duke University simultaneously exposed house sparrows and mice to a simulated altitude of 6,100 meters, which represents somewhat less than half the atmospheric pressure at sea level and therefore less than half the partial pressure of oxygen at sea level. At this low level of oxygen the sparrows were still able to fly, but the mice were comatose. The blood of the sparrow does not have any higher affinity for oxygen than the blood of the mouse; otherwise the ability of the sparrows to take up oxygen at low pressure could be explained as a difference in the blood. What can explain the difference between birds and mammals under these conditions is the unidirectional flow of air in the bird's lungs.



LONGITUDINAL SECTION of parabronchi in a bird's lung shows the spongy structure that enables air to flow through the lung as water flows through a sponge. This scanning electron micrograph was also made by Duncker; the enlargement is 90 diameters.

One can depict the flow of air and blood in the bird's lungs with a simple diagram [*see bottom illustration on opposite page*]. In the diagram the airflow through the lungs is shown as a single stream and the flow of blood as another single stream. The salient point is that the two flows are in opposite directions.

In this way it becomes apparent that the blood, as it is about to leave the lungs, can take up oxygen from air that has the highest oxygen concentration available anywhere in the system. As the air flows through the lungs it gives up more and more oxygen to the blood before it enters the anterior sacs, where it is held until it is exhaled. It will be noted that the air, just before it leaves the lungs, encounters venous blood that is low in oxygen. This blood is therefore able to take up some oxygen, even though much of the oxygen in the air has already been removed. As the blood passes through the lungs it meets air of increasing oxygen concentration and therefore can continuously take up more oxygen until, just before it leaves the lungs, it meets the maximally oxygen-rich air coming from the posterior sacs.

The end result of this countercurrent flow is that more oxygen can be extracted from the air than would otherwise be possible. The system is similar to the flow through the gill of the fish, where the blood and the water flow in opposite directions. The blood just as it leaves the gill therefore encounters water with the highest possible oxygen content. Because of this type of flow, fish can extract from 80 to 90 percent of the oxygen in the water. The oxygen extraction normally reached in mammals under normal conditions is about 20 to 25 percent of the oxygen present in the air.

We are still trying to obtain better evidence that the flow of air and blood in the bird's lungs is as proposed in the scheme I have described, but the performance of birds at high altitude could hardly be explained in any other way. Examining the exchange of carbon dioxide rather than oxygen, we found several years ago that the air in the anterior sacs has a content of carbon dioxide that is much higher than the concentration in the arterial blood. This relation too can only be explained if the air coming from the lungs to the anterior sacs has received carbon dioxide from venous blood instead of being in equilibrium with arterialized blood as exhaled air in mammals is.

To what I have said so far, which I regard as hypotheses well supported by physical evidence, I should like to add a wild speculation. It is well known that some large birds, notably cranes and swans, have an extremely elongated trachea. This long trachea would seem to be a disadvantage, since at the end of an exhalation it would represent dead space filled with exhaled air that would have to be reinhaled at the beginning of the next breath, thus diluting the fresh outside air that follows.

The usual interpretation of the long trachea of swans and cranes is that it aids in vocalization. Such a luxury could not be allowed, however, if the large increase in dead space were physiologically detrimental. In fact, the increase in dead space may be an advantage. For aerodynamic reasons large birds have a slow wingbeat. For anatomical reasons the wingbeat and breathing in flying birds may be synchronized, since the large muscles that provide the downstroke of the wing are inserted at the keel of the breastbone and pull on it. It would therefore seem simple to attain simultaneous movements of wing and chest; indeed, it may be difficult to avoid.

The reasoning now goes as follows. If a slow wingbeat is determined by the size of the bird, and if respiration is synchronized with wingbeat, enough air can be taken in only by making each breath deeper. If each breath is deeper, and it is necessary (as I pointed out earlier) to achieve a certain level of carbon dioxide in the posterior air sacs, the amount of exhaled air reinhaled with each breath must be increased. In other words, to achieve the necessary concentration of carbon dioxide it is necessary to increase the volume of dead space.

Perhaps this speculation will have to be modified as more evidence becomes available. At present we do not have adequate information about the synchronization of wingbeat and respiration in any of the larger birds. In fact, the respiration of birds during flight remains an interesting and almost uncharted field of physiology.

The Rotation of the Earth

An analysis of recent measurements indicates that one of the main nonuniformities of the earth's rotation—its tendency to wobble gently about its rotation axis—may be excited by major earthquakes

by D. E. Smylie and L. Mansinha

The fact that our planet rotates has far-reaching implications. Besides providing the daily rhythm of our lives the phenomenon of rotation makes the earth a noninertial frame of reference, requiring the introduction of the apparent centrifugal and Coriolis forces to earth-based mechanics. The centrifugal force in turn gives rise to the principal feature of the earth's shape: its departure from sphericity, or the fact that it is flattened at the poles and bulges at the Equator. The Coriolis force, on the other hand, plays an important role in determining the wind patterns in the atmosphere, the currents in the ocean and the flow of material in the earth's outer core. The influence of the Coriolis force on the motions of the outer core is thought to be critical to the operation of the self-exciting dynamo that generates the main magnetic field of the earth; its effect in turn may explain the near-alignment of the earth's magnetic axis and its rotation axis.

It is hardly surprising, therefore, that the problem of describing the rotation of the earth accurately has intrigued physicists for more than two centuries. The realization that even the theory of the rotation of a rigid body is not a simple subject goes back to the great 18th-century mathematician Leonard Euler, whose investigations in this area form a significant part of classical physics.

The earth of course is not a rigid body but consists of several parts that are either liquid or deformably solid, and as a consequence its rotation is exceedingly complex. The nonuniformity of the earth's rotation manifests itself in several ways; for example, the rotation exhibits variations in speed (corresponding to changes in the length of the day), variations in the direction of the axis of rotation in space (precession) and variations in the orientation of the rotation axis within the earth (wobble). Recent measurements have shown that the continuous excitation required to maintain the natural wobble of the earth about its rotation axis may be supplied by major earthquakes.

It was Euler who first demonstrated that a rigid body, in addition to being capable of a stable, uniform rotation about either its axis of greatest rotational inertia or its axis of least rotational inertia, can wobble freely when the spin axis is displaced from either of these two principal axes. (Rotational inertia is measured by the sum of the products of all the mass elements of the body with the squares of their distances from the rotation axis. The resulting quantity is called the moment of inertia. The dynamical behavior of a rigid body in rotation can be completely characterized by the moments of inertia about three mutually perpendicular principal axes through its center of mass.)

If the moments of inertia about two of the principal axes are equal, and the rotation axis is slightly displaced from the third axis, the resulting motion can be represented as two circular cones rolling on each other without slip [*see illustration on opposite page*]. The line of contact is the instantaneous spin axis, the axis of the small cone is the angular-momentum axis and the axis of the large cone is the symmetry axis. These three axes lie in the same plane. To an observer in space the small cone would appear fixed and the large one would roll uniformly around it, giving the body a wobble. An observer riding the body (provided that he has some spatial reference objects) would see the axis of rotation uniformly describe the surface of the large cone within the body as though it were fixed and the small cone rolled on its interior.

When the Euler theory is applied to the earth, it predicts that the latitude of a given point on the earth's surface will vary regularly with a period of 304 days. Since the latitude of an observer is the complement of the angle between the rotation axis and the local vertical, the conical motion of the spin axis through the body of the earth results in a periodic variation in latitude. The period of the latitude variation in days is almost equal to the ratio of the angle of the large "earth-fixed" cone to the angle of the small "space-fixed" cone. (To be precise, the period in sidereal days, or days measured by rotation with respect to the stars, is equal to the ratio of the angles minus one.) This ratio is equal in turn to the ratio of the polar moment of inertia to its excess over the equatorial moment of inertia, which is known from measurements of the rate of precession of the spin axis in space to be 306 to one.

A succession of prominent scholars, among them Friedrich Wilhelm Bessel of Germany, James Clerk Maxwell of Britain and Simon Newcomb of the U.S. searched the latitude records for a variation with the Euler period. A premature announcement of the confirmation of the existence of the Euler wobble was made by Lord Kelvin in his 1876 presidential address to the British Association for the Advancement of Science. His conclusion was based on the amplitude of .05 second of arc, which Newcomb had obtained in his analysis of latitudes measured at Washington, D.C.

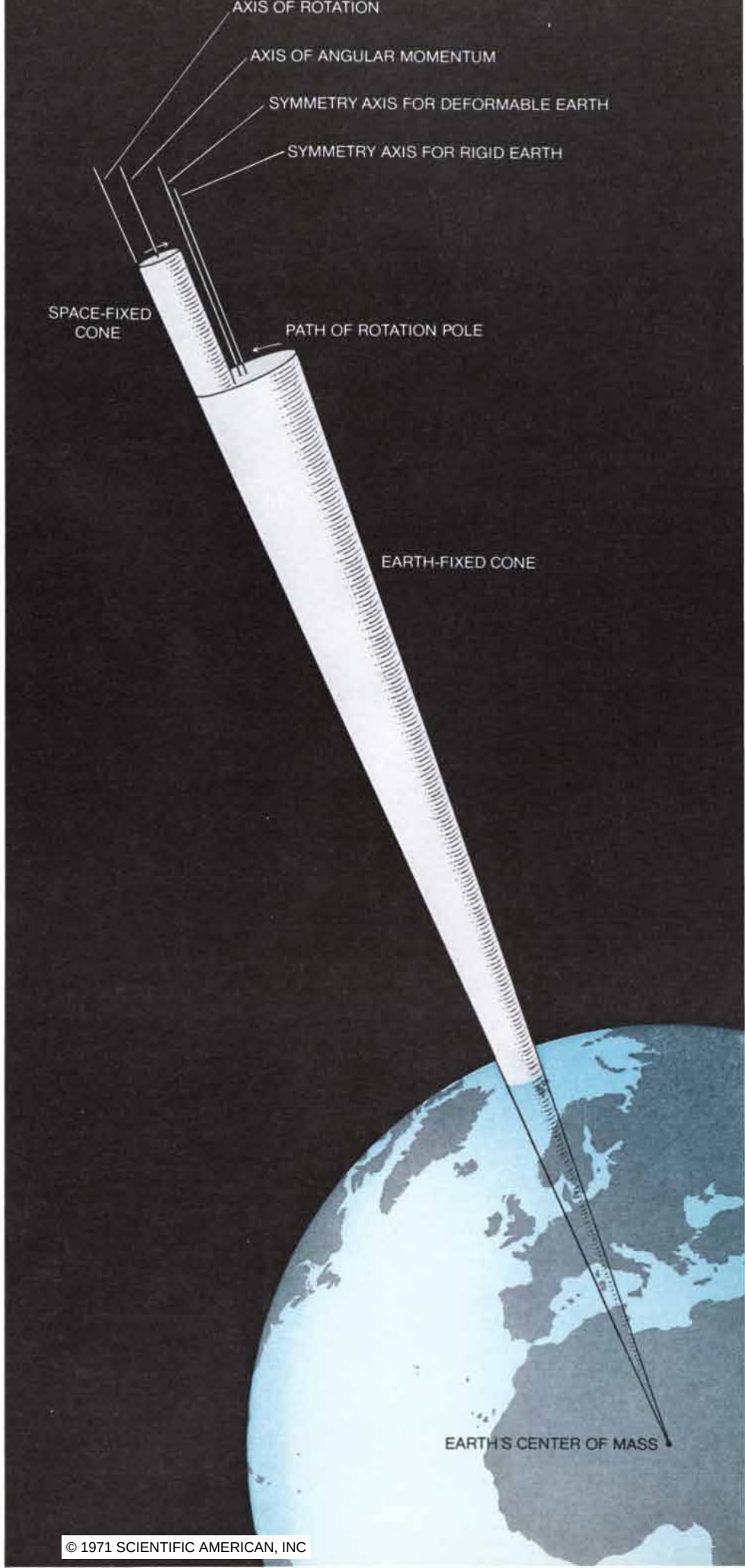
The reality of the variation of latitude was proved beyond doubt by a special series of observations organized by the International Geodetic Association and the U.S. Coast and Geodetic Survey in 1891. Simultaneous measurements were

made at a number of locations in Europe and the U.S., and at Waikiki in Hawaii. Waikiki is roughly 180 degrees removed in longitude from the European stations and its latitude variation showed the expected opposite sense.

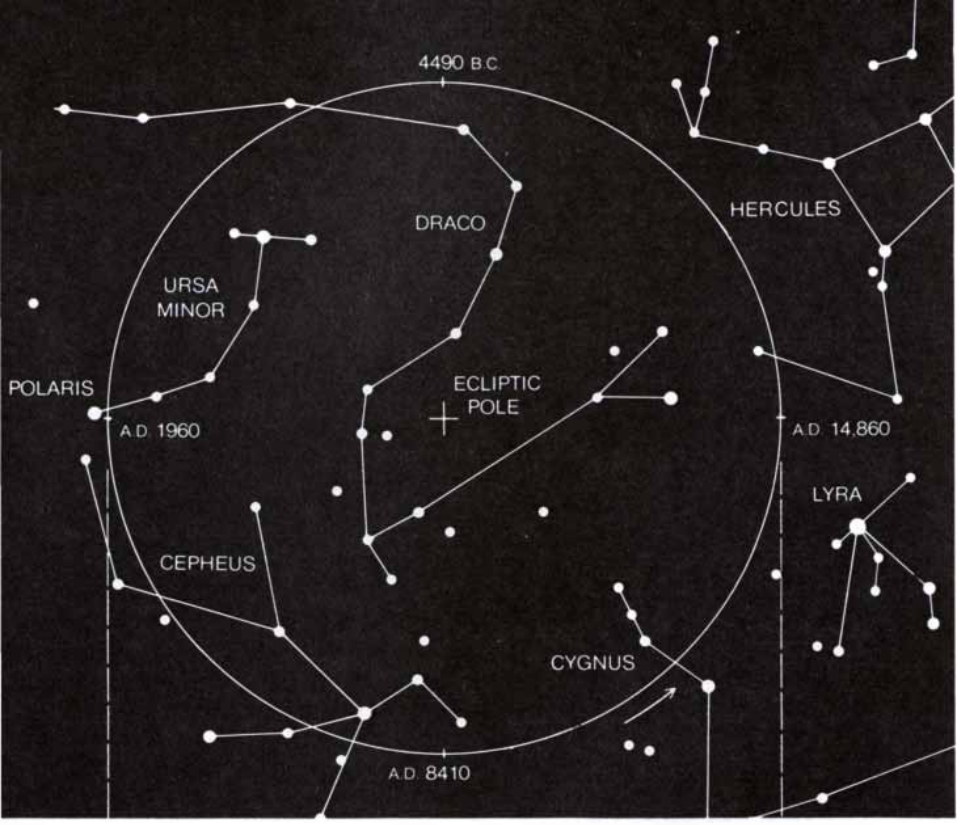
In the same year S. C. Chandler, an actuary and amateur astronomer living in Cambridge, Mass., reported that he had found the latitude variation to contain two periodic components with periods of 428 days and one year. There was no evidence of the 304-day period that Euler's rigid-body theory had predicted and that Kelvin had suggested Newcomb had found. Chandler's 428-day variation, now called the Chandler wobble, was quickly ascribed by Newcomb to a free wobble with a period lengthened from 304 days by the response of a deformable earth to rotational forces.

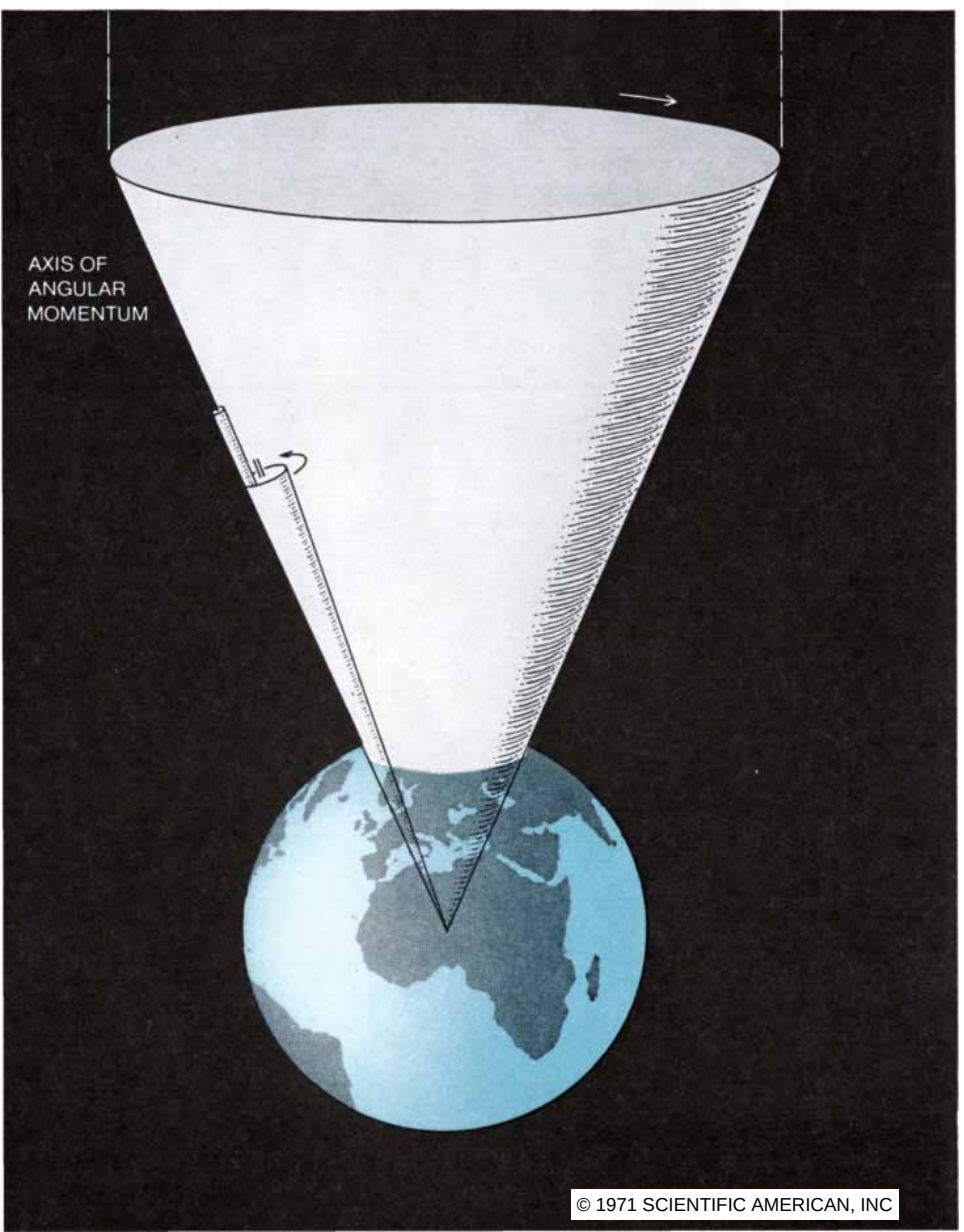
When the spin axis shifts within the body of the earth, the action of the centrifugal forces is modified, resulting in an adjustment of the symmetry axis through 30 percent of the angular distance toward the new position of the rotation axis. In the absence of disturbances the Chandler wobble can still be visualized as a cone-on-cone motion. The symmetry axis is no longer the axis of the large earth-fixed cone, however, but rather describes a cone coaxial with it.

The realization that the lengthened Chandler period was caused by the response of a deformable earth to rotational forces not only led to one of the first estimates of the overall rigidity of the earth but also presented a long-standing puzzle of geophysics: What is



EARTH'S WOBBLE can, in the absence of other disturbances, be visualized by an earth-bound observer in terms of a small cone rolling inside a large cone without slip, the line of contact being the instantaneous spin axis. The axis of the small cone is the angular-momentum axis. In a rigid earth the axis of the large cone would be the symmetry axis. Since the real earth is deformable, the symmetry axis is in fact shifted 30 percent of the angular distance toward the rotation axis. Deformation in response to the varying rotational forces increases the period of the wobble from 304 days to 435 days. The ratio of the angles of the two cones is almost equal to the period of the wobble in days. Viewed from space, the large "earth-fixed" cone rolls once a day around the small "space-fixed" cone. The angles of the cones are grossly exaggerated in the illustration; actually the large cone subtends an angle of only about .3 second of arc at the earth's center. All four axes always lie in roughly the same plane.



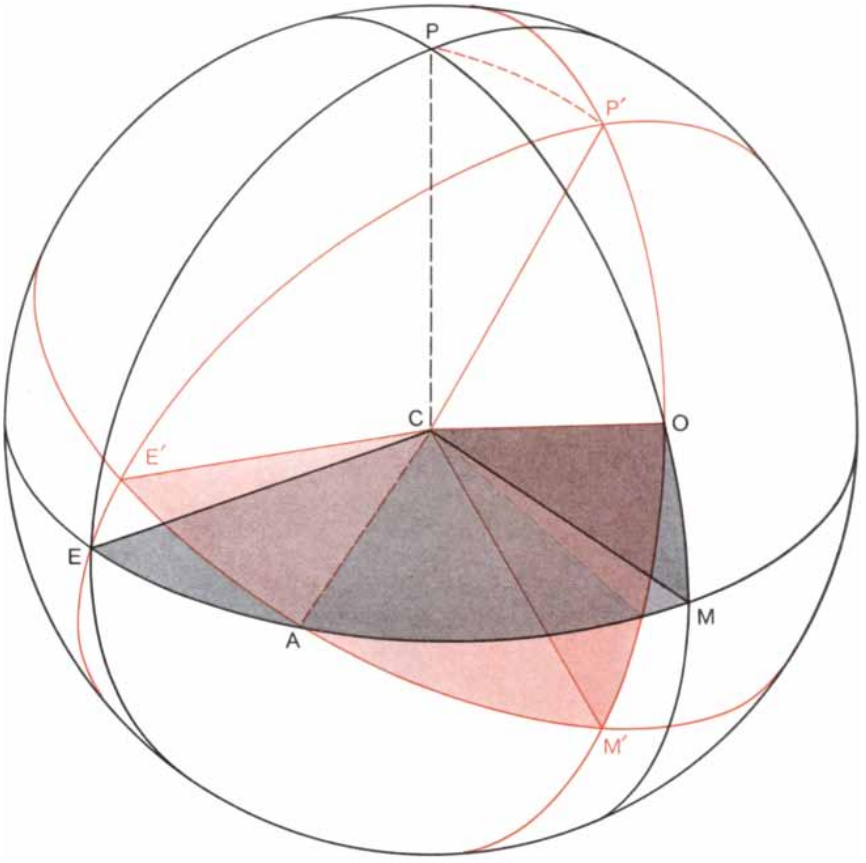


the Chandler wobble's source of excitation? Deformation implies the dissipation of energy by inelastic processes, so that the wobble must be more or less continuously excited.

By the time of Chandler's discovery the precession of the earth's spin axis in space was well understood, both observationally and theoretically. The phenomenon was known to the ancients and Isaac Newton had given an account of it in terms of his gravitational theory. The plane of the earth's Equator is inclined to the plane of the sun's apparent orbit (the plane of the ecliptic) by 23.5 degrees, and the plane of the moon's orbit is slightly inclined to the plane of the ecliptic (by five degrees). The gravitational attractions of the sun and the moon, acting together on the earth's equatorial bulge, produce a torque in the sense required to bring the equatorial plane into coincidence with the ecliptic plane. Because of the earth's rotation this does not happen. Instead the additional angular momentum adds vectorially to the angular momentum associated with the rotation; the resultant is a vector unchanged in magnitude but altered in spatial orientation. The effect of the gravitational attraction of the moon is about twice that of the sun. As a consequence the celestial pole moves almost uniformly along a circle on the celestial sphere with a period of 25,800 years. (The celestial pole is the point where the rotation axis pierces the celestial sphere, a globe of indefinite radius on which the stars can be regarded as being fixed. The celestial pole is now near the star Polaris; 5,000 years ago it was near Alpha Draconis; 5,000 years hence it will be near Alpha Cephei.)

PRECESSION of the earth's rotation axis cuts out a cone in space subtending an angle of 47 degrees at the earth's center (*bottom*). The projection of this motion on the celestial sphere (*top*) describes a circle with a period of 25,800 years. On this time scale Polaris serves only temporarily as the pole-star; the position of the pole at other epochs is indicated by the dates adjacent to the circle. Superimposed on the precession of the earth's rotation axis in space are small irregularities called nutations (*not shown*), the principal one being an elliptical motion with semiaxes of nine and seven seconds of arc and a period of 18.6 years, which is caused by changes in the position of the moon's orbit. All these motions are unrelated to the free wobble of the earth depicted on the preceding page. In addition the geographic and rotation axes both move daily about the axis of angular momentum.

The precession of the earth's axis of rotation is subject to small superimposed irregularities called nutations. The principal nutation is an elliptical motion of the celestial pole with semiaxes of nine and seven seconds of arc and a period of 18.6 years. This irregularity results from a variation of the same period in the orientation of the plane of the moon's orbit with respect to the plane of the ecliptic. The line of intersection of these two planes (called the line of nodes) regresses with an 18.6-year period under the joint attractions of the sun and the earth. Whereas the steady precession can be accounted for satisfactorily by regarding the earth as being rigid, Sir Harold Jeffreys of the University of Cambridge and R. O. Vincente of the University of Lisbon have shown that the presence of the liquid core has a detectable effect on the amplitude of the nutation.



POLAR MOTION changes both the latitude observed at a particular point on the earth's surface and the sidereal time at that point. (Sidereal time is time measured by the rotation of the earth with respect to the stars.) If the pole moves from point *P* to point *P′* on the earth's surface, for example, the Equator pivots about an axis passing through the surface point *A* and the center of the earth (*C*). The latitude observed at point *O* changes from the angle *OCM* to the angle *OCM′*. Sidereal time prior to the movement of the pole is given by the angle *ECM* and after by the angle *E′CM′*. Before the polar shift *E* is the point on the earth's Equator directly below the vernal equinox on the celestial sphere (that is, the point on the celestial sphere where the sun crosses the celestial equator on its springtime journey northward), whereas *E′* is the same point on the Equator after the polar shift.

The interest aroused by the verification of the reality of a latitude variation and by Chandler's discovery of the lengthened Euler period led to the establishment of the International Latitude Service. By the turn of the century it was operating observing stations at six locations, all at 39 degrees eight minutes north latitude. The stations at Mizusawa in Japan and Ukiah, Calif., have operated continuously ever since. Observations at Carloforte, on a small island off Sardinia, were interrupted briefly during World War II. The Cincinnati observatory ceased operations in 1916. The Gaithersburg, Md., station was closed for financial reasons from 1915 through 1931, and the station at Tschardjui in the U.S.S.R. had to be moved to Kitab because of a change in the course of the Amu Darya, a large river nearby. Mizusawa is the present headquarters of the International Polar Motion Service, successor to the International Latitude Service.

The development of atomic clocks by late 1955 led the international time service, the Bureau International de l'Heure in Paris, to begin the compilation and reduction of latitude measurements from a group of observatories, including the five International Latitude Service stations. At the millisecond level of timekeeping that atomic clocks allow, time variations and latitude variations are inextricably bound together. For example, with the pole of rotation at *P*, an observer at *O* measures his latitude as the angle *OCM*, where *C* is the earth's center and the meridian circle through *O* meets the Equator at *M* [*see illustration above*]. Sidereal time at *O* is given by the angle *ECM*, where *E* is the point on the Equator directly below the vernal equinox on the celestial sphere (the point on the celestial sphere where the sun crosses the celestial equator in its springtime journey northward). If the pole of rotation now shifts to the new position *P′* on the earth's surface but the celestial pole remains fixed, both the latitude of *O* and its sidereal time are altered. To earthbound observers the Equator appears to pivot on an axis passing through point *A* and the center of the earth. The latitude at *O* is now the angle *OCM′* measured along the new meridian circle through *O* to the point *M′* where it intersects the new Equator. Sidereal time at *O* is now given by the angle *E′CM′*, where *E′* is the point on the Equator directly below the vernal equinox on the celestial sphere.

One of the simplest and most accurate instruments for making observations of time and latitude is the photographic zenith tube [*see illustration on next page*]. Light from stars near the zenith (the projection of the local vertical on the celestial sphere) passes through a lens of long focal length. It is reflected from a mercury surface and brought to a focus on a photographic plate. Four successive exposures are made. During each exposure the plate is driven west to east to keep the star images stationary. The lens head and plate are rotated 180 degrees between each exposure. Exposures begin at precisely timed equal intervals.

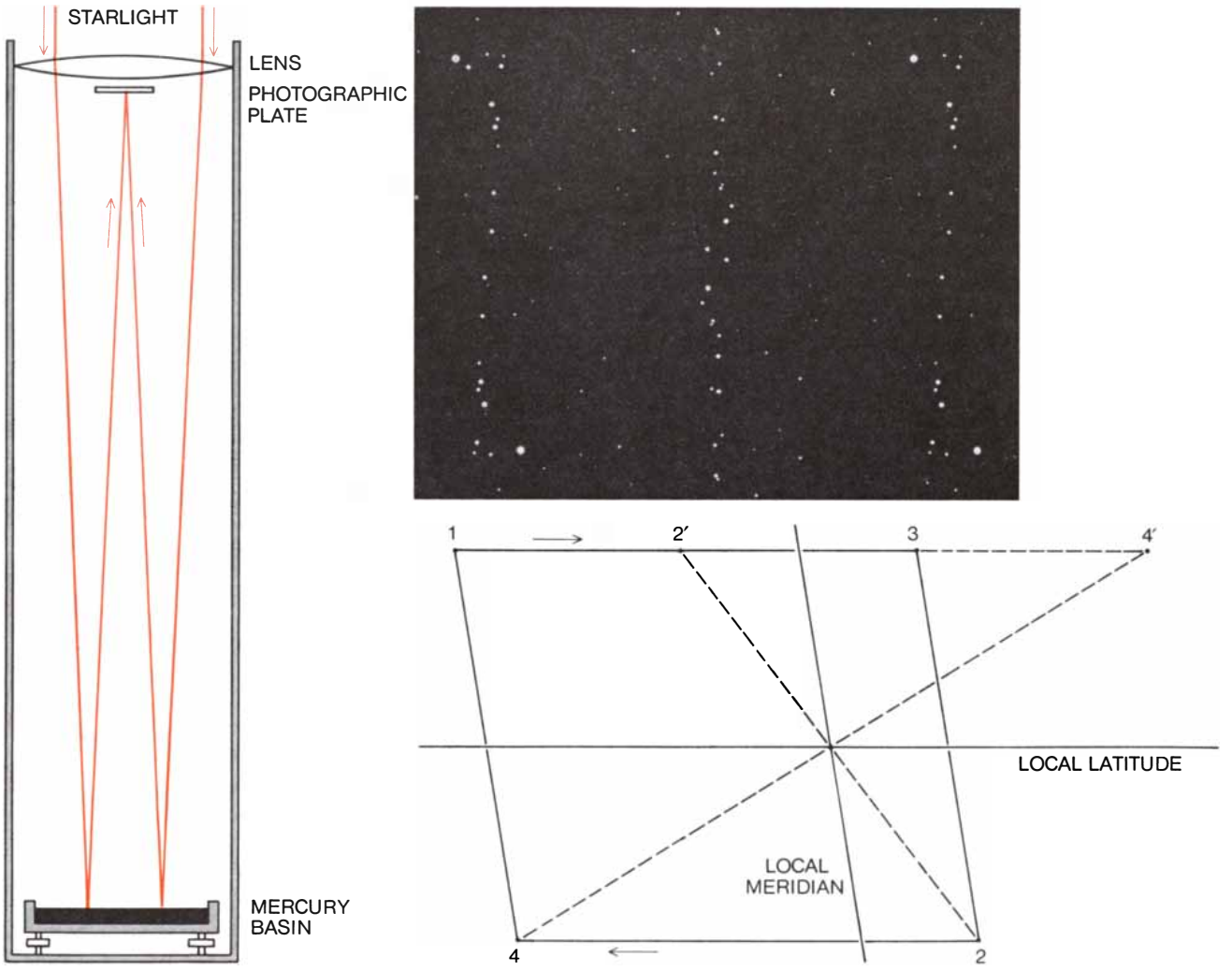
The result is a pattern of star images set on the vertexes of parallelograms. Sidereal time at the transit of a star across the local meridian is equal to the star's right ascension. The local latitude

is equal to the star's declination minus half of the distance between its north and south images on the photographic plate.

Right ascension and declination are the angular coordinates of a star on the celestial sphere and are available from star catalogues, established over long periods of careful observation. Right ascension is the angle measured from the vernal equinox eastward along the celestial equator to the point where the great circle from the celestial pole through the star's position intersects the celestial equator. The declination is the elevation angle of the star above the celestial equator.

Simultaneous compilation and reduction of time and latitude measurements at a group of stations allow that part of the variation of sidereal time due to polar motion to be separated from that part due to variations in the earth's speed of rotation. Information on the speed of rotation has also been obtained from recorded astronomical observations, principally on the discrepancy in longitude of the positions of the sun and the moon from the predictions of gravitational theory made under the assumption of a uniform rotation rate. The effects of tidal interactions can be removed from such records. When the nontidal variations in the length of the day back as far as 1800 are represented in the form of a smooth curve, irregular fluctuations appear with a time scale of approximately 10 years and an amplitude of a few milliseconds [*see top illustration on opposite page*].

The late E. H. Vestine of the Carnegie Institution of Washington first presented evidence to suggest that these irregular fluctuations in the length of the day are correlated with changes in the rate of drift of the earth's main magnetic field, which is thought to be carried westward with the highly conducting outer liquid core of the earth. The transfer of angular momentum between the



PHOTOGRAPHIC ZENITH TUBE (*left*) is used for making observations of latitude and sidereal time. Light from stars near the zenith (the projection of the local vertical on the celestial sphere) passes through a lens of long focal length and is reflected from a mercury surface onto a photographic plate in the focal plane. During exposure the plate is driven west to east to keep the star images stationary. Four exposures are made at precisely timed equal intervals. Between each exposure the lens and the plate are rotated together by 180 degrees. Latitude and time are deduced from the resulting pattern of star images (*upper right*). The portion of the exposed photographic plate shown was made with a photographic zenith tube located at Ottawa by R. W. Tanner of the Canada Department of Energy, Mines and Resources. One millimeter on the photograph corresponds to an angular distance of about 10 seconds of arc. Rotating the plate by 180 degrees between exposures results in the star images appearing at the vertexes of a parallelogram (*lower right*). The first image is at position *1*. The second image would appear at *2′* but actually appears at *2* because both the plate and the lens have been rotated about a vertical axis by 180 degrees. Similarly, the fourth exposure results in an image at position *4* instead of *4′*. Arrows indicate the directions of the plate's motion during the exposures. From the known position of the star on the celestial sphere, the instantaneous latitude and sidereal time can be deduced from measurements on the photographic plate.

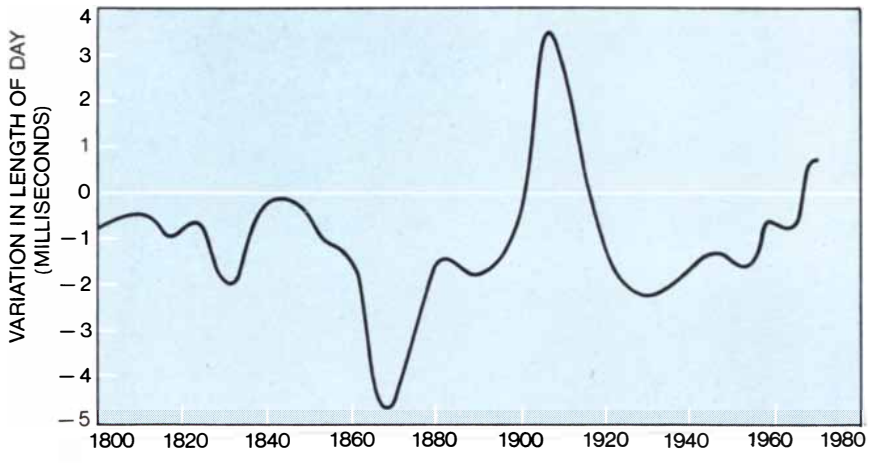
outer core and the mantle through electromagnetic coupling would explain the correlation. Electromagnetic coupling has been shown by M. G. Rochester of the Memorial University of Newfoundland to be just barely adequate to accomplish the requisite transfer.

Since 1955 the greater resolution afforded by atomic timekeeping has provided much more detail on such variations in the speed of the earth's rotation. Superimposed on the 10-year fluctuations are annual and semiannual variations [*see middle illustration at right*]. The earth runs slow in the spring and early summer of the Northern Hemisphere and fast in the fall. The annual variation amounts to an amplitude of about half a millisecond in the length of the day and the semiannual variation amounts to about a third of a millisecond.

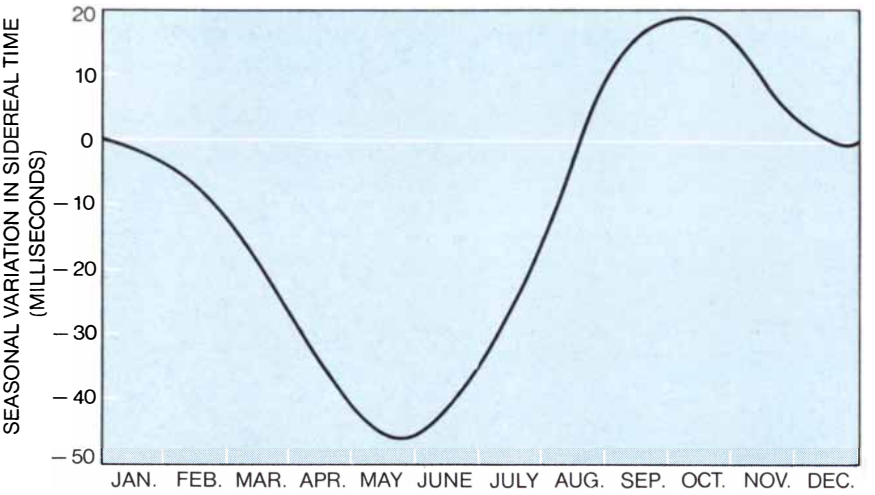
Walter H. Munk and his co-workers at the University of California at San Diego have shown that most of the annual variation can be accounted for by seasonal changes in the winds of the atmosphere. These also contribute to the semiannual variation along with ocean tides. The question of the origins of the annual and semiannual variations is by no means closed. A long list of effects have been considered, including seasonal changes in vegetation, snow load, air mass, ground water and atmospheric loading of the oceans.

Much greater difficulty is encountered in trying to find an explanation for the "sudden events" that are occasionally observed [*see bottom illustration at right*]. These amount to defects in the earth's timekeeping of several milliseconds established in periods as short as one week. A very large impulsive torque that acts first in one direction and then in the opposite direction is required. S. K. Runcorn of the University of Newcastle upon Tyne has suggested that large toroidal magnetic fields carried suddenly to the surface of the earth's core by hydromagnetic waves burst like sunspots and provide the necessary impulsive torque on the mantle. Runcorn has spent several years recording signals on abandoned undersea telegraph cables in an attempt to detect the electric fields that would be associated with strong toroidal-magnetic-field changes at the surface of the core. Encouraging results have been obtained, but the recordings are difficult to interpret with certainty.

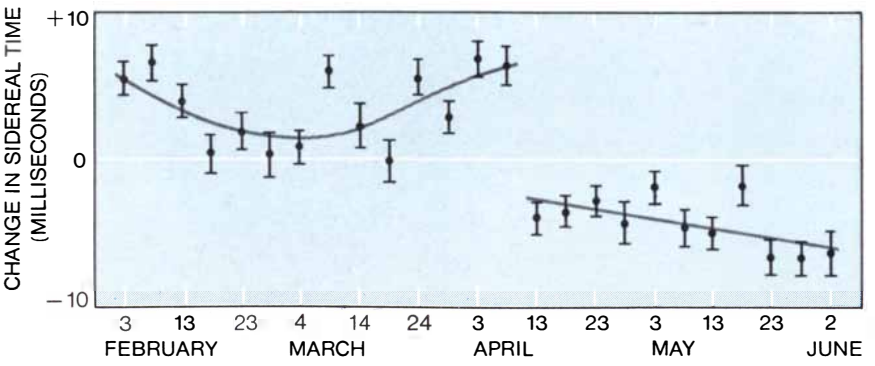
Owing to the continuous operation of the International Latitude Service since its formation, the polar-motion rec-



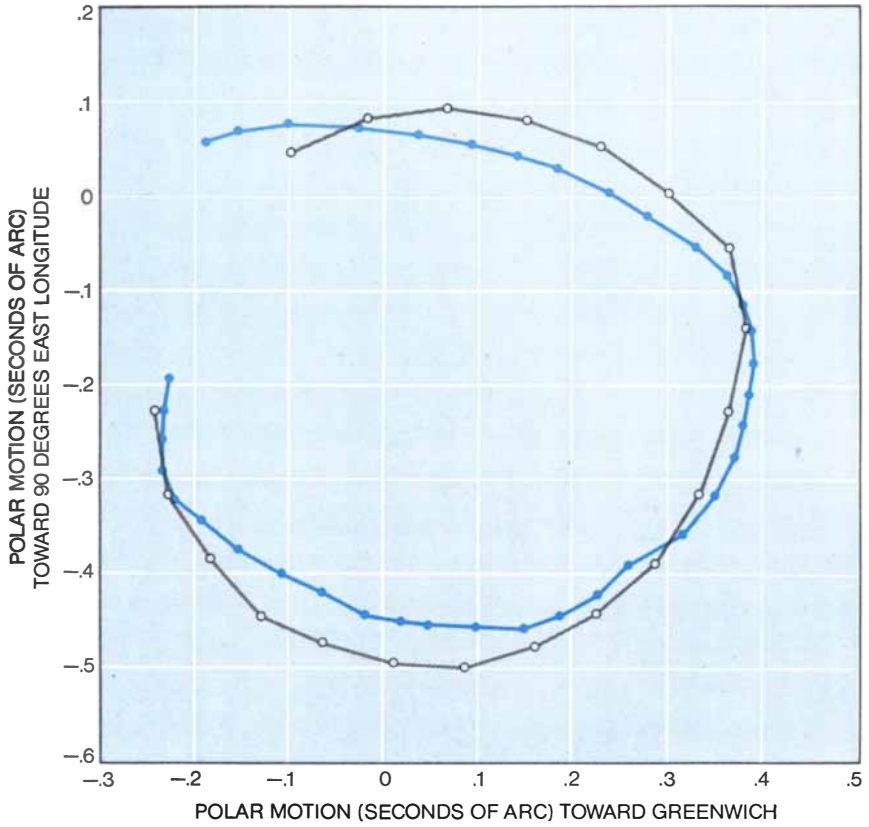
FLUCTUATIONS IN LENGTH OF DAY attributable to nontidal forces are represented on this graph for the period from 1800 to 1970. Before the development of atomic clocks in 1955 the variation in the speed of the earth's rotation could only be detected on a long time scale by measuring the discrepancy between the observed positions of the moon and the planets and those predicted by gravitational theory. As the graph reveals, the fluctuations occur on a time scale of about a decade. The explanation of these irregular fluctuations may lie in the electromagnetic coupling of the earth's mantle to its fluid outer core.



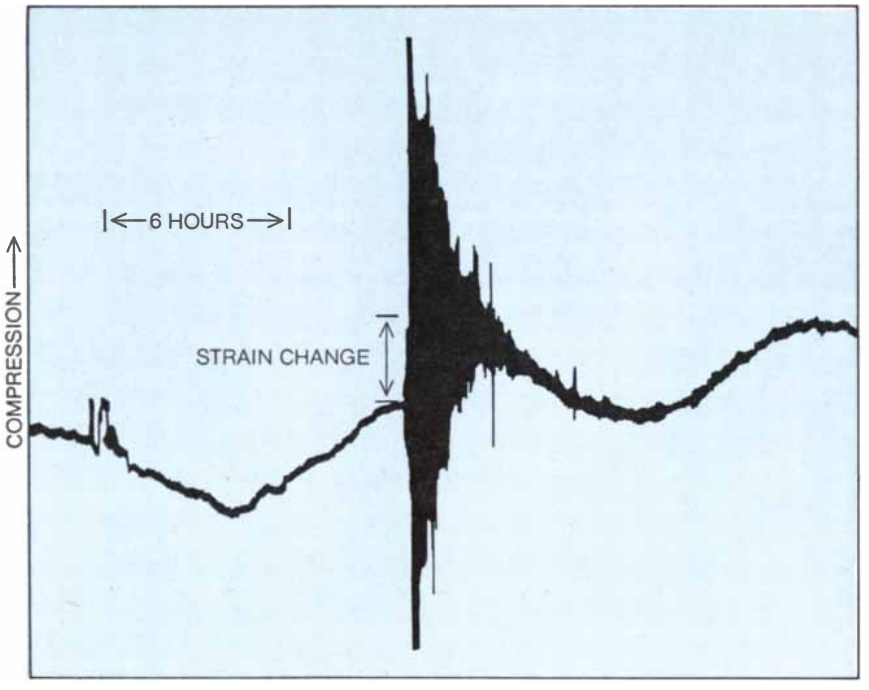
SEASONAL AND SEMISEASONAL VARIATION in the speed of the earth's rotation is charted in this graph in terms of the variation in sidereal time at a given location during the year 1970. A linear drift associated with the decade fluctuations shown at top has been removed. The earth runs slow in the spring and early summer of the Northern Hemisphere, fast in the fall. Atmospheric winds and ocean tides account for most of this variation.



"SUDDEN EVENT" in the earth's rotation appears in this graph of the variation of sidereal time at a given location. Changes of up to 10 milliseconds occur occasionally in sidereal time. No entirely satisfactory explanation has yet been given for such changes. The graph was prepared by B. Guinot of the Bureau International de l'Heure in Paris.



POLE PATH FOR 1957 is represented here by open circles, denoting measurements made at the stations of the International Latitude Service, and by colored dots, showing the positions computed by the Bureau International de l'Heure in Paris. Both paths are highly smoothed versions of the observations. The motion of the pole is counterclockwise and is expressed in seconds of arc; at the surface of the earth one second of arc is approximately equal to 100 feet. The origin is near the mean North Pole for the period 1900–1905.



ABRUPT CHANGE IN STRAIN caused by the great Alaskan earthquake on March 27, 1964, was recorded by a strainmeter at Kipapa in Hawaii by L. Blayney of the Seismological Laboratory of the California Institute of Technology. The sinusoidal fluctuations correspond to tidal motions in the solid earth. Such distant strain measurements indicated that the displacements caused by major earthquakes are more extensive than had been thought.

ord is now more than 70 years long. The production of a pole-path record from independent observations, and lately the simultaneous reduction of both time and latitude measurements by the Bureau International de l'Heure, have provided an opportunity to compare results. Disagreements as large as .1 second of arc show up [*see top illustration at left*].

The origin used in expressing polar-motion measurements is near the mean pole position for the period 1900–1905. Evidently the mean pole position has shifted since then by as much as .3 second of arc. This low-frequency motion, called the secular polar shift, could result from a permanent rearrangement of mass, such as might be caused by earthquakes.

The long record of latitude measurements accumulated since Chandler's discovery has allowed considerable improvement in the resolution of the frequency spectrum of the polar motion. The annual motion appears almost as a line feature in the spectrum. The Chandler wobble has a broadened peak centered on a period of 435 days. On the assumption that the excitation of the Chandler wobble is random, the breadth of the resonance gives an indication of the damping. A decay time of 20 years has been estimated in this way. Therefore left to itself the Chandler motion would decay to half its initial amplitude in about 14 years. Since it has been observed to exist for more than 80 years, a source of energy to regenerate the wobble is implied.

From an analysis of a long series of barometric pressure records Munk and E. S. M. Hassan of the University of California at San Diego have shown that the annual component of the polar motion is due mainly to the seasonal variation in the mass distribution of the atmosphere. This finding confirms a suggestion made originally in 1901 by Rudolf Spitaler of the University of Prague. The shift in air mass is principally associated with the extremely high pressure that prevails over Siberia in the winter.

Because the Chandler resonance is not far removed from an annual period, it was thought for some time that seasonal effects might be the source of its excitation. The seasonal variation in atmospheric mass distribution was particularly suspect. As the record of polar motion grew in length, however, it became apparent that the annual motion was distinct from the Chandler resonance. Munk and Hassan have calculated that the contribution of the atmosphere to the excitation of the Chandler wobble is

between 10 and 100 times less energetic than the observed motion requires.

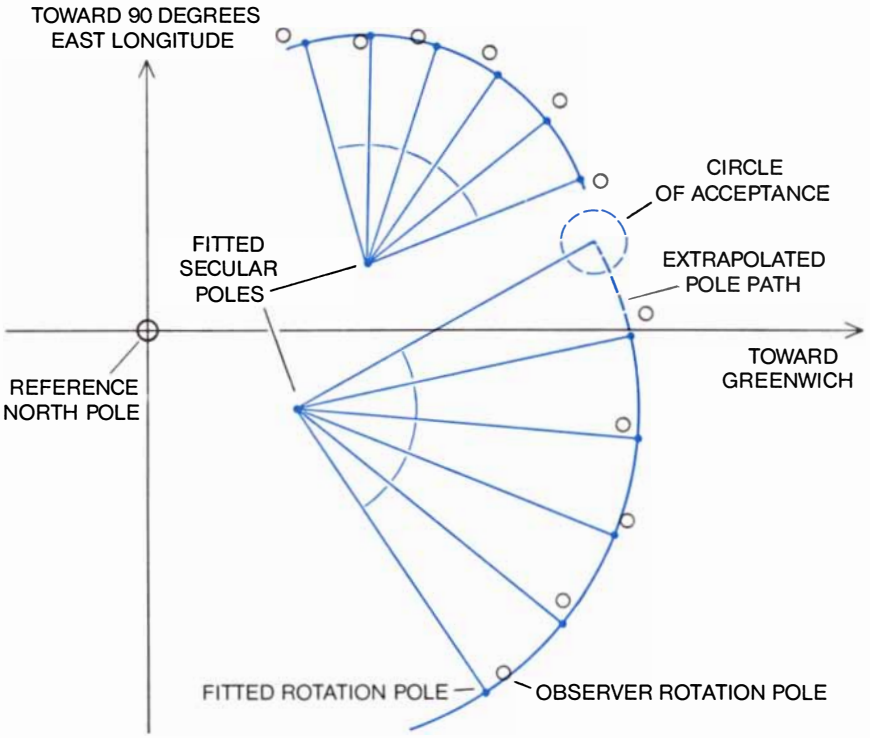
A connection between earthquakes and polar motion was made by the seismologist John Milne as long ago as 1906. Quantitative considerations, based on the assumption that the displacements caused by earthquakes were largely local, appeared to rule out the possibility that they could be the source of the excitation. This was the prevailing view until 1965, when Frank Press of the Massachusetts Institute of Technology used both the theoretical predictions of elasticity theory and the recordings of distant strain measurements to argue that the displacements were much more extensive than had been thought.

The displacements given by elasticity theory had been worked out earlier by J. A. Steketee, M. A. Chinnery and Rochester at the University of Toronto and applied to the interpretation of measured offsets near earthquake faults. Working at the University of Western Ontario and the University of British Columbia, we applied this theory to calculate the Chandler-wobble excitation that could be expected from earthquakes. We found that between a sixth and a third of the observed level could be accounted for. This was several thousand times greater than earlier estimates based on the assumption that the displacements were entirely local.

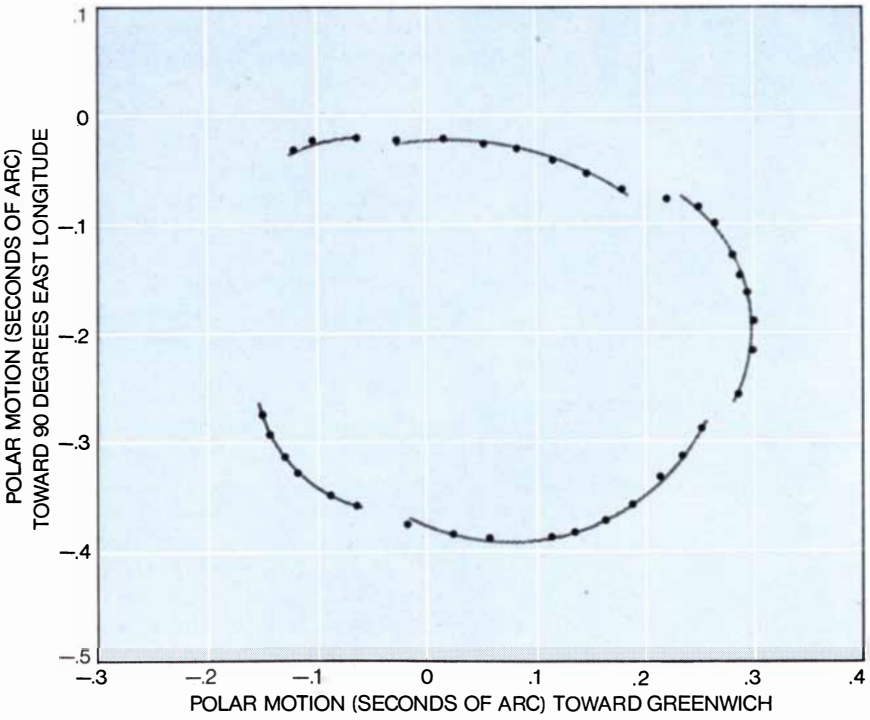
We have since improved the theoretical calculations to take into account self-gravitation, the fact that the earth has a liquid core and the variation in the elastic properties, density and gravity of the earth's interior. There is now substantial agreement between the computed and the observed levels of excitation.

A test of the theory has been made on the polar-motion observations. Earthquakes are sudden events, and the displacements they cause are expected to be established suddenly. Mathematically such changes in time are represented by "step functions." A redistribution of mass in the earth, as might be caused by a step-function displacement of material by an earthquake, results in a polar motion that consists of two successive circular arcs [*see top illustration at right*]. Before the earthquake the pole traverses the first arc at a uniform angular rate. At the time of the earthquake the pole begins to traverse a second circular arc at the same uniform angular rate. There is only a slight immediate change in the path of the pole; the principal discontinuity is a second-order one in the curvature of the path.

With pole positions uniformly spaced in time the angle subtended at the cen-



METHOD USED to analyze polar-motion data to detect signals of the form expected from earthquake excitation is demonstrated here. The angle subtended between data points equally spaced in time is a constant determined by the period of the earth's wobble. A circular arc is fitted to the data by the least-squares technique until the measured pole position lies outside a small "circle of acceptance" drawn around the predicted pole position. The arc is then broken and a new arc is fitted to this and subsequent pole positions.



CIRCULAR ARCS were fitted to the 1957 pole-path record of the Bureau International de l'Heure by the method shown above after the effect of the pole's annual motion was removed. An unusual correlation of earthquakes with a magnitude greater than 7.5 with breaks in the arcs was found for the 11-year period analyzed (from 1957 to 1968). Most of the large earthquakes in this period took place before 1964. Low seismic activity (in terms of the incidence of major earthquakes) during the past seven years has not allowed a reliable test of this observation to be made using more recent measurements of polar motion.

ter between two successive positions on a circular arc is known from the Chandler period. When the subtended angle is fixed, a circular arc can be fitted uniquely to two pole positions. A prediction of the next location can be made by extending the arc fitted to the first two positions through the subtended angle. Because of the presence of noise in the polar-motion measurements it is necessary to allow some tolerance in comparing the predicted position with the measured one. A small circle of acceptance is drawn around the predicted position. If the measured pole position lies outside the circle, the fitted arc is broken and a new one is fitted to this pole position and succeeding ones. If the measured pole position lies inside the circle of acceptance, the arc is refitted to this position and the preceding ones by the mathematical procedure of least squares, and a prediction of the next location is made.

In this way a series of breaks in the pole path was computed after the annual motion had been removed. The locations of these breaks in the pole path were then compared with the times of occurrence of major earthquakes. They were found to be highly correlated. The probability of obtaining an equal or better correlation on a random basis is about .1 percent. Of great interest is the unexpected result that the breaks in the pole path often *precede* the correlated earthquake. It is not yet clear whether this premonition is real or results from the smoothing procedures used in reducing the observations to obtain pole positions. The questions raised by the lengthened period of the Chandler wobble and its damping time have been perhaps less puzzling than the problem of its excitation, but completely satisfactory geophysical answers have yet to be given.

The study of the propagation of seismic waves inside the earth has greatly improved our knowledge of the interior's physical properties since the time of Newcomb. We can say with some confidence that the elasticity of the mantle lengthens the period of the Chandler wobble by 120 days. Because the outer core of the earth and the oceans are fluid, their effects are much more difficult to calculate. Neglecting flow (an omission that must surely be unjustified), the oceans are calculated to lengthen the period by 40 days and the outer core to shorten it by 30 days.

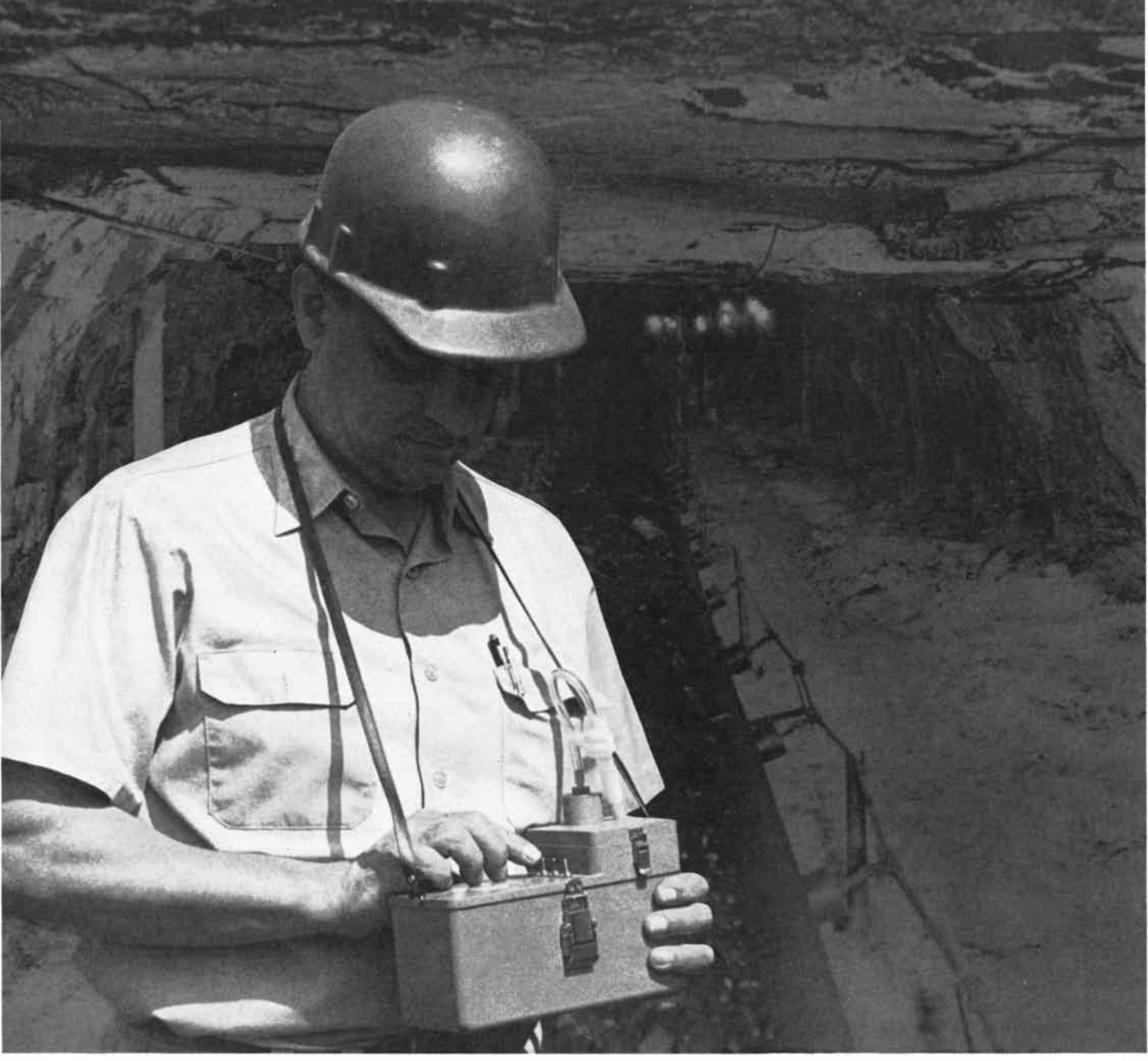
The inelastic dissipation of seismic waves in the earth's mantle has been extensively studied. Although the periods of seismic waves are all less than one hour and the results should be extrapolated to periods as long as the period of the Chandler wobble with caution, the damping of the wobble appears to be much too severe to attribute it to the inelasticity of the mantle. Both viscous and electromagnetic dissipation in the outer core seem inadequate except under the most extreme assumptions. Ocean-bottom friction has been dismissed and reinstated. No definite conclusions can be drawn as yet.

Even less certain is the role the gravitational torques of the moon and the sun play in events in the earth's interior. The core of the earth is considerably less oblate than the outer layers of the mantle and the tidal torque on it is correspondingly smaller. There is no evidence in surface measurements of the main magnetic field, however, of the violent magnetic disturbances that would result from a large differential motion. It is assumed that the core and the mantle are somehow coupled on the 25,800-year time scale of the earth's precession.

The nature of this coupling is critical to understanding the dissipation of tidal energy. It is known that the earth is slowing down in its speed of rotation because of this dissipation. The length of the day increases at the rate of about two milliseconds per century as a consequence. Dissipation in shallow seas was long suspect but now appears inadequate. The effect of the core cannot be accurately estimated without a knowledge of the coupling mechanism.

There has been no sudden jump in the quality of observations of the polar motion comparable to the one that followed the development of atomic clocks in the measurement of time. Several new methods of measurement currently being developed promise greatly increased accuracy. Already Doppler tracking of U.S. Navy navigation satellites has produced pole paths comparable to those of the Bureau International de l'Heure and the International Latitude Service. The techniques of very-long-base-line interferometry, used in radio astronomy, also promise to provide a method of accurately determining the earth's orientation in space. Laser-ranging of satellites is currently being tested in an international geodetic program.

Much remains to be learned about the earth's rotation. Challenging theoretical problems that draw on nearly every aspect of geophysics remain to be solved. As our theoretical understanding increases, demands on measurement become ever more stringent and tax the ingenuity of experimentalists.



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The Talking Drums of Africa

In spite of an abundance of tall tales, drum talk is a reality. Moreover, the drummers of Africa may well have been the first to utilize the principle of redundancy in their communications

by John F. Carrington

Stories about African drum language usually elicit either uncritical acceptance or unwarranted skepticism. The former accounts for the attention wasted on such extravagant claims for drum talk as a speed of transmission greater than the speed of sound, or on the purported existence among "primitive" men of extrasensory perceptions that have atrophied among more civilized peoples. There is, of course, no need to invoke telepathy to explain drum talk. The procedure is usually more long-winded than swift, but no one who has lived in central Africa can doubt its existence. The presence of one or more drum sheds in many Congo villages and the use of drum talk to broadcast the most banal messages suffice to banish disbelief.

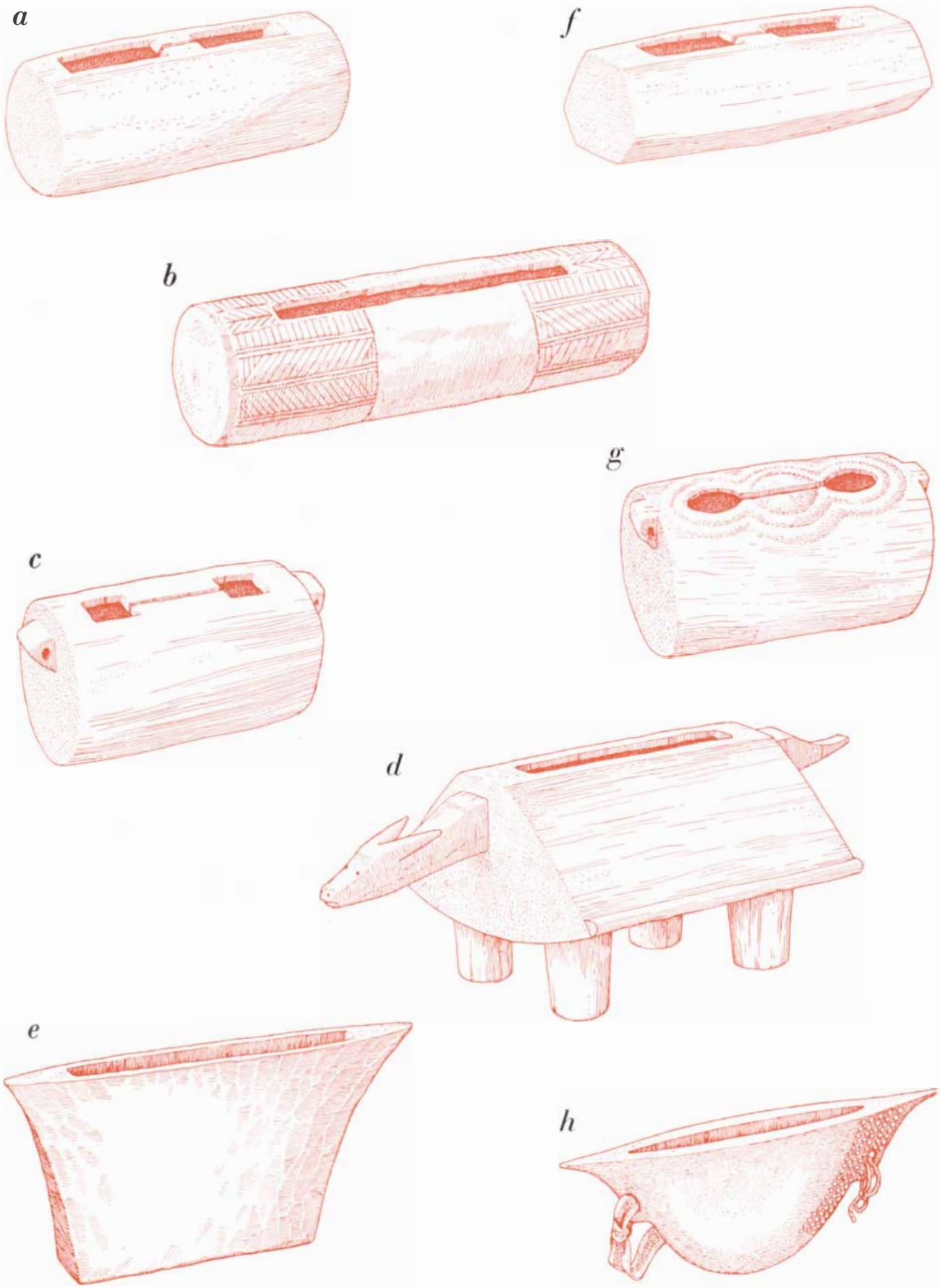
I remember seeing two men approach me along a village street one day. One of them darted into the village drum shed and beat out a quick message before rejoining his friend. The village was in an area whose drum language I did not know, and I was eager to find out what the man had signaled in such a short time because the usual message takes several minutes. He told me he had left his cigarettes that morning in his house in a village half a mile away. Knowing that a friend there intended to join him later, he had called him on the drum, asking that he bring the cigarettes along when he came. Messages of no greater import than this can be heard morning and evening and often through the day and night in many a village in the Republic of the Congo and elsewhere in sub-Saharan Africa.

The subject of drum language—or, as it is more proper to call it in the Congo, gong language—has been shrouded in mystery partly because of the confusion of one early investigator, the German linguist Carl Meinhof. Listening to the gong-beaters in one community in the Cameroons, he tried to compare their beaten notes with their spoken words. For instance, in order to signify a dog, the gong-beaters sent a six-syllable signal that they rendered phonetically as *kuku totokulo*. Their spoken word for "dog," however, was *mbo*. Meinhof published his conclusion that "there is no resemblance between the beaten elements and the spoken language of the people," and thus gave rise to an illusory mystery that has beclouded the subject ever since. Meinhof's informants were not, however, purposely deceiving him; it may take six or 10 or more syllables of gong language to unambiguously express a meaning that is clearly conveyed in a single syllable of spoken language. Among the Lokele, the Upper Congo linguistic group that is most familiar to me, the gong-language phrase for "dog" has 14 syllables and the spoken word for "dog" (*ngwa*) has only one syllable. The gong phrase, in translation, is "giant dog, little one that barks *kpei kpei*." To be sure, the word "dog" appears in the gong phrase, but all the other words are designed to make it clear that what is being described is a dog and not something else described by a low-toned one-syllable word.

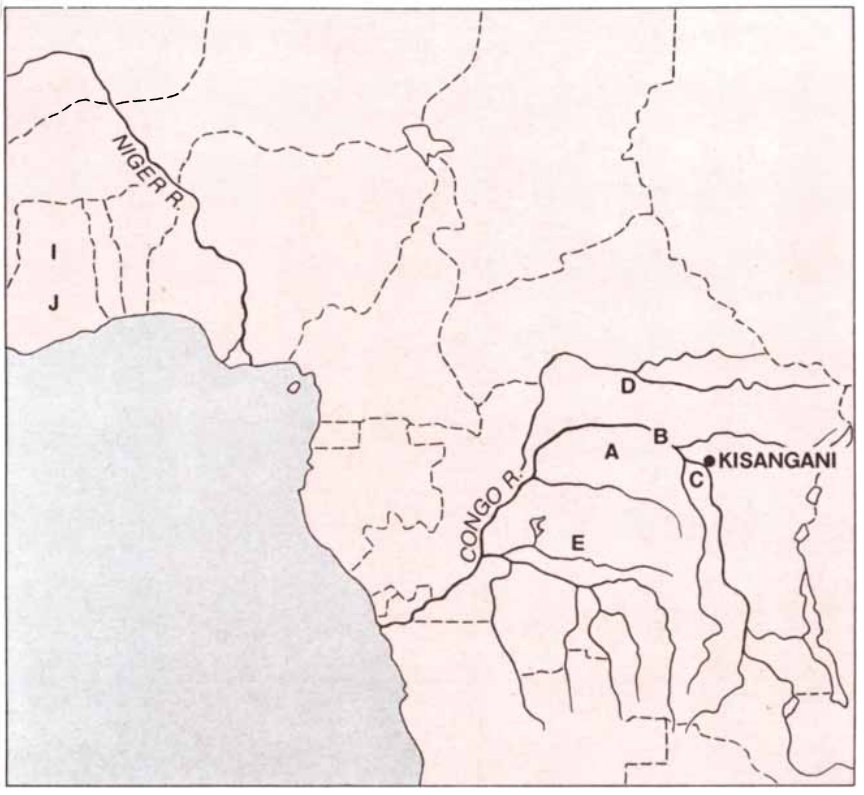
What dictates this form of gong language is the phenomenon of tonality, which is a key element in most African languages although it is virtually absent from European tongues. Let us consider an example in English. The sentence "They're in the house," when spoken with equal stress on each word, is quite recognizably different in meaning from an interrogatory "They're in the *house*?" or an emphatic "They're *in* the house!" In the first instance the speaker's voice falls in pitch throughout the statement. In the second, "house" is spoken with a rise in pitch and in the third "in" is emphasized. In Congolese languages this "semantic use of tone" is evident in every individual word. In spoken Lokele, which has 19 consonants and seven vowels, only 133 distinctly different syllabic sounds—the product of 19 times seven—are possible. By means of tonal variation, however, words consisting of identical syllables can be distinguished from one another. In the examples that follow, a high-toned syllable will be indicated by capital letters and a low-toned syllable by small letters. Take the word for copper: *bosongo*. The same three syllables also mean "river current" and "pestle." The three syllables for "copper," however, are low-toned, whereas "river current" is *bosoNGO* and "pestle" is *boSONGO*. Similarly, *longo* is "irritation," *LOngo* is "hill" and *loNGO* is "skull." Curiously there is no such word in Lokele as *LONGO*, the fourth possible tonal variation.

Since each syllable in such a language can be spoken in either a high or a low tone, there are four ways to accent a two-syllable word, eight ways to accent a three-syllable word, and so on. The unwary outlander can easily encounter difficulties. For example, *liAla* means "fiancée" and *liala* means "rubbish dump." He who says *aSOoLAMBA bolli* instead of *aSOolaMBA boili* has stated that he is boiling his mother-in-law rather than watching the riverbank.

Bearing in mind the presence in the spoken language of two distinct tones, one high-pitched and the other low, let us now consider talking drums and talking gongs. A drum is a membranophone; the membrane of skin, which vibrates when it is struck, is stretched over a resonator made of wood, pottery or some other material. The instrument used to send messages in the Upper Congo is made solely of



DRUMS OF THE CONGO, which are actually gongs made from a particular tree, vary widely in shape. The Lokele favor a simple cylinder (*b*). The slots of Bankundo gongs (*a*) and Baluba gongs (*c*) are more complex. Azande gongs (*d*) take the form of animal effigies and Batetela gongs are triangular in cross section (*e*). The other three gongs (*f–h*) exhibit variations on these basic shapes.



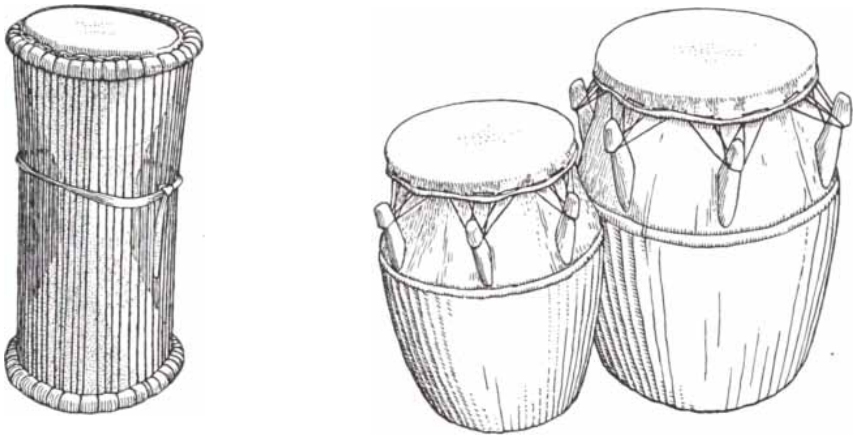
TRUE DRUMS, in contrast to the wood gongs of the Congo area, are used in West Africa. Two kinds of Ashanti drums (*I and J on map*) are shown in the illustration at bottom of page. The Congo gongs that are located on the map (*A–E*) are shown on preceding page.

wood, and the entire instrument vibrates when it is struck. It is thus an idiophone, like metal gongs and the wood and metal bars of the xylophone and the glockenspiel. The wooden gongs of the Congo are nearly always made of the red heartwood of a forest tree that also yields a powdery substance that is smeared on the body on ceremonial occasions.

The gong-maker gouges a slot in a round log of this red wood and then hollows out the log, making sure to remove more wood from under one "cheek" of the slot than the other. As a result when one lip of the slot is struck with a rubber-covered stick, the gong emits a low-pitched note, and when the other lip is struck, it produces a higher note. The Africans who use talking gongs generally speak of the lower sound as the husband's voice and the higher one as the wife's. This refers, however, to penetration rather than to pitch alone. If a gong's high sound has more carrying power than the low one, it is the sound that carries farther that is considered male. The sound of a gong can carry a remarkably long way. If a large instrument is situated on a riverbank, it can be heard for five or six miles in the cool, quiet hours of evening and early morning. Smaller gongs will carry two or three miles.

The simplest form of talking gong is one used by the Lokele living near Kisangani (formerly Stanleyville), where it is known as a *boungu* or *bongungu*. It is simply a cylinder of red heartwood hollowed out through the long side slot. The Mongo of the central Congo use a quite similar gong (which they call a *lokole*), but the lips of its slot have small projections in the middle. The gong of the Katanga region (called a *mondo*) has even longer projections. The lip area under the *mondo* projections is so thick that the opening appears to consist of two square cavities connected by a narrow slit. The gongs used in the Mayombe area, nearer the Atlantic coast, are similar; their exterior, however, is not circular in cross section but almost triangular. To the north the Azande and related peoples produce elaborately carved gongs that they shape in the form of an animal such as an antelope, complete with head, tail and four legs; the slot follows the line of the animal's backbone.

How can the gongs talk? The reader has probably already surmised a connection between the high and low tones of Congolese languages and the two "tones of voice" of the gongs, and he may have recognized the hint contained in the Cameroons broadcasters' need to use six drummed syllables to express their one-syllable spoken word for "dog." The answer is that the gong's two tones are used not to transmit vowels and consonants but to mimic the tones of well-known stock phrases. Each phrase is understood by sender and receiver alike to represent one word or another of the spoken language, as the following examples show. In spoken Lokele the word for "banana" is *likondo*. The equivalent gong-language phrase is *likondo LIbo-TUmbela,* which means "bunch of bananas propped up." The spoken word for "manioc" is *lomata;* the gong phrase is *lomata oTIkala KOndo,* or "manioc left behind in the fallow ground." Similarly, the word for "up above" is *likolo* and the gong phrase is *likolo koNDAUSE,* or "up above in the sky." "Leopard" is *ngoi* but is beaten out as *ALONGA losambo,* or "he tears up the roof," "goat" is *MBUli* and is beaten out as *iMBUmbuli SHAo-*



ASHANTI SINGLE DRUM (*left*) is changed in pitch by pressure on the thongs connecting the two drumheads. Pair of drums (*right*), known as "husband and wife," differ in pitch.

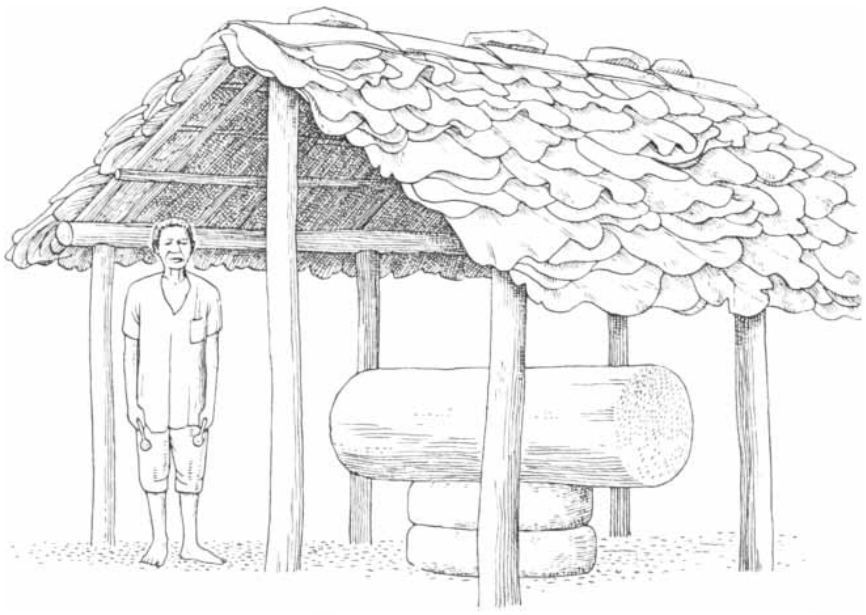
KENGE, or "little goat of the village," and "firewood," *toAla*, is beaten out as *tokolokolo TWAtoAla*, or "little bits of firewood."

Now, if the broadcaster simply sent the tones of the first three spoken words listed above—*likondo*, *lomata* and *likolo*—each would be represented by an identical three blows on the "husband's" lip of the gong and the sounds would be indistinguishable from one another. Since each word is represented instead by a lengthy accented phrase, the total melody of the phrase is sufficient to identify it. All that is necessary is that both sender and receiver share a stock of stereotyped phrases.

It is probably to facilitate the memorizing of a sizable vocabulary of such stereotypes that the phrases are often cast in joking or amiable forms. The gong form of "dog" in the Lokele language—"giant dog, little one that barks *kpei kpei*"—is an affectionate diminutive of the kind that in European languages turns Jack into Jackie and Jan into Janneke. So is the gong form of "goat" and "firewood" and, on analysis, the gong form of "manioc" ("what remains behind in the fallow ground are the little bits left after the main crop is harvested"). Dan Crawford, who worked as a missionary in the Congo, wrote affectionately of this aspect of the *mondo* gong of his area: "Not a dull... rub-a-dub but a drum with a tongue wagging out even gossip; a drum that, provided you do not crack it, can actually crack a joke. Again and again... you can hear... a burst of laughter. [The listeners] are laughing at the pleasant wit of Mr. *Mondo* five miles off."

The phrases also tell us a good deal about the culture of the people who invented them. Manioc will keep in the garden for a long time until one has a need for it. As bunches of bananas grow heavy they need to be propped up with forked sticks so that they do not pull over the plant's weak stem and rot on contact with the soil. Leopards are dangerous even when the goat shed has strong doors; they can tear away the roof thatch in order to reach their prey.

The Lokele broadcaster has been doing for centuries something that Western communications theorists learned to be necessary only a few decades ago. He utilizes the principle of redundancy. In 1928 Ralph V. L. Hartley of the Bell Telephone Laboratories, who was investigating the intelligibility of telephone communications, expressed the required relationship between the quantity of information in a message (H) and the number of signs (N) employed out of the total number available (S) in the equation $H = N \log_2 S$. If we use Hartley's equation to estimate how many Lokele syllables need to be broadcast when the total number of available syllables in the language is 266 (133 vowel-consonant combinations spoken in a high tone and 133 in a low tone), it appears that about eight gong-phrase syllables are needed for every syllable in a spoken word. If the reader examines the phrases I have cited, he will see that Lokele broadcasters have not usually gone that far, although an occasional phrase may exceed the Hartley ratio. The Lokele nonetheless achieve the required redundancy quite simply by repeating each phrase. It is because of this repetition that it takes several minutes to broadcast even fairly brief spoken messages.



GONG SHED in Yakuso village, some 15 miles west of Kisangani in the Republic of the Congo, is thatched with banana leaves. The gong is supported on two worn-out truck tires.

The need to construct a gong phrase that is much longer than the spoken word is reflected in the gong names given to both individuals and villages. For example, the village of Yakusu, 15 miles west of Kisangani, has the gong name *afaKA kolaaLEmbu*, a phrase that is probably derived from the names of two ancestral villagers. The villagers of Yaalufi, near the Yangambi Agricultural Station, claim by their gong name to be "The elders of Yaokanja" (the geographical name of the central Lokele area); the villagers of Yatuka, 50 miles upstream from Yaalufi, proudly use the gong name "Masters of the river."

Sometimes the gong names commemorate historical events. For example, the villagers of Yatuka showed that they were indeed masters of the river on one occasion when a nearby village on the same bank of the river challenged them to a fight. At the time the gong name of the other village was "They had medicine to overcome curses." After Yatuka had won the battle, it forced the other village to move to the opposite bank of the river, where the gong name was changed to "The evil spirit has no friend nor kin."

When personal names are transmitted, the extended version may reflect the spoken name directly, may identify the individual by parental references or may be purely imaginative. A medical assistant I knew in Kisangani was an orphan, and his spoken name was Lotika, which is the word for orphan in the Lokele tongue. His gong name explained in picturesque language just what an orphan is: "The child has no father nor mother, he begs for his food in the communal hut." Another young man from the same village had a purely imaginative gong name: "Don't laugh at a black skin, because everybody has one."

Marriage is patrilocal among the peoples of the Upper Congo. All the children in a polygamous household have the same paternal name, but their mothers seldom come from the same village. Thus when a gong name is extended by the addition of paternal and maternal references, it is usually the father's given name and the name of the mother's village that are appended. Another Kisangani medical assistant of my acquaintance, John Litumanya, enjoyed one of these imposing three-part gong

names. "Evil spirit with the spear" was his own gong name. "Son of the spitting cobra" was his father's gong name and "of the village of Middle Yafolo" specified his mother's original residence. Litumanya had inherited his own gong name from his grandfather.

Even the gongs themselves can have personal names; the broadcaster will beat out the name of the gong at the beginning or the end of his message. Today Congo villages are declining as the young people move to the larger population centers. One consequence of this is that many of the names given to the gongs have a bitter flavor. The Yamengwendua clan of Yangomu village has named its gong "Birds do not steal from a person without food." The two large gongs of the Bakama of Bandio are named "We eat the last bits of food" and "Ears of mine, do not listen to what people say" (an admonition to be stoical when other clans mock their reduced numbers).

Some villagers are less embittered. The name of the gong of the Yabita clan of Yalemba is "An empty gourd cannot be kept beneath the surface of the river," and the gong of the Yamongbanga of Bokondo proclaims the clan's self-identification with a tree that is noted for its thorny bark: "The bolongo tree is not beaten with the hand for fear of its thorns." The Bogula clan of the same village calls its gong "The male elephant waves his trunk about."

The two-toned phrases of a gong language can be broadcast by instruments other than gongs. For example, hunters carry small horns, usually made from antelope horn but sometimes made from ivory. The horns have a hole at the small end and a second hole, through which the hunter blows, in the side. By covering and uncovering the end hole the blower produces the necessary high and low tones. The range of these horns is a mile or more.

Even the human voice is used to transmit two-toned phrases over distances of a mile or so, particularly along a river in the cool of the evening when the sound of a voice carries a long way. Homeward-bound Lokele fishermen will signal their success with shouts long before they reach the village. Rather than giving high-pitched and low-pitched shouts, they substitute the syllables *ki* or *li* for the gong-language high tone and *ke* or *le* for the low tone. The fishermen of Yalemba use the same method, but their substitutes for the high-pitched syllables are *ko* and *go* and for the low-pitched ones *ku* and *gu*.

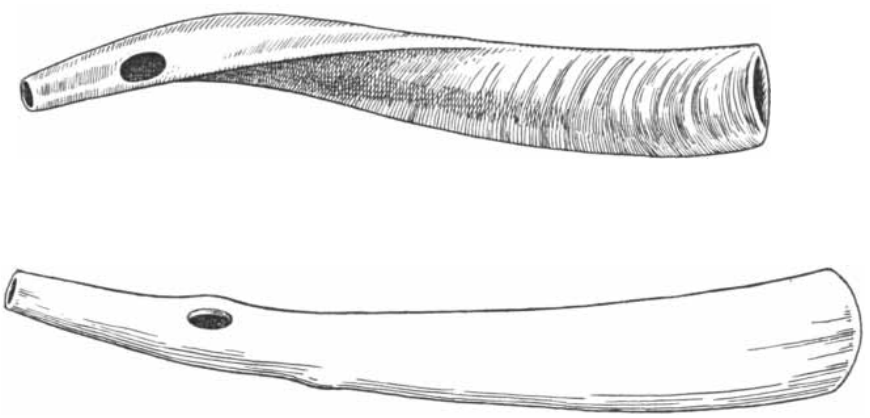
Although it is more proper to speak of gong languages rather than drum languages in the Upper Congo region, skin-covered resonators are often used to broadcast messages in other parts of Africa. The Ashanti, for example, use two drums for this purpose: a small one to produce the high-pitched tones and a larger one for the low-pitched tones. They call the pair "husband and wife." Drummers often accompany important Ashanti chiefs on festive occasions, beating out praise names on single small drums held under the arm. The drummer is able to produce two notes on the one drum because the resonator is shaped like an hourglass. By increasing or diminishing the pressure of his arm on the taut cords that run between the two drumheads he can tighten or loosen the membrane and alter the drum's tone.

Stories of the long distances that drum messages travel can be explained by the willingness of successive broadcasters to relay significant news. As Henry Morton Stanley relates in his diaries, his passage down the Congo was heralded by Lokele drummers. It is certain that important messages travel from village to distant village in this manner even today. When a message reaches a linguistic border, however, it cannot travel farther without translation. This is not as serious a handicap as might be supposed. Most border-village families have female members who have come from neighboring tribes, so that the children grow up speaking both their father's and their mother's language. The result is that bilingual broadcasters are usually available.

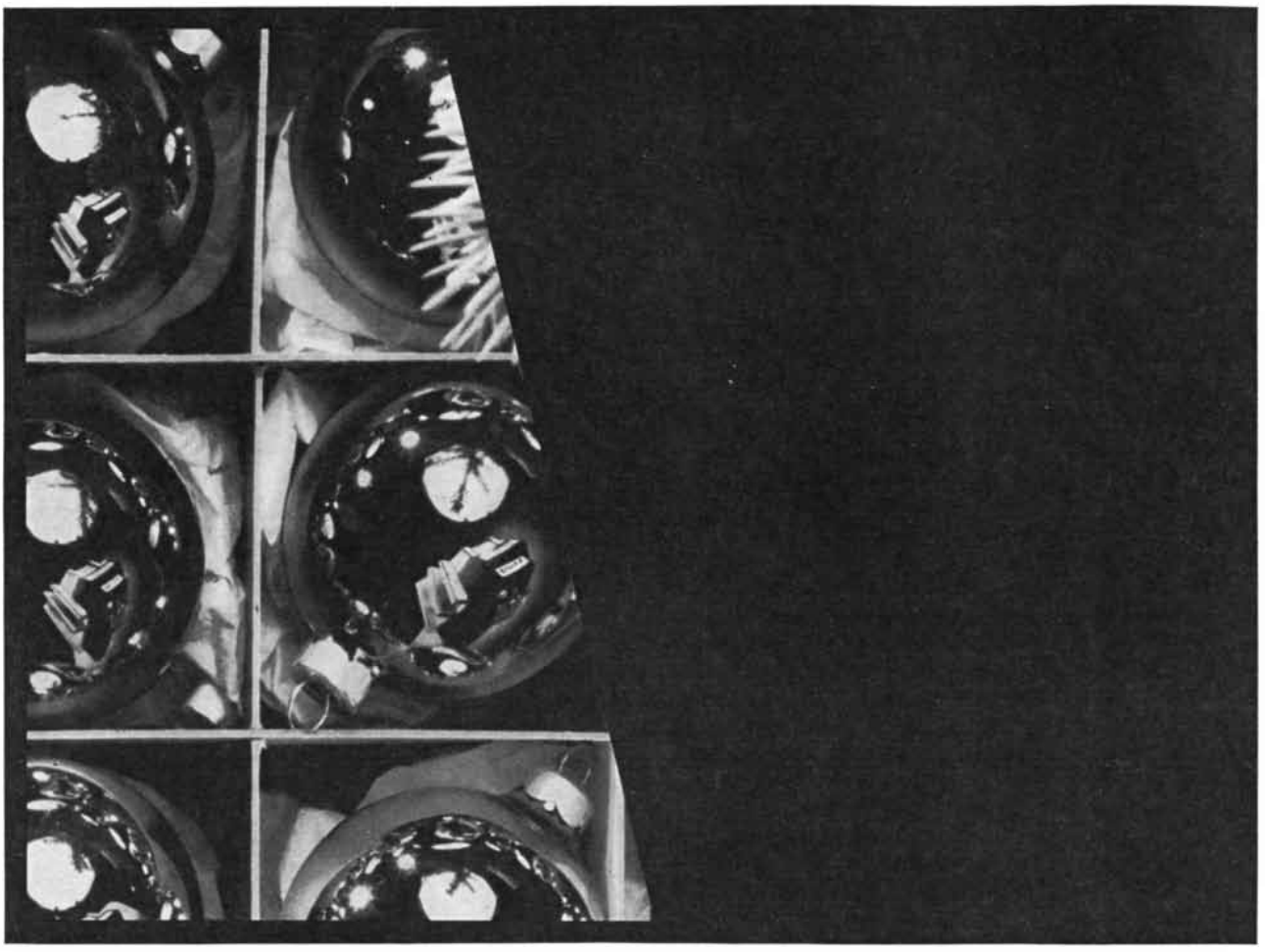
In addition to skin drums, horns and the unaided voice, whistles are sometimes used to transmit gong language. Small children sometimes fashion whistles and proceed to broadcast praise names outside the house of some important villager, expecting a reward for doing so. Whistling by mouth serves to pass messages secretly within a group on the appearance of a stranger. Many travelers in Africa have commented on arriving in an apparently deserted village and hearing whistling from the empty houses or the nearby forest. The stranger is being carefully described to the community at large by people who watch his progress through the settlement.

In earlier years there were no secrets about gong language; it was public for everyone to hear. Indeed, it was such an integral part of tribal culture that when I sought information on the subject from Lokele broadcasters, they simply assumed that we Europeans had similar instruments at home. The only time I ever encountered difficulty with an informant was when I asked a Lokele fisherman what his gong name was. He replied that he would tell me his if I would tell him my own. When I said I did not have a gong name, he responded that I was a liar. Convinced that I was withholding the information, he never did give me his name.

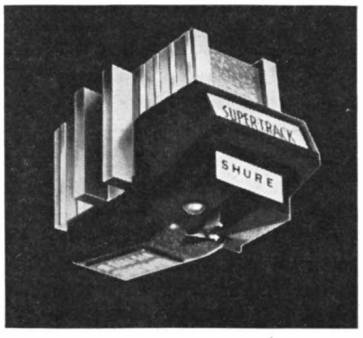
Today, as a result of population shifts, fewer and fewer young Africans are familiar with gong language. In a typical village of the Upper Congo the gongs talk every morning and evening, but in the city of Kisangani few exist and they are seldom heard. One of the rare broadcasters in Kisangani, whose small gong is audible at times throughout most of the city, has told me with regret that he can no longer recall all the gong-language phrases his father knew and transmitted. I suspect it is high time that interested linguists and ethnologists began to record these unique languages before they disappear forever.



WIND INSTRUMENTS, usually fashioned from the horn of an antelope (*top*) but sometimes made of ivory (*bottom*), can produce a high-pitched and a low-pitched note and thus can be used to broadcast gong language. Used by hunters, they have a range of about a mile.



A cartridge in a pear tree.



A gift of the *Shure V-15 Type II* Improved stereo phono cartridge will earn you the eternal endearment of the discriminating audiophile who receives it. What makes the V-15 such a predictable Yuletime success, of course, is its ability to extract the real sound of pipers piping, drummers drumming, rings ringing, et cetera, et cetera. Stereo Review, in a test report that expressed more superlatives than a Christmas dinner, described the performance of the V-15 Type II Improved as ". . . . Unstrained, effortless, and a delight to listen to." All of which means that if you're the giver, you can make a hi-fi enthusiast deliriously happy. (If you'd like to receive it yourself, keep your fingers crossed!)

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MATHEMATICAL GAMES

Further encounters with touching cubes, and the paradoxes of Zeno as "supertasks"

by Martin Gardner

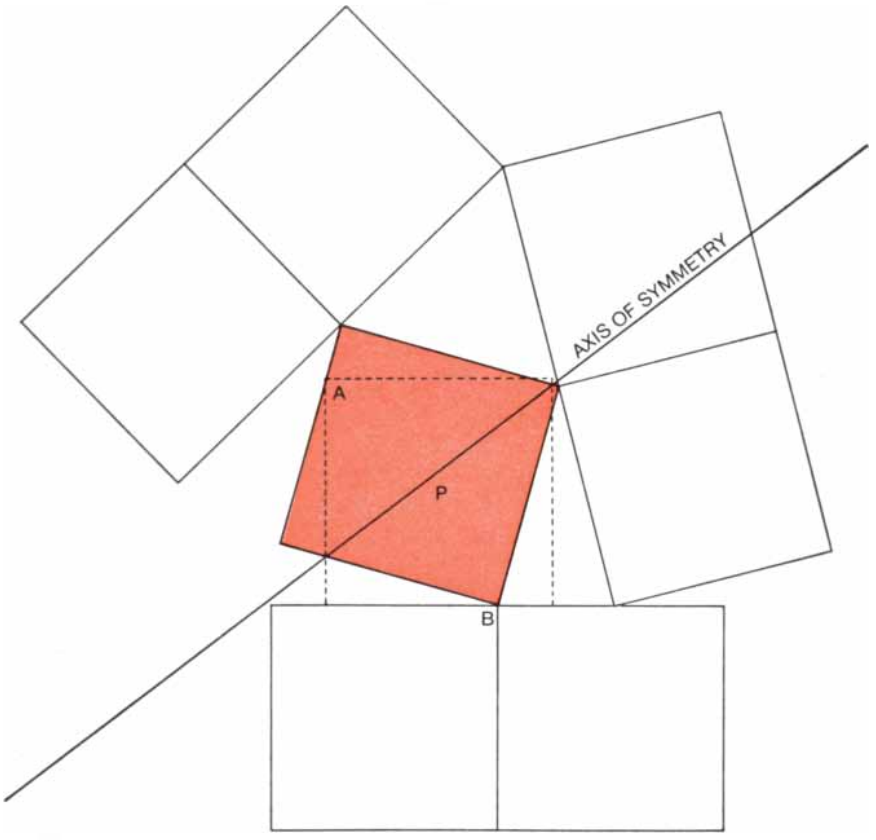
It is not often that a new problem arises in elementary geometry, particularly one that is easy to state but has a difficult and startling solution. It is equally rare to encounter a new paradox about limits, closely related to Zeno's famous paradoxes of motion, that has not been exhaustively analyzed by mathematicians and philosophers. This month we present an elegant example in each category.

It is hard to believe, but as far as I know no one has seriously considered before the simple question of how many unit cubes can share a positive surface area with a given unit cube. I asked this seemingly innocent question in a collection of short problems in July and in August gave the best answer I had been able to find: 20 cubes. It is likely that this is indeed the best answer if one adds the condition that the surface of the given unit cube (we shall distinguish it from the others by giving it a color and leaving the other cubes white) be completely covered by the touching cubes. This proviso, however, was not part of the original problem. Last month I explained two methods discovered by readers of this column for placing 22 white cubes so that each abuts the colored cube. Now I disclose a truly astonishing solution, found by Robert S. Holmes, a high-speed particle physicist, that raises the number of white cubes to 24.

His technique begins with placing seven white cubes on one colored face [*see illustration below*]. Three pairs of cubes (think of each pair as being glued together) are placed around a face of the colored cube so that the midpoint of each pair touches a corner of the colored face. A seventh white cube (*P*, drawn with broken lines) overlaps the colored face as indicated, the two faces having an axis of symmetry shown as a diagonal line. By rotating the white cubes clockwise, keeping corner *A* on the left edge of the fixed colored face and preserving the bilateral symmetry, the pattern shown in the top illustration on the opposite page is reached. If the broken-line cube *P* is now moved up a trifle, the two meeting corners of each pair of glued cubes can have a tiny positive-area overlap with a corner of the colored face. These three overlaps can be made arbitrarily small without allowing the white cubes *P* and *Q* to project to the left beyond the vertical line *CD*. As a result angle *e* and distance *d* can also be made arbitrarily small.

This pattern of seven cubes goes on the front and rear faces of the colored cube. Then one cube goes exactly on top of the colored cube, another goes flush against the colored cube's base and two more cubes abut the right face of the colored cube. Although 18 cubes now abut five faces of the colored one, its sixth face (on the left) remains completely exposed. The bottom illustration on the opposite page shows the colored cube with the exposed face toward you. On both its left and right sides are seven cubes; they are not shown in the drawing. (Also not shown are the single cubes above and below and the two cubes that abut the colored cube's back face.) Cube *K* is placed so that it overlaps the top of the colored face along a thin horizontal strip of height *d* that can be arbitrarily small. This allows five more cubes to abut the face, below cube *K*, as shown, bringing the total number of touching cubes to 24 ($7 + 7 + 1 + 1 + 2 + 1 + 5$). A full proof of this construction would be long and tedious, but interested readers should have no difficulty convincing themselves that it can be done in spite of the extremely minute overlaps that are involved. The 24-cube solution is probably the maximum, although proving it appears to be formidable. Until that is done there will remain the gnawing suspicion that one or more additional white cubes can somehow be squeezed in.

The second problem—an amusing new variant on Zeno's paradoxes—was contributed by A. K. Austin of the University of Sheffield to *Mathematics Magazine* for January, 1971. This is how I re-



Beginning arrangement for Holmes's 24-cube solution

phrased it when I gave it as the final problem in the July collection:

"A boy, a girl and a dog are at the same spot on a straight road. The boy and the girl walk forward—the boy at four miles per hour, the girl at three miles per hour. As they proceed the dog trots back and forth between them at 10 miles per hour. Assume that each reversal of its direction is instantaneous. An hour later, where is the dog and which way is it facing?"

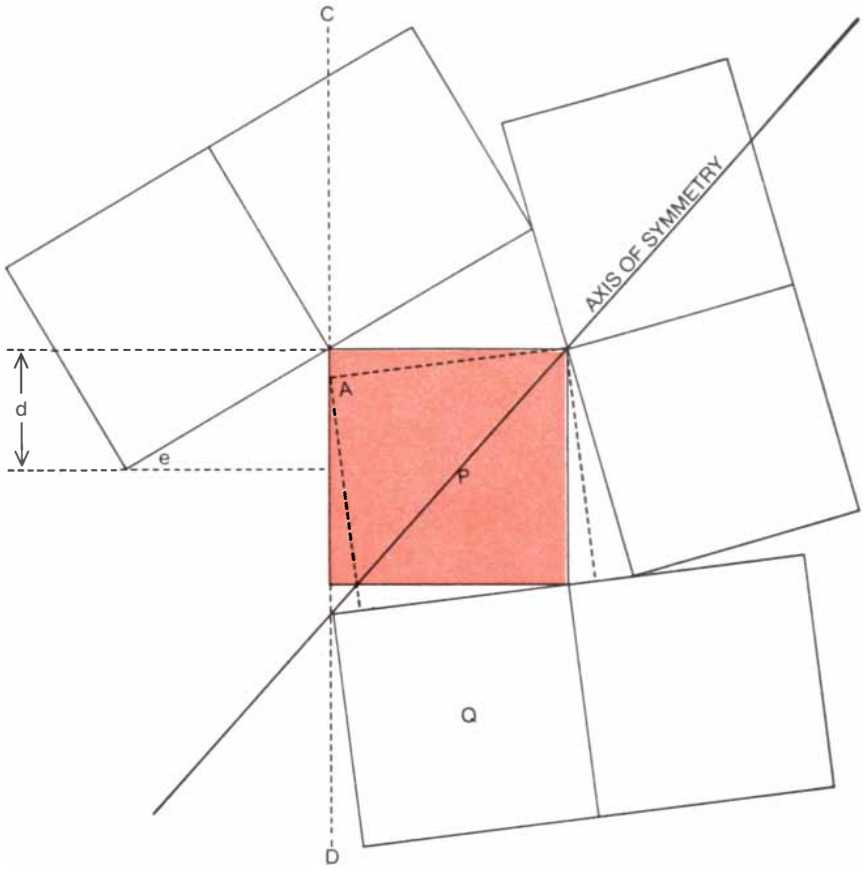
Answer: "The dog can be at any point between the boy and the girl, facing either way. Proof: At the end of one hour, place the dog anywhere between the boy and the girl, facing in either direction. Time-reverse all motions and the three will return at the same instant to the starting point."

Even before this answer appeared I began receiving letters from readers protesting that the problem is meaningless because its initial conditions are logically contradictory. No matter how small we make the starting interval, many wrote, the dog will have to make an infinity of reversals that would drive it crazy. Others contended that the three "points" (as in all such problems the boy, the girl and the dog symbolize ideal points) could never get started because the "instant" they did so the dog would either leap ahead of both boy and girl or run the opposite way, thereby ceasing to be between the boy and the girl.

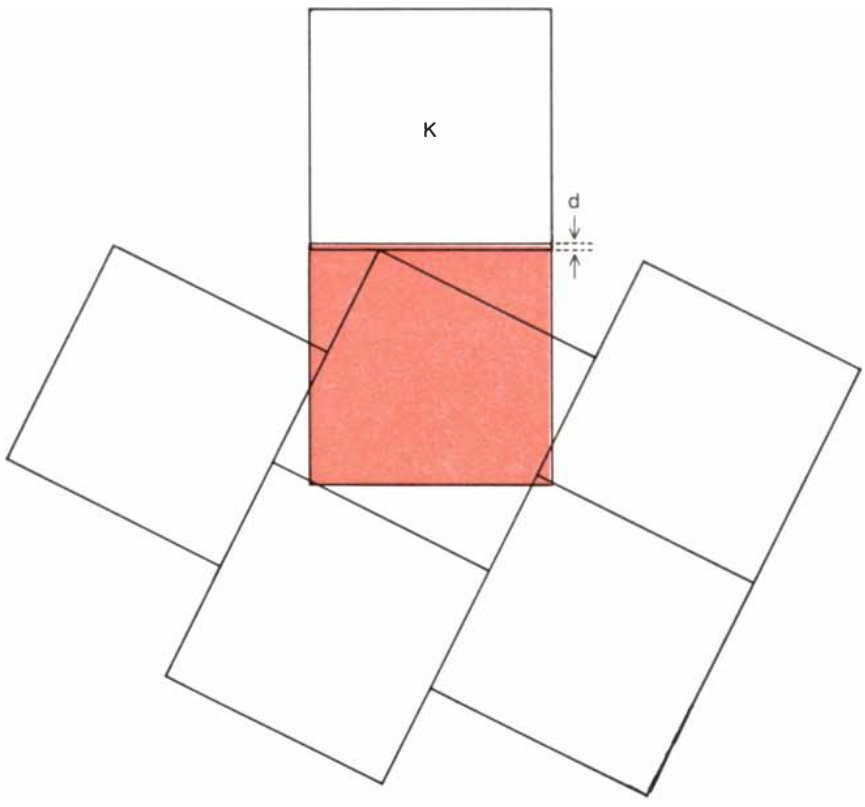
As Wesley C. Salmon of Indiana University immediately recognized, Austin's paradox has innumerable other forms, one of the simplest of which is a time reversal of the familiar puzzle about two locomotives and a bird. The locomotives, starting at *A* and *B*, 30 miles apart, move toward each other on the same track at, say, 15 miles per hour until they collide at *C*. A bird, starting at *A*, flies back and forth at 60 miles per hour between the locomotives until they collide. How long is the bird's path? There is no need to sum an infinite series. Since the bird flies for one hour, the path must be 60 miles. If we time-reverse the event, specifying that the bird end at *A*, a unique zigzag path is defined that the bird can travel in either direction.

Suppose, however, we do not state where the bird must be after the locomotives have moved backward to points *A* and *B*. Without this information a unique path for the bird cannot be defined. Because the bird can now take an infinity of possible paths, the most we can say is that the backward-flying bird must end somewhere between *A* and *B*.

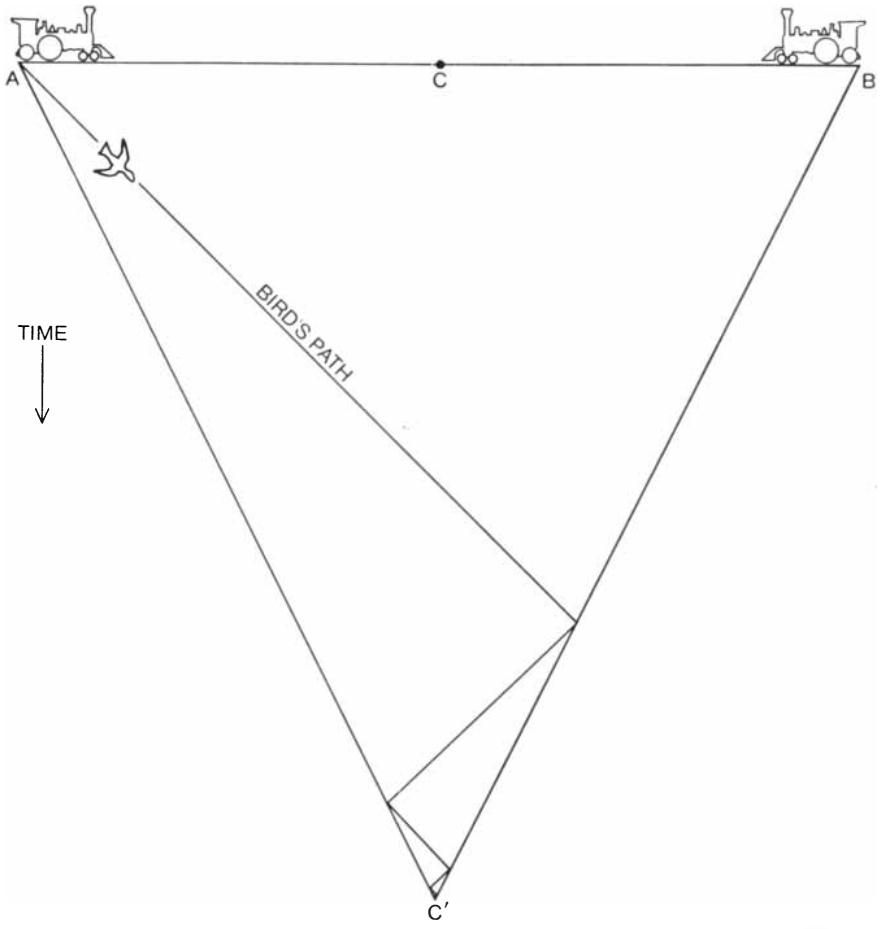
But is it really permissible to say this? No, many mathematicians contend, be-



Step 2 in the 24-cube arrangement



Final step in 24-cube solution covers remaining exposed face



Space-time graph of bird's path between moving locomotives

cause a singularity arises in the time-reversed version that creates contradictory initial conditions. "There is no general justification in analysis," one mathematician put it, "for inverting the limit operator." When the locomotives move toward each other, it is only the bird's position that converges. "The velocity vector diverges, so that there is the same difficulty [as in Austin's problem] in finding a unique inverse to the limit process. The accepted rules of differential calculus have evolved because if followed properly they avoid contradictions."

It is helpful to plot a space-time graph of the bird's path from A to C' [*see illustration above*]. Of course, we cannot finish drawing the bird's path to C' because the zigzags are infinite, but we certainly can assume that the ideal line exists. Surely if this line can go down from A to C', there is no logical objection to saying that it can go up from C' to A. If the final destination of the bird is not specified, an uncountable infinity of such graphs can start at C' and end anywhere on the track between A and B. It is true that calculus cannot solve Austin's similar problem if "solve" means to pinpoint the dog's final position, but Austin's "solution" is precisely one that shows this to be impossible. Since the dog is not told how to start, it can start in any way it pleases provided that it always stays between the boy and the girl. Consequently its path can end anywhere between boy and girl.

Salmon has commented on Austin's problem as follows:

"Almost everyone has heard the old chestnut about the bird that flies back and forth between two approaching locomotives . . . [as given above]. Or, to achieve historical perspective, suppose Achilles is pursuing the tortoise and a Trojan fly buzzes back and forth between them. Given a set of velocities and distances, and our latter-day assurance that Achilles will overtake the tortoise at a determinate time and place (see my book *Zeno's Paradoxes*, Bobbs-Merrill, 1970), we can easily figure out how far the fly will travel. Up to this point we have no new Zenonian paradoxes. . . . We see that Austin's problem is just the time-reversal of the bird-and-train problem.

"In order to retain historical perspective, let us go back to Achilles and the tortoise. In spite of the initial handicap traditionally imposed on Achilles, he catches the tortoise, and to redress the grievance he has long held against Zeno he keeps on running, steadily increasing his lead over the fortunate tortoise. [I consider the tortoise fortunate in this version of the tale, at least in comparison with Lewis Carroll's account "What the Tortoise Said to Achilles," in which Achilles stops and seats himself on the back of the tortoise, much to the tortoise's discomfort.] Now consider the Trojan fly, which attempts to continue flying back and forth between the two runners even after the faster overtakes the slower. When Achilles and the tortoise are just even, the fly finds itself precisely in the position of Austin's dog.

"For the sake of definiteness, say that the tortoise travels at one mile per hour, Achilles at five miles per hour (he has been running since 500 B.C., so that he is not as fleet as he once was) and the fly at 10 miles per hour. They all arrive at the common meeting point without difficulty. How can they go on? If the three start simultaneously from the common point, the fly immediately either advances ahead of both or moves behind both, each of which violates the condition that the fly be always in the interval between the two (end points included). It would seem we could argue that in any time interval $\epsilon > 0$, however small, the tortoise travels a distance of 1ϵ, Achilles runs a distance of 5ϵ and the fly goes 10ϵ. Hence in an arbitrarily small time after the meeting the fly leaves the interval between the tortoise and Achilles. Even if we have shown how Achilles can perform the 'supertask' of catching the tortoise, and how the tortoise can perform the 'supertask' of initiating its motion, it appears that the fly now faces the new 'supertask' of continuing to fly back and forth between Achilles and the tortoise after the tortoise has been overtaken. In other words, the fly now faces the supertask of *not* passing Achilles!

"The apparent difficulty seems to me analogous to the problem pointed out by Zeno in his regressive dichotomy paradox. There is no doubt that the fly will outdistance both Achilles and the tortoise *if it flies steadily in one direction without turning around*, even in the arbitrarily small period of duration ϵ. This fact does not render the fly's motion impossible, however, since no matter how small a time interval we choose the fly has already reversed its direction during that interval (infinitely many times, so that it is really quite dizzy). This simply means that there is no *initial* nonzero interval during which it flies straight without reversing its direction; thus it does

not follow that the fly immediately leaves the interval between the tortoise and Achilles. In fact, we can see precisely how the fly's rapid reversals enable it to stay between Achilles and the tortoise after the meeting by examining the time reversal of this motion in the fly's approach to the point of meeting from the earlier side. The fact that the fly does not traverse an *initial* nonzero straight path is analogous to the fact that the tortoise, in leaving its starting point, does not traverse any initial nonzero segment of its path. The lack of a suitable initial segment is not a serious obstacle to either of them.

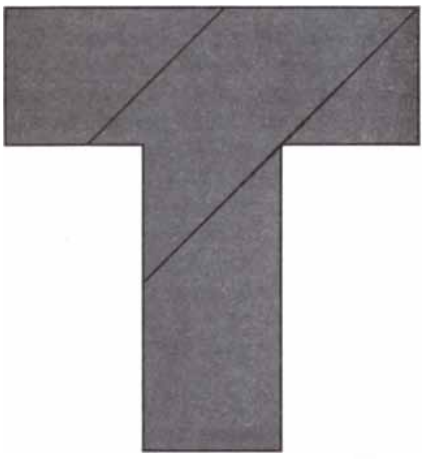
"The recent literature on Zeno's paradoxes has contained a good deal of discussion of 'infinity machines.' These are idealized devices that purportedly perform an infinite sequence of tasks; they have been introduced into the discussion because of difficulties they seem to encounter in completing the infinite sequence of tasks (a 'supertask'). The resolution of the problems surrounding the infinity machines is strongly analogous to the resolution of the progressive form of Zeno's dichotomy paradox. The motion of the Trojan fly up to and including the moment Achilles overtakes the tortoise involves exactly the same considerations. I am not aware that anyone has explicitly introduced the kind of infinity machine that would be analogous to the regressive form of Zeno's dichotomy paradox, a machine whose difficulty lies in getting started with its series of tasks, in contrast with the usual infinity machine whose difficulty lies in finishing its series of tasks. As it turns out, our Trojan fly, in its motion from the point of meeting of Achilles and the tortoise through the subsequent part of the run in which Achilles is ahead of the tortoise, constitutes just such an infinity machine (as does Austin's dog)—a regressive infinity machine, we might say. Just as the treatment of the standard infinity machine closely parallels the resolution of the progressive dichotomy paradox, so does the treatment of the Trojan fly in the latter part of its flight closely parallel the resolution of the regressive dichotomy paradox.

"One further problem about the motion of the fly deserves explicit attention, namely what is the state of motion of the fly at the precise instant of meeting? The fly's position is well determined; it coincides with the position of Achilles and the tortoise. The mathematical function that describes the fly's position is a continuous function of time that passes through the meeting point at the appropriate instant. The fly's velocity function, on the other hand, is discontinuous. Its value is +10 when the fly is moving forward, −10 when it is moving backward and (we might as well say) zero when the fly meets either Achilles or the tortoise (or both). Thus we can appropriately assign the value zero to the fly's velocity at the instant when all three meet. Obviously the velocity function has infinitely many discontinuities on each side in the neighborhood of the point of common meeting. Each *finite* discontinuity in the velocity function corresponds to an *infinite* discontinuity in the acceleration, since it requires an infinite acceleration for the fly to change velocity instantaneously from +10 to −10 and vice versa. Moreover, as Austin's problem and its solution show, the state of motion of the fly (or dog) at the point of meeting does not uniquely determine how the motion is to continue beyond that point. In other words, although we have shown how (in some sense of 'possible') it is possible for the fly to continue its motion through the meeting point and beyond, the motion beyond the meeting point can be executed in infinitely many distinct ways, all of which are consistent with the conditions imposed by the problem. To say that there are alternative ways of performing a task does not, however, prove that the task is impossible to execute.

"In the customary formulations Zeno's Achilles and dichotomy paradoxes involve a finite number of discontinuities of the type just mentioned: Achilles and the tortoise are assumed to accelerate instantaneously at their starting points to their respective average velocities, and to decelerate instantaneously to zero at the finish. Similarly, most of the 'infinity machines' (for example Black's transferring machines and the Thomson lamp) involve infinitely many such discontinuities clustering around some moment of termination (see *Zeno's Paradoxes,* pages 204–244). Using a mathematical function supplied by Richard Friedberg, Adolf Grünbaum has shown how such motions can be modified so as to eliminate all the discontinuities and still achieve the desired total outcome. It seems reasonable to conjecture that a similar approach could be applied to the problem of the Trojan fly (or Austin's boy-girl-dog) in order to achieve a totally unobjectionable description of the motion."

Obviously I have not done justice to those who have written contending, in opposition to Salmon, that Austin's problem is logically contradictory and therefore meaningless. Letters taking this line have been brief and do not deal with the basic issues Salmon raises. (Short statements by four mathematicians who consider Austin's problem to be self-contradictory appeared in *Mathematics Magazine,* Vol. 44, September, 1971, pages 238–239.) Although it is not possible to reply to all the dissenting letters that may now descend on me, I welcome opinions pro and con and shall return to the debate in a later column.

The solutions to three of the dissection puzzles given last month are shown in the illustrations below.



Solution to the* T*-puzzle

Solution to the square puzzle

Solution to Sam Loyd's Pony Puzzle

THE AMATEUR SCIENTIST

An osmotic pump, an unusual timer and how to enhance contrast in astronomical photographs

Conducted by C. L. Stong

The description of a perpetual saltwater fountain in this department last June by Seelye Martin of the University of Washington set Octave Levenspiel of Oregon State University thinking about the possibilities of exploiting the principle of osmosis. He proposes to use it to draw fresh water from the ocean. Levenspiel writes:

"The idea of bringing salt water to the surface from ocean depths by employing the chimney effect of a vertical pipe is interesting. What if it were possible to bring up fresh water from the depths of the sea—perpetual fountains of it to drink, wash in and make deserts bloom? Such an achievement would make the dreams of the alchemists look pale.

"The apparatus with which I propose to desalinate the seas resembles the perpetual saltwater fountain that has been successfully demonstrated but differs from it in one essential respect. Whereas the saltwater fountain is based solely on the chimney effect, my device includes the principle of osmosis.

"To demonstrate osmosis, close the end of a glass tube with a semipermeable diaphragm such as a sheet of cellophane or parchment. The tube can be about a foot long and of any convenient diameter. Partly fill the tube with salt water of any concentration. Insert the tube vertically in a container of fresh water until the level of the brine is even with the surface of the surrounding fresh water. By osmosis fresh water will spontaneously diffuse through the membrane, thus creating an upward-flowing column of increasingly dilute brine that will eventually spill over the top of the tube.

"The spontaneous flow of fresh water through the diaphragm can be stopped by exerting sufficient pressure on the brine. The effect necessitates redesigning the experimental apparatus slightly. A length of pipe is divided at the middle by a semipermeable diaphragm. Fresh water is on one side of the diaphragm and salt water on the other side [*see illustration below*]. If the pressures are equal on both sides, fresh water will diffuse through the diaphragm and dilute the brine, as demonstrated in the first experiment.

"To stop the flow one must impose a pressure of roughly 22 atmospheres (about 320 pounds per square inch) on the salt side if the salt side consists of seawater. That pressure would be equivalent to what is exerted by a column of water about 700 feet high. To reverse the flow and produce fresh water from salt water one must apply a pressure in excess of 22 atmospheres on the salt side.

"Keeping these pressure effects in mind, consider the merits of my proposed freshwater fountain. We close the bottom of a long pipe with a semipermeable membrane, fill the pipe with fresh water and lower it into the ocean. Since the density of seawater is about 3 percent greater than that of fresh water, the pressure on the outside of the pipe will be higher than it is on the inside. The difference in pressure increases with the depth to which the pipe is lowered. A depth can be reached where the pressure difference becomes 22 atmospheres. If the pipe is then lowered a bit more, the pressure on the outside will exceed the pressure on the inside by more than 22 atmospheres, a condition suggesting that fresh water will perpetually diffuse into the pipe at the bottom and flow out at the top. We might even consider the idea of letting the output of the fountain flow through a waterwheel for generating electric power as a by-product!

"Spoilsports may contend that we must push the pipe pretty far down (about five miles), that no real membrane has been developed to date that will stand these pressures and that the temperature, density and salinity of the oceans change with depth. Complications of this kind do not alter the main argument, which relies on gravitational work to separate water from salt, rather than on heat, phase change or other traditional desalination techniques." I leave Levenspiel's proposal with readers of this department for appraisal. I shall have more to say about it in a subsequent issue.

Influence of pressure on osmosis

Rodney A. Wolf of Highland Park, Ill., uses the acceleration of gravity as the basis of a clock that approaches the ultimate in simplification. He merely drops a weight and interprets the distance of its fall as a measure of time. Wolf built the clock for determining the energy of projectiles that are launched by a slingshot, but it can be applied in experiments of many kinds. He describes his project as follows:

"One day while I was shooting stones straight up into the air with a slingshot and trying to make them land nearby I realized that I could quite easily measure the energy of the projectiles. In theory a projectile spends equal time going up and coming down, and it strikes the ground at the same velocity with which it left the slingshot. The time a

projectile spends in flight can be measured with a stopwatch.

"The projectile is in free fall during half of the interval. The maximum height from which the projectile falls is equal to half the product of the acceleration of gravity multiplied by the square of the time. The potential energy of the projectile at the highest point in its trajectory is equal to the product of the mass of the projectile multiplied by its maximum height and by the acceleration of gravity.

"By means of these formulas, a stopwatch and a laboratory balance I determined the potential energy of a number of projectiles. The precision of the method was good. All my measurements were consistent. I learned later, however, that my results were in error by as much as 50 percent. I had not taken the resistance of the air into account.

"To minimize the influence of air resistance I redesigned the experiment. Projectiles were shot at high velocity along a relatively short, horizontal trajectory. The time of flight was correspondingly reduced. The stratagem minimized the effects of air resistance but introduced the need for an accurate clock capable of measuring time in small fractions of a second.

"Usually one must pay a high price for an accurate timing device, but in this case I looked around for cheaper ways of timing accurately. Falling objects accelerate at the rate of 980 centimeters per second per second. With this fact in mind I made a clock by fastening a piece of ticker tape to a weight. When the weight is dropped from the edge of a table, it pulls the strip of paper across the top of the table. Intervals can be timed by dropping the weight at the beginning of an event and placing a mark on the moving tape at the end of the event. The duration of the interval can be calculated by knowing the distance the tape moved during the event, as indicated by the mark.

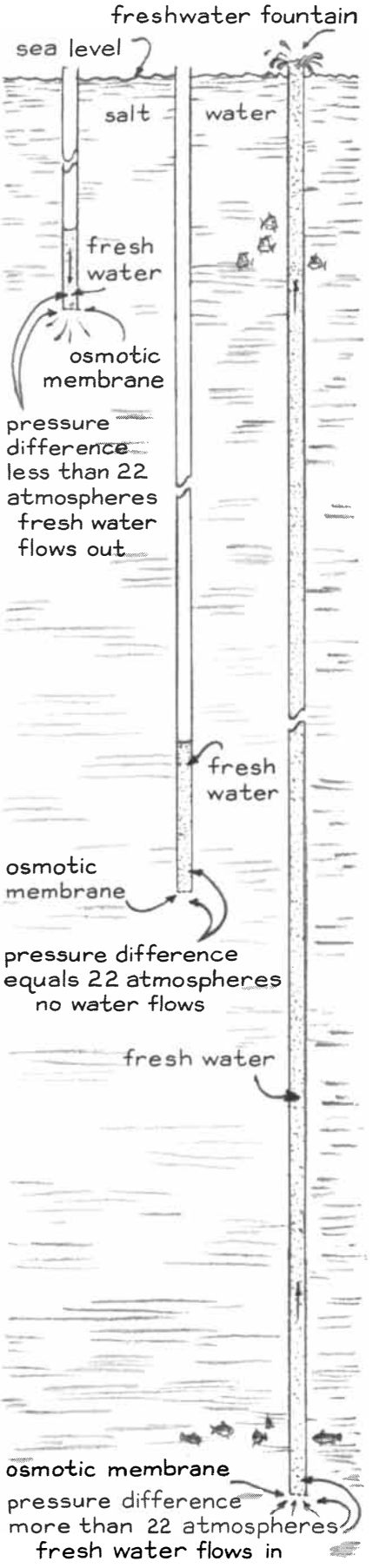
"Several accessory gadgets were improvised to drop the weight and mark the tape automatically [*see top illustration on next page*]. A slingshot of the rubber-band type was mounted to the end of the table, along with a meterstick. Shots of reasonably uniform velocity could be made by stretching the rubber to a predetermined length, as indicated by the meterstick. The weight that pulls the tape is normally supported near the end of the table by an electromagnet, which is energized by a storage battery. The circuit of the battery includes a switch that is opened by the slingshot. The paper tape slides under a marking stylus that is normally supported above the tape by a second electromagnet. The circuit of this electromagnet includes a switch that is opened when a projectile strikes the distant target, releasing the stylus, which prints a dot on the tape.

"The elapsed time in seconds is equal to the square root of the distance in centimeters, as measured from the beginning of the tape to the dot made by the stylus, divided by 490. The distance between the slingshot and the target is known: 20 feet in the case of my experiments. The velocity of the projectile, in feet per second, is equal to 20 divided by the time of flight in seconds. The kinetic energy imparted to the projectile by the slingshot is equal to half the product of the mass of the projectile multiplied by the velocity. The energy, in joules, is equal to $4.65(10^{-5})mv^2$, where m is the mass of the projectile in grams and v is the velocity of the projectile in feet per second. The constant $4.65(10^{-5})$ is a conversion factor.

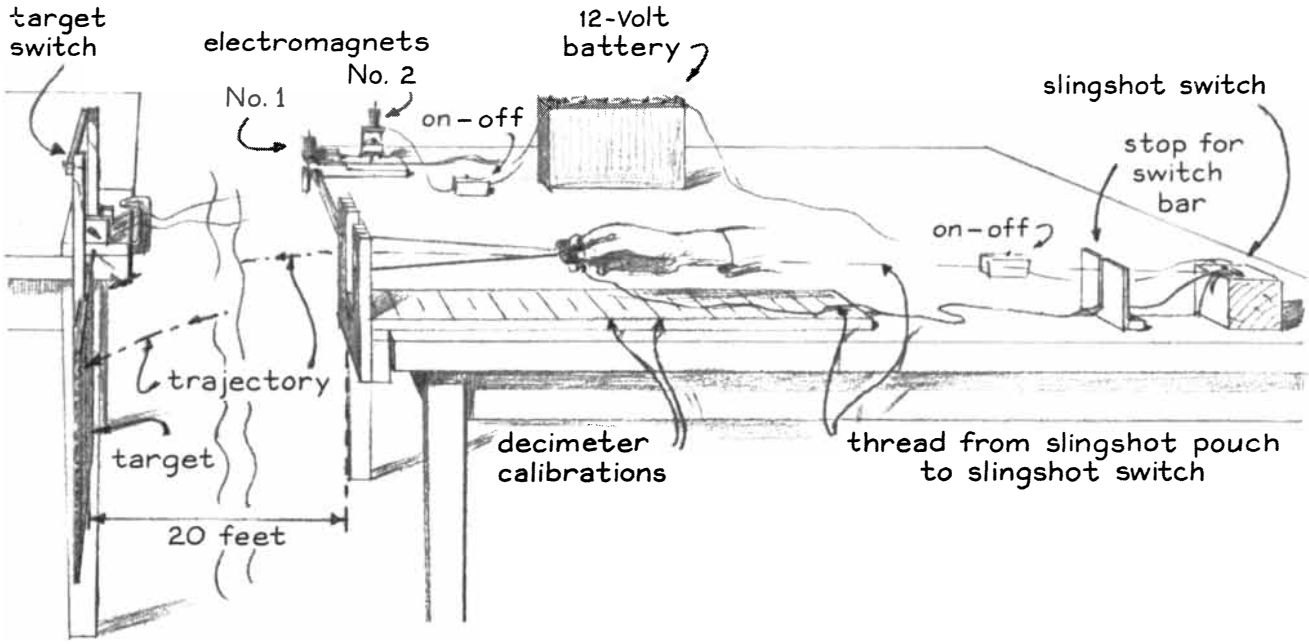
"The electromagnets can be made at home by wrapping about 1,200 turns of No. 22-gage magnet wire on iron bolts 3/8 inch in diameter [*see bottom illustration on next page*]. The ends of the spool can be disks of cardboard. The bolts should be wrapped with a layer of electrical tape before the winding is applied. The weight of my clock is a hefty iron bolt about five inches long that I found near some railroad tracks. It weighs about half a pound. To protect the floor I catch the falling bolt in a bucket filled with rags. I made a hook of coat-hanger wire and taped it to the bolt near the top. The hook is useful for supporting the weight close to its normal position temporarily before power is applied to the electromagnet. The magnets tend to overheat if power is applied continuously.

"The stylus that marks the tape can be made of the same iron that is used for the core of the magnets. Any soft iron rod about 3/8 inch in diameter is satisfactory. I drilled a hole about 1/16 inch in diameter transversely through the stylus near the top. A rubber band was passed through the hole, stretched and tacked to the supporting bracket. The band exerts downward force and helps to accelerate the stylus when it is released by the electromagnet. A penny was cemented to the base of the apparatus directly under the stylus to serve as an anvil.

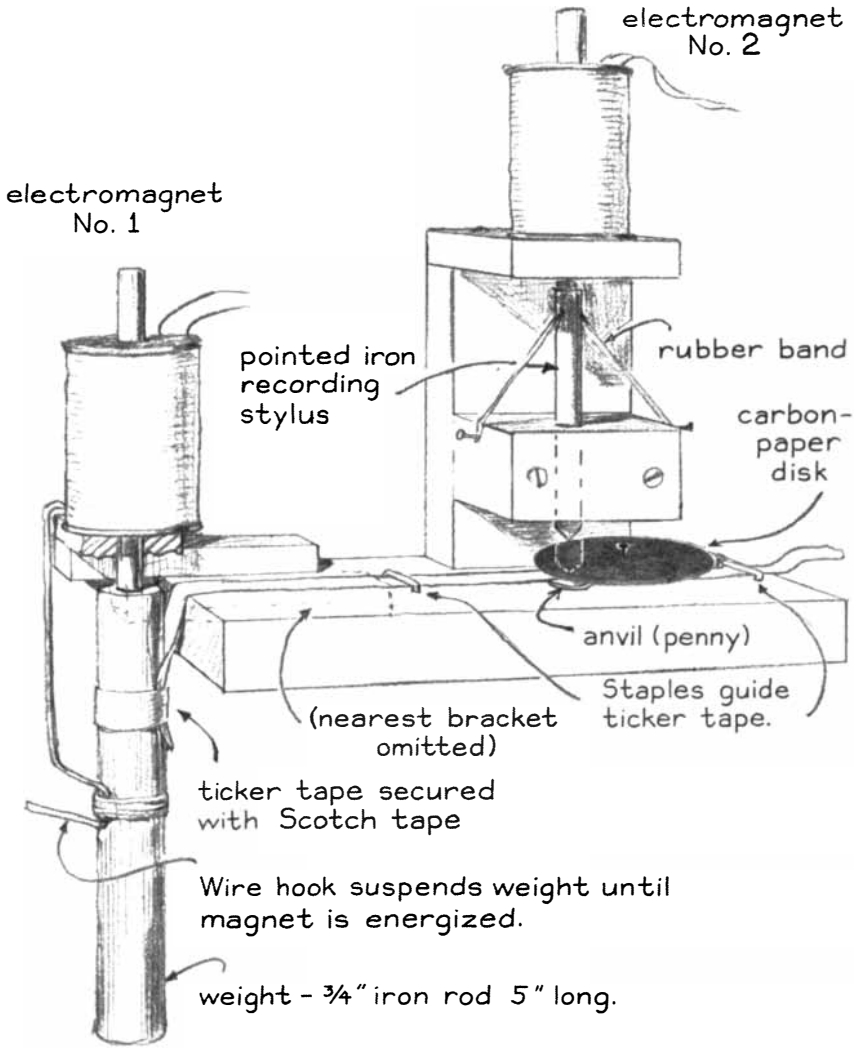
"A disk of heavy carbon paper is sandwiched between the pointed end of the stylus and the paper tape. The disk is loosely attached to the supporting base



Octave Levenspiel's fountain



Rodney A. Wolf's timing mechanism



Details of the clock and the stylus

bracket by a thumbtack through the center of the disk. The carbon paper rotates freely on the tack as the tape slides by, presenting a fresh surface of carbon after each mark is made. The tape is guided across the tabletop by loose-fitting staples made of coat-hanger wire.

"The switch that is operated by the slingshot consists of a pair of small brass plates that can be cemented with epoxy to a block of wood [*see top illustration on opposite page*]. The switch is closed by placing a strip of brass across the contacts. An alligator clip is screwed to the center of the brass strip. The switch is operated by a length of fishing line, one end of which is tied to the pouch of the slingshot. The line runs from the slingshot through a saw kerf in a bracket to the alligator clip, where the end is clamped between the jaws of the clip.

"The length of the line is adjusted to be snug when the brass strip is in position on its mating contacts and the rubber bands of the slingshot are fully relaxed. When the slingshot is cocked, the line is slack. The projectile attains maximum velocity at the moment when the rubber bands have fully relaxed. Simultaneously the moving pouch of the slingshot draws the line tight and pulls the brass strip away from its contacts, starting the clock. The alligator clip wedges against the saw kerf and drops free as the moving pouch pulls the line from the jaws of the clip. The end of the line continues through the kerf. I learned to wear a shirt with long sleeves when operating the apparatus because the line can cut a bare arm.

"The target assembly is an 18-inch square of corrugated cardboard glued to a stick about three feet long. A transverse hole in the stick about six inches from the cardboard slips over a horizontal axle that supports the assembly and also enables the target to swing freely [*see bottom illustration at right*]. On the free end of the stick is a small brass plate that normally makes contact with a similar plate cemented to a fixed bracket. These plates are the contacts of the target switch and form part of the circuit that includes the electromagnet controlling the stylus. The impact of a projectile rotates the target assembly, separating the contacts of the switch.

"The velocity of projectiles launched by a slingshot ranges from about 100 to 300 feet per second. The clock can measure intervals of about a hundredth of a second with good accuracy. The distance between the target and the point where the slingshot releases the projectile was accordingly made about 20 feet. On the average the ticker tape moves about 11 centimeters during the flight of a slingshot projectile.

"I normally load the clock with a strip of tape about a foot long. A pencil line is drawn across the tape to mark its initial position with respect to the stylus. The line should be drawn exactly under the point of the stylus, but the magnet is in the way. For this reason I put the mark an inch ahead of the stylus and subtract the inch when I measure the distance between the mark and the timing dot made by the stylus.

"The apparatus can be used for timing projectiles of higher velocity by increasing the range enough to maintain about the same interval of flight. The optimum range in feet is approximately equal to the velocity of the projectile multiplied by .15. The probable velocity can be estimated. The muzzle velocity of a .22-caliber pellet pump gun might be 550 feet per second and that of a .22-caliber rifle 1,300 feet per second. Appropriate ranges for timing these projectiles would be 80 and 200 feet respectively. As I have mentioned, the velocity of the projectile is equal to the quotient of the range (in feet) divided by the time of flight.

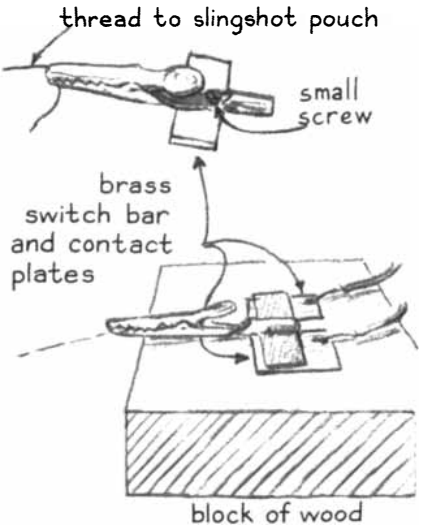
"When the slingshot is released, everything happens so fast that the experimenter cannot observe the action in detail. You must trust the machine. Just make sure that the target has been hit. I have sometimes missed the target and hit the table, with a resulting jar that caused the stylus to drop. These measurements are discarded.

"Often a string of dots appears on the tape. They are caused by bouncing of the stylus. The first dot in the string is the one that counts. Circle it with a pencil and cross out the others. Tape can be used more than once because dots made during earlier shots can be identified by the circles.

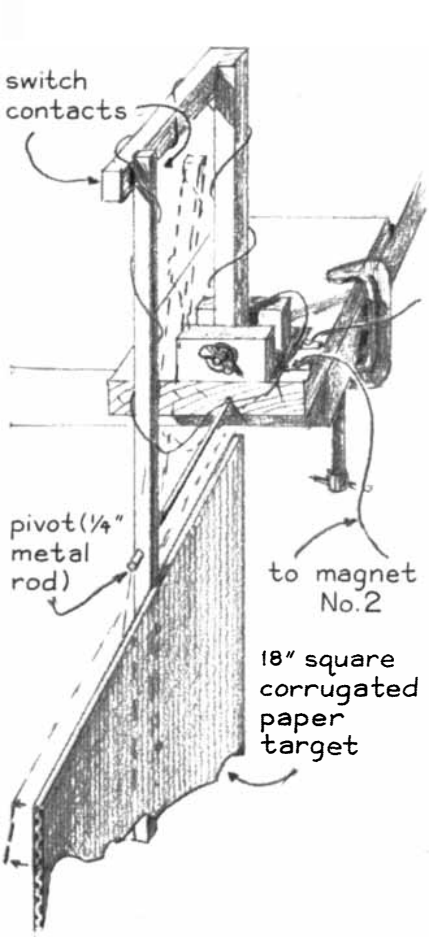
"Having determined the velocities and energies of numerous projectiles, I measured the efficiency of several slingshots: the ratio of energy carried away by the projectile divided by the energy expended in stretching the rubber bands, expressed as a percentage. Input energy was determined by hooking a spring scale to the pouch of the slingshot and reading the force at a series of points as the rubber was increasingly stretched. It turns out that slingshots of the highest efficiency are not necessarily the easiest ones to use. Part of the energy used to cock the slingshot is transformed into heat by the rubber when the pouch is released. This loss increases disproportionately with increased stretching of the rubber and with the velocity at which the rubber snaps back. The efficiency increases with the mass of the projectile because the greater inertia causes the rubber bands to contract more slowly. These experiments suggest only a few of the effects that can be investigated with the simple clock. The apparatus can be modified easily for experimenting with the ballistics of projectiles, measuring acceleration and so on."

Although amateur astronomers make excellent pictures of the moon and the brighter planets, their photographs of nebulas and unresolved portions of the Milky Way usually show some evidence of underexposure. The prints are characterized by low contrast: a narrow range of grays in which prominent details of the objects are submerged. The low surface brightness of these objects lies somewhat beyond the grasp of the small telescope and the sensitivity of ordinary, uncooled photographic emulsions. Even so, an underexposed negative may contain much latent detail that can be made visible by the use of appropriate development and printing techniques. Charles L. Townsend of Oxnard, Calif., has recently been experimenting with a procedure for enhancing differences in intensity between bright and faint areas of underexposed negatives. His procedure more than doubles the detail disclosed by normal processing. He writes:

"My technique for enhancing intensity differences in underexposed negatives is based on repeated copying. I use 35-millimeter Kodak Plus-X film and develop it with Kodak HC-110B developer according to the manufacturer's recommended procedure. From the developed negative I make a projection print in the form of a positive transparency, using Du Pont Type-S Orthochromatic Litho-Negative material. When making the exposure, I stop down the lens of the



Slingshot switch

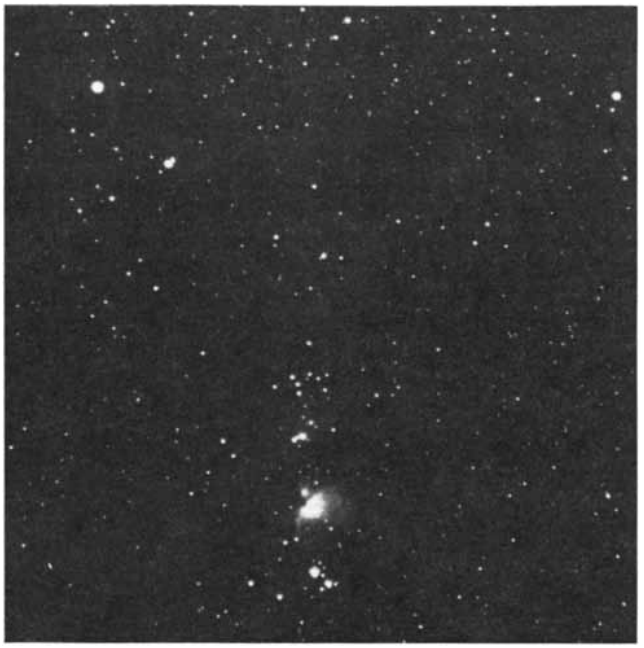


Target array

enlarger as far as possible. The positive transparency is then printed by contact on a second sheet of the Litho-Negative material. This step yields a negative transparency of identical proportions but of substantially higher contrast. The resulting negative transparency is used for making a contact print on Luminos F-3 Bromide paper. The result is a positive print that has high contrast and displays much photographic detail that is lost during normal processing.

"I use Printol paper developer for processing both the transparencies and the final print. With two exceptions I develop the transparencies and print according to the recommended procedures of the National Research and Chemical Company and the Eastman Kodak Company. When I make up the stop-bath solution for the transparencies, I depart from the recommended procedure by using one part of Kodak indicator stop-bath working solution to 20 parts of water. The developed transparencies are processed in Kodak fixing solution. The fixing is stopped promptly when the transparencies lose their milky appearance (as viewed with a red safelight). I normally rinse the fixed transparencies in a bath of Kodak Clearing Agent to minimize washing time.

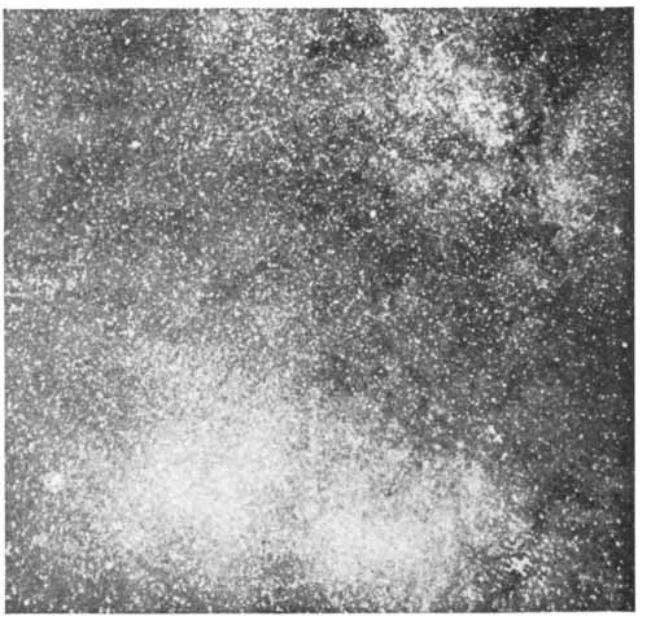
"Most of my negatives are made using an *f*/2.8, 135-millimeter-focal-length Lentar lens stopped down to *f*/3.5 or *f*/4. The Lentar lens is mounted in a Praktica camera body, and this combination is attached to the tube of an equatorially mounted *f*/6.3 refractor guide telescope with a focal length of 500 millimeters. A small, frequency-controlled, synchronous motor drives the assembly in right ascension. A manually controlled tangent arm is used for making small changes in declination."



Normally processed photograph of the Great Nebula in Orion

Orion nebula in a photograph processed by Charles L. Townsend

The Milky Way in a normal photograph



The Milky Way in photograph of enhanced intensity

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

Optimal Control of Oil Refineries

A Unique Application of Optimal Control Technology May Improve the Yield and Profit of the Catalytic Cracking Process.

Optimal control synthesis techniques offer a basis for more efficient control of many complex, industrial processes where several variables must be carefully controlled. Problems of this kind are common in the hydrocarbon industry. Although the efficiencies of petroleum companies have increased steadily, there appears to be a strong need for more precise control of their operations, especially among process functions and their associated systems control interfaces. Typically, control functions in the hydrocarbon industry are carried out semi-automatically under control of an operator who monitors a large control board. In the catalytic cracking process, as well as in many other processes, hazards to safety and equipment are always present. For example, reactor and regenerator temperatures can reach dangerous levels very quickly. In addition, a small percentage increase in yield or quality of yield can amount to sizeable dollar amounts.

Quadratic optimal control theory, and computer techniques for rapid solution of the optimizing Ricatti equations, have both been available to the control engineer for some time, but they have not been used extensively in the petroleum refining industry. Petroleum companies have been reluctant to change over to on-line computer installations because the benefits of continuous operation far outweigh any possibility of a shutdown. Early computers were unreliable and expensive and, thus, computers in refineries have been used almost exclusively in an off-line mode. Another great deterrent is the fact that the optimal solution obtained is a result of feedback of the state of the system whose variables are not easily measured.

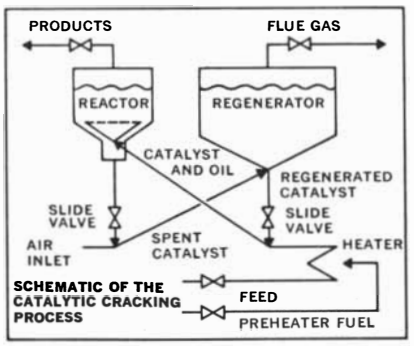
Two means of coping with this problem are: (1) estimation of the full state of the process from the measurable quantities available and (2) simplification of the model or controller or both to include only measurable quantities. State estimation has usually led to a more costly control than seems warranted for the improved performance obtained. However, model simplification introduces more uncertainty about the correspondence of model and performance. A number of recent investigations have focused on this problem of optimal control.

Honeywell scientists and engineers, in attempting to improve the safety and yield and profitability of hydrocarbon processing, have developed this latter control method to the point where it is useful for synthesizing linear controllers for complex multivariable processes when a specified sub-set of the state variables is measurable.

Honeywell chose the catalytic cracking process for its initial study because of its importance to the hydrocarbon industry. This process converts a high-boiling fraction of distilled crude oil into lower-boiling materials such as gasoline.

Several variables in this process can be adjusted by the operator or automatically: rate of air delivery to the regenerator, reactor catalyst level, catalyst flow rate, fuel gas to feed pre-heater, and input feed rate. The objective is to maintain, by proper settings and manipulation of these variables, the conditions for required product yields as well as safe stable process operation. It is particularly important to maintain the regenerator temperature and flue gas oxygen below certain specified values. The principal disturbance affecting the operation of the process is the fluctuation of feed properties.

The premise at Honeywell was that if a mathematical model and a computer program could be formulated for the cracking process, an on-line computer could monitor and automatically set the controls on the control panel. Honeywell engineers and scientists pioneered in applying these operational techniques to the catalytic cracking process by formulating a mathematical model of a catalytic cracker and synthesizing an optimal control algorithm with eight multi-variable control laws of varying degrees of complexity.



SCHEMATIC OF THE CATALYTIC CRACKING PROCESS

The model describes the process in terms of seven non-linear heat and material balance equations, plus a group of kinetic equations relating conversion, catalyst fouling, and carbon burning to the process parameters. The model also provides performance indices in terms of product yields and maintenance of safe operating conditions. The most complex control law postulates five control variables operating on information fed back from seven process variables. The simplest uses two control variables and two process measurements. The investigating team wrote a computer program which simulates the catalytic cracking unit based on the mathematical description and the control laws which were derived. The initial results based on data from an operating unit were promising. These data were analyzed by scientists and engineers from Honeywell's Corporate Research Center, from the Aerospace and Defense Group's Systems and Research Center, and by the process control specialists in Honeywell's Industrial Division.

Honeywell will soon begin a joint venture with a petroleum company in an effort to verify these results in an actual installation. Sensors and data recorders in the refinery will monitor and record temperature, fluid flow and pressure fluctuations. This information will then be fed into a computer which is wired into the control boards of the refinery. The input of information will then automatically alter the settings on the control board. This control system will not eliminate the job of the operator who monitors the control board but it will increase efficiency and decrease the risk of operational error or explosion.

If you are working in the area of quadratic optimal control, applied to the petroleum refining industry, and want to know more about Honeywell's investigations, please contact Mr. Jack Post, Honeywell Corporate Research Center, Hopkins, Minnesota. Honeywell carries out basic research in all of the sciences pertinent to its business at its Solid State Electronics Center, Plymouth, Minnesota, and Information Sciences Center, Cambridge, Massachusetts, as well as its Corporate Research Center, Hopkins, Minnesota, under the direction of Dr. John Dempsey, Vice President of Science and Engineering.

Honeywell

The Automation Company

BOOKS

Books about science for the younger reader: an annual Christmas survey

by Philip and Phylis Morrison

Out of this year's set of books for children comes one particular impression. Many books, judging by their length, visual design and presentation, were prepared and marketed for readers between eight and 10 years old. Indeed, the books selected here will reach that audience. Nevertheless, the logical and informational structure of such a book often allows it to meet even more squarely the need of a youthful or adult reader looking for an introduction to the subject. A good book for children is a good start on any subject for anyone.

Biology in General

IN THE SHADOW OF MAN, by Jane van Lawick-Goodall. Photographs by Hugo van Lawick. Houghton Mifflin Company ($10). The author of this personal, discursive and fascinating account of the life of chimpanzees, and of those who cast a shadow on them, still has the worn toy chimp she dragged everywhere in childhood. Now she and her husband and their five-year-old son are about to return permanently to the Gombe Stream Research Centre in the Gombe National Park of Tanzania, in the damp green hills beside Lake Tanganyika, to continue life among the chimpanzees. Gombe is the boy's "favorite place," although he spent a good deal of time there caged up; chimpanzees catch and eat small primates, usually baboons but sometimes human children.

Dr. van Lawick-Goodall came to Nairobi a decade ago; she always longed for Africa and its animals. Once there she walked in on L. S. B. Leakey—the *deus ex machina* of the story—and on the spot got a job as an assistant secretary. When she had spent half a year with Leakey in the office and the field, he asked her to undertake a serious long-term study of chimpanzees in the wild. His judgment of this young woman, who had left school at 18, whose experience was in no way scientific, has been magnificently confirmed. She is, of course, now one of the most celebrated of observers in the field; on the fly she earned a Ph.D. from the University of Cambridge; the Gombe Stream Centre, which arose from her work, is now a thriving institution with a dozen students and an entire little village of logistic and touristic support.

In the Shadow of Man is mainly about the chimpanzees she watched year after patient year, learning how to know them as friends, giving them not numbers but names. There was David Graybeard, now dead of influenza, who long ago was the first to allow her closeness to the point of contact. When he took a palm fruit from her and held her hand gently, she felt "the barrier of untold centuries ...was, for those few seconds, broken down." Here are the chimpanzees' portraits, in photograph and drawing, with family trees. Here too is the straightforward story of how and what you learn by watching apes: birth, death, the way of chimpanzee mother and child, of male and female, of adolescence, in these closest relatives of man. The tools they make and use are clearly depicted and described; it was this remarkable result that gave Gombe Stream its widest fame. The photographs by Hugo van Lawick—Hugo and Jane met at Gombe, and their wedding cake bore a model of David Graybeard—are striking.

Apes and men are both real in this book. Junior-high-school readers and older ones will like all of them, mourn the death and crippling by poliomyelitis from which both suffer (Leakey sent the oral vaccine that limited the epidemic in both species) and learn much about the two primates. Both sexuality and death among chimpanzees are explicit and important in these pages. Such a mirror as the apes provide, framed by the sober and honest commentary of the author, is an excellent aid to viewing from every side the emotions we primates share. This is a fully adult book, but it is a superb book for children as well.

QUESTIONS AND ANSWERS ABOUT SEASHORE LIFE, by Ilka Katherine List. Woodcuts by the author. Line drawings by Arabelle Wheatley. Four Winds Press ($5.50). Do starfish take care of their young? Why are some seaweeds dotted with specks of plaster? Is the horseshoe crab dangerous? Do lobsters lay eggs? To each of well over 100 questions, arranged topically, there is a brief, simply written answer in this very handsome book. The questions are chiefly quite natural ones, based on observation at the shore itself (sometimes stimulated by the fish market). The life discussed is that of plants and invertebrates, mainly Atlantic-centered, from the familiar clamshell (Are shells alive?) to spirorbis and plankton. This is a first-rate book, whether as stimulating reading, direct reference or guidance at the actual shore; it is accessible to readers in the lower grades.

ANIMAL FEET, written and illustrated by George F. Mason. William Morrow and Company ($3.95). Comparative anatomy, with its message of evolution, was filled with excitement 100 years ago in the hands of Thomas Huxley. Mason restores that quality in this deft book for fifth graders and up, with his account of such adaptations as the suction cups of the gecko lizard and the reversible hind claws of the squirrel. The book is personal in tone, with the authentic ring of direct observation. Naturally its emphasis is on observable adaptation and not on the inferred selection and descent. It cuts a wide swath through the animal kingdom, from mantis to man. The human foot is not slighted; you can see snowshoes, crampons, flippers and a ballerina's toe slippers as adaptations, although the author clearly prefers the simpler world of biological fitness to that of human culture.

SHELF PETS: HOW TO TAKE CARE OF SMALL WILD ANIMALS, by Edward R. Ricciuti. Photographs by Arline Strong. Harper & Row, Publishers ($4.50). Monkeys are not suitable pets for a child. They are dirty and difficult to keep; even worse, a monkey in solitary confinement is an unhappy, incomplete animal. This fond and expert guide to the husbandry

of pets beyond the usual domestic range makes no such errors; it is based on both knowledge and responsibility.

Its range is wide: frogs, turtles, crayfish, guinea pigs, snails, crickets, grasshoppers, katydids, guppies and a dozen more. Crickets? Keep a few in a cage with a sandy bottom, a couple of twigs and a rock to hide under. They want to be warm but shaded. They thrive on lettuce, peanut butter and cracker crumbs; water is offered in a small glass vial plugged with wet cotton. Your songsters will die in the fall. Come spring you can catch others under a log or a rock, by hand or by net.

This practical book treats each animal in a couple of pages, at the level of detail displayed for the cricket. It is a valuable resource for any school or group, or for the individual pet-loving child, from about 10 years.

HIDDEN VALLEY OF THE SMOKIES: WITH A NATURALIST IN THE GREAT SMOKY MOUNTAINS, by Ross E. Hutchins. Illustrated with photographs by the author. Dodd, Mead & Company ($6.50). Drive up the gorge of the Little River in the Great Smoky Mountains National Park until you reach the end of the surfaced road. The line of cottages stops. From there on a woodland road meanders up the tumbling mountain stream through the dense, ferny, varied Tennessee forest. That is Hidden Valley. Hutchins, a superb photographer, takes the reader along to see waterfall and albino squirrel, tiny crickets kept as pets by the ants, ginseng berry and caddis fly. He uses long lens and magnifying closeup with equal skill and in all seasons. His prose evokes pictures too. He does not range as widely over the literary and moral landscape as the classical nature writers do. He sticks much more closely to what one can see and understand of the natural world directly, and never goes so far afield as a man once did by Walden Pond. He does frequent the deep past, to bring fossils and geology to view as sharply as today's mushroom. This is a book to read by desk and fireside, and also a model of how to see. Good readers will enjoy it at any age.

THE CARROT AND OTHER ROOT VEGETABLES, by Millicent E. Selsam. Photographs by Jerome Wexler. William Morrow and Company ($4.50). Seeds grow to carrots, and the carrots can be pulled up for eating. Their tops, however, can flower. From the flowers, pollinated by insects, tiny prickly carrot fruit will form, and the circle can close. This is shown strikingly here in pointed closeup shots, some in full color. The text is lucid and nontechnical, although in one place it carefully names and describes the parts of the flower. The turnip, the beet and the sweet potato are briefly contrasted with the carrot. Children in the early grades who raise plants such as the carrot will find this book a pleasure and a guide. The scale of the pictures is not always made as clear as it might be.

GOBBLE, GROWL, GRUNT, by Peter Spier. Doubleday & Company, Inc. ($4.95). Some 600 animals, all drawn with care, humor and visual clarity, fly, leap and graze in the pages of this book for preschool children and slightly older readers. The pictures are arranged with good zoological sense. One page takes you to the African veld, another to the deep sea, a third to the night woods, and so on; it is biogeography (or ecology, in the fashionable phrasing). The animals too are far from being stiff and static; the baby elephant showers in its mother's trunk fountain, the seal quite unexpectedly balances an ostrich egg on its nose. It is zoology that is neither trite nor overexotic; the familiar house mouse is here, a clown-hero throughout the book, along with the oryx and the cassowary.

This bestiary is enough to make a first-class book in itself, but it does not account for the essence of the most original and satisfying young children's science book of the year. The animals are noisy; next to each one is some apt phonetic rendering of the sounds it makes. These representations are conventional where that sounds right, as in the bullfrog's *jug o'rum more rum;* unexpected, as in the two-page chorus of 71 drab, gregarious starlings murmuring *fee-you* and *sweet, twee* and *weet,* or absolutely novel, as the *arrrf-arf* of the colorful toucan. The broad deck of the snorting Indian rhinoceros rocks by as a squadron of oxpeckers aboard chirp *key, key, key.* There is a hushed page too: the snail, the mute swan, the moth and the condor. These are not idle inventions; they sum up many a zoo visit and many an interview with zoological travelers. The distant future and the little apprentice reader of today have here a wonderful guide to English sounds as they are spelled. No other book this year combines as much observation, helpful pedagogy and sheer fun.

Specific Forms of Life

SIGNALS FOR SURVIVAL, by Niko Tinbergen and Hugh Falkus. Drawings by Eric Ennion. Oxford University Press ($8). A nature reserve for shorebirds lies just off a big shipyard on the coast of Lancashire. In winter it is all but empty but by spring it is a city of birds dominated by tens of thousands of gulls. This remarkable story, with many photographs and admirable watercolors, grew out of a prizewinning television film. It relates in terms of one species, the lesser black-backed gull, how this bird city, "a city of thieves and murderers," is nonetheless peacefully organized by an elaborate ritual-and-call "language." A gull can and will eat its neighbors' chicks, yet these cannibals raise their young successfully in nests only a few yards apart. The paradox is carefully explained; the birds are stringently ruled by mutual signals that organize them territorially. The males, seized by a deep tension between aggression and fear, stake their claim, assert title to all their borders by a sequence of standard calls and threats, which only rarely lead to lethal fights, and advertise their landholding by a special call to the females, who fly about seeking an established mate. Gradually, again always in tension, the pair-bond "marriage" is made secure by feeding and partnership; what was territory for one is now home for two. The chicks too have their special signals and routines. A wandering chick is in mortal peril from adult neighbors, but a chick in the home nest is secure. Should a flying predator appear, a cloud of screaming gulls will join in harassing it, and all the nesting birds sound the air-raid-warning signal of the gulls.

This is a taut, candid, unsentimental but admiring book. It is acceptable for any reader who can understand the brief but not easy text. (The illustrations make it easier to follow.) It is a work of genuine distinction.

THE ELUSIVE ZEBRA, by D. C. Ipsen. Drawings by Ben Stahl. Addison-Wesley Publishing Company ($3.95). Darwin held that the stripes of the zebra could not offer the horsy beast any protection. So did a hunter such as Teddy Roosevelt, and one lifelong hunter on the African plains writes: "I look upon the theory that the brilliantly striped coats of these animals render them in reality inconspicuous as absolutely untenable." But two other witnesses say: "In the dusk... he is one of the least easily recognized game animals" and "It was amazing how their black and white stripes made them practically invisible."

What is the truth of the matter? More important, how do we get at the truth? What is it that science does? That is the burden of this brief, readable, hand-

some, lively, skeptical book, suited for the upper-grade reader. The argument touches the history of zoology, the experiments (not with zebras) on the utility of color for concealment, the adaptive origins of animal traits and the limitations of simplicity. Line by line direct and interesting, the book is even more valuable between the lines. "A zebra is a complex animal leading a complex life." Might the stripes help in heat regulation? Do they assist recognition among families? Do they aid sexual selection? Are they left over from an old habitat among reeds? Do they protect against lions at night when those predators are most active?

It seems that staining the white zebra stripes yellow did not make any difference in the field. Too bad the marking stain was not black! A side conclusion: The quagga, a kind of half-zebra, striped only on the foreparts, provides a clue to the old saw that a zebra is really a dark animal with white stripes.

CHIPMUNKS ON THE DOORSTEP, written and illustrated by Edwin Tunis. Thomas Y. Crowell Company ($4.95). A CYCLE OF SEASONS: THE LITTLE BROWN BAT, by Lucille Wood Trost. Young Scott Books ($4.25). Two excellent natural histories devoted to small mammals, these books contrast in form as well as in subject. The chipmunk is a familiar of everyone who knows Eastern woodland; the little brown bat, like all other bats, is a creature strange to us, at most a form flitting by at dusk.

Tunis has made his chipmunks homey. We see them as he sees them: in the yard, responsive to his motions, individual, each with a pet name. He helps us to see as well as he does, deeply and carefully. The chipmunks are sunnily drawn from life in all kinds of action and in subtle and convincing color: among rocks and acorns, in battle with chipmunk neighbors, rushing a robin. A few pages on how to tame a chipmunk are entertaining and plausible; they stand as a sign of the rapport the author has achieved.

The bat book is in quite another style. As the title implies, it is a chronological narrative. Its dramatic illustrations are sepia photographs, suggesting the uncolored night world of the bats. We learn intimately of the little female flier, of her heartbeat and her mating. But our knowledge, however intimate, is like what we get from a novel. It is more than we could ever see for ourselves, filling space and time less as men know them than as bats do. Mrs. Trost has chosen a gripping way to tell her curious story, a way very young readers will enjoy, particularly when two children come on the little bat hanging asleep from the roof beam of the old barn in the hot June days.

THE CHICKEN AND THE EGG, by Iela and Enzo Mari. Pantheon Books ($3.95). Beyond the title page of this book there is not one word. None is needed. The Italian artist-designers have drawn large for us, in strong natural colors against pure white or black backgrounds, the hen laying the egg, the egg developing within, the chick pipping out and the chick growing to strength and independence. It is a graphic wonder of scale and form.

Field Guides

THE ANIMALS NEXT DOOR: A GUIDE TO ZOOS AND AQUARIUMS OF THE AMERICAS, by Harry Gersh. Fleet Academic Editions ($3.50). From cheetah-coursing near Edmonton to the university zoo of Valdivia in southern Chile, this paperback lists every public zoo in the Western Hemisphere by state, province or country, with compact entries generally giving animal populations, treasured exhibits, activities, hours and the like. The volume includes a good introduction to the whence, why and what of zoos in general, and it ends with a grim list of some 300 endangered species. Florida, subtropical and tourist-conscious, offers the largest zoo selection, everything from boxing chimpanzees to a baby aardvark and a killer whale. This is a book for travelers and for many an animal-mad young reader. It has a few wood engravings by Thomas Bewick as endpaper ornament.

Save the golden-rumped and golden-headed tamarin of Brazil (a mammal)!

AMERICA'S ANCIENT TREASURES: GUIDE TO ARCHAEOLOGICAL SITES AND MUSEUMS, by Franklin Folsom. Rand McNally & Company ($2.95). The core of this beautifully designed paperback is a list, region by region, of the museums and the prepared outdoor sites (north of Mexico) one can visit to see the works of the peoples who settled this continent long before the caravels sailed from Spain. Around these listings, which give exact locations and a description of the place in a few clear sentences, are placed some 40 engaging little essays comprising an introduction to American archaeology. There are many photographs and drawings (the latter by Rachel, the author's daughter). You can read of projectile points and tepee rings, religions, spear-throwing and dating techniques. One unusual photograph (among many) shows a limestone outcrop in the tawny landscape of the California mother lode, where the women of the Miwok tarried long at the acorn-grinding; some 1,200 mortar cups are worn into the flat bedrock. Nearly 200 locations are listed in this volume, with sites or museums in just about every state and province. It is an indispensable reference work for anyone who cares about the American past.

THE FORESTS AND WETLANDS OF NEW YORK CITY, by Elizabeth Barlow. Foreword by René Dubos. Little, Brown and Company ($8.95). "Green islands in an urban sea," patches of true wildness, not mere man-made parkland, remain within New York City. This volume, elegant in word and thought and in photograph, map and old drawing, describes half a dozen of them. The largest is Jamaica Bay, where a wildlife sanctuary thrives (the count of bird species sighted has reached 310) only two or three miles west of the jet runways of Kennedy airport. That refuge "is not a natural but a re-created landscape, whose artful construction has been the lifework of one man—Herbert Johnson, a Parks Department employee." Bus, subway and walking will get you to all six of the wild places treated here. The essays prepare you for what you find; they are part history, part praise song and part anxious pride. This is a fine book for the literate of word and wood.

Man

THE LONG AND SHORT OF IT: FIVE THOUSAND YEARS OF FUN AND FURY OVER HAIR, by Bill Severn. David McKay Company, Inc. ($5.95). Uncle Sam himself, although always long-haired, grew his beard gradually, beginning about the time of the Civil War. James Buchanan, 15th president of the U.S., was the "last of the doughfaces"; only one of his predecessors (William Henry Harrison) wore facial hair. After Buchanan followed a dozen presidents of whom only one was clean-shaven (Andrew Johnson); our last 10 presidents were again clean-shaven. Make of the cycle what you will; this droll volume of social history shows that controversy over hair length among men and women, and over facial hair among men, has been virtually a constant of Western history. The Puritan style was close-cropped for men; Harvard College ruled in 1655 that it should not "bee lawfull for any to weare Long haire." The brave

Spartans, on the other hand, spent hours combing their long hair before battle, and Diogenes the Cynic asked the clean-shaven youths of Corinth if they were not seeking to be like women. We are told that those who ignore history are doomed to repeat it; it seems that even when they know history, they repeat it! This swift-paced side look at history is good reading throughout, particularly for high schoolers.

NORTH AMERICAN INDIAN ARTS, by Andrew Hunter Whiteford. Edited by Herbert S. Zim. Illustrated by Owen Vernon Shaffer. Golden Press ($1.25). INDIAN BOYHOOD, by Charles A. Eastman, with illustrations by E. L. Blumenschein. Dover Publications, Inc. ($2). A brilliant paperback encyclopedia for the pocket, *North American Indian Arts* crams careful, colorful little paintings on almost every page into a terse, descriptive text, presenting arts of the entire continent (north of Mexico) in all mediums, from feather bonnets to totem poles. The map places 138 major tribes; there is even room for a compact documentation, so that every object depicted can be located. The paintings are so small that they are exposition rather than art, but on those terms they are fully successful. Half a dozen copper projectile points drawn in a few square inches show the oldest known metal artifacts of man, hammered into shape from native copper in the northern Great Lakes region at least 7,000 years ago. This is an informational best buy for anyone with the collector's feeling. Take it along to a museum.

Charles Eastman, the author of *Indian Boyhood*, was born Ohiyesa among the Santee Sioux, who had fled Minnesota for the Canadian West after the Mankato massacre on the eve of the Civil War. This is his direct and absorbing "imperfect record of my boyish impressions and experiences up to the age of fifteen years." It is a rare firsthand account of life among the Plains people when they were mirthful and free. The book is a facsimile of the first publication in 1902. Eastman's father, pardoned by Lincoln, lived among the whites. He reclaimed his boy at 15, when "my wild life came to an end, and my school days began." We owe this loving witness to that double life.

RACE AND RACES, by Richard A. Goldsby. The Macmillan Company ($5.95). Goldsby is a young Yale professor, an American black biologist. He has written a crisp, closely argued book, based squarely on the biological evidence and cast in language both accurate and accessible. He says what he means, and what he means gets to the roots. Where we do not know, he tells us, so that we can form an opinion (or withhold one).

Race is real, although it is statistical. A race is a population that "for reasons of geography or culture mates largely within itself," so that over a period of time there is established a set of gene frequencies distinct from the sets of other populations of the species. The book describes the cellular basis of inheritance and the diverse types of men around the world, as they appear to the eye and the calipers of classical physical anthropology and also as they are revealed to the more penetrating tools of the biochemist in properties such as blood groups and patterns of amino acid excretion. There is a short summary of what we know of human biological evolution, and an account of the present dominance of cultural evolution over the slower biological processes that in the deep, less mobile past made far-flung mankind adaptively polytypic. (It seems likely that in the long run culture change and mobility will remix our genes and there will be only one randomly breeding human population.)

Behavior too is heritable, but it is intricate. Basketball superiority tends to follow height; there will be few Japanese Wilt Chamberlains. The decathlon, on the other hand, samples a broad spectrum of athletic and personal traits; it is confirmatory that the list of decathlon stars includes Bob Mathias, C. K. Yang and Rafer Johnson. I.Q. is a contrived trait that is not well enough understood to lead to any firm conclusion. The environmental explanation of I.Q. gradients in the U.S. is socially hopeful; the genetic one "could produce a policy of contraction and exclusion." The author does not much extend his arguments to cultural anthropology and to history; it would seem that almost all human populations are magnificently successful with the intrinsically human complexities of language, art and innovative technology; witness the diverse origins of wheat, maize, yam and rice. The test of common humanity, of why men should "try to respect, admire, trust, understand and even love each other," is written in man's cultural legacy.

This is an outstanding book for readers of high school age and beyond. There is still more to be said, but here is an honest, solid start.

AFRICAN ANIMALS THROUGH AFRICAN EYES, by Janet and Alex D'Amato. Julian Messner ($4.95). THE OX OF THE WONDERFUL HORNS AND OTHER AFRICAN FOLKTALES, retold and illustrated by Ashley Bryan. Atheneum Publishers ($5.95). These two well-illustrated books for younger readers share a single form: they are devoted translations of diverse ethnographic material into a form accessible to children. *African Animals through African Eyes*, intended for children of nine or older, is a survey of the strong figurative art of Africa, from the Sahara to the Limpopo. In it the artists present three dozen evocative renderings of works in every medium and scale, from a Benin ivory gong to the carved stone pillars of Zimbabwe. The text tells something of the people who made these works, and of how the works came to be made. *The Ox of the Wonderful Horns*, for younger readers, is prose with a rhythm fit to be read aloud to the unbooked. It presents four lighthearted animal fables and one tale of a young man who succeeds in a magical journey. It is a beautiful book to see and to hold, both for the overall design and for the artist's striking prints. The gay story of Frog, who enjoyed his life with two wives until one day both summoned him to eat his mush at the same time, is the Angolan people's subtler counterpart of Buridan's ass.

LANGUAGE AND MAN, by Irving and Joyce Adler. Illustrated by Laurie Jo Lambie. The John Day Company, Inc. ($3.27). THE CHINESE LANGUAGE FOR BEGINNERS, written and illustrated by Lee Cooper. Charles E. Tuttle Company ($1.50). Third graders and up can read *Language and Man*, a clear, humane and attractive little book about a profound question. Animals can signal, but the story of the parrot that could speak fluently but could not save itself from the cook pot ("Why didn't he say so?" asked Grandma) shows the gulf between bird calls and human language. The book deals neatly with the universality of language and some of its diversity.

The Chinese Language for Beginners begins by presenting "The man is big" in two characters next to a simple drawing of such a man, a dragon embroidered on his ample chest. It is a charmer of a start toward just under 40 characters' worth of spoken and written Mandarin, including its effortless syntax. Read downward, and note how one quick dab of the brush turns the character for "big" into one for "too much"!

ANIMALS AND ARCHITECTURE, by David Hancocks. Praeger Publishers

($13.95). Diversely and beautifully illustrated, this book by a young English architect who is a zoo designer is fascinating. Animals build wonderfully for themselves, and men build for them over a range of species extending from bees to bats. We make the animals artificial environments, perhaps doing rather well for our old friends the bees but surely being rather self-centered when it comes to porpoises, tigers and elephants. In the Basle zoo elephants live in dignity and joy among green trees. The sacred cows of Gaokana in India have good stalls, which are built behind an ornate façade the cows certainly cannot appreciate. Oysters, rabbits, dormice, venom-producing snakes, trout, fur animals—the list is longer and stranger than one might think. All of them have had human architects, or at least builders. The economic and moral problems of intensive farming (say raising hens that are confined, debeaked, kept quiet in dim red light in vast slums of 100,000 birds) are not overlooked.

The book is not specifically aimed at young people, but its catholic approach and unique topic recommend it highly.

Perception

SCIENCE, ART, AND VISUAL ILLUSIONS, by Robert Froman. Drawings by Laszlo Kubinyi. Simon and Schuster ($4.50). In a scene painted by Simone Martini the watchers crowd out of the city gate to see Christ carrying the cross. They are huge personages to our modern eyes, because the 14th-century master painted them just as large as the central actors in the foreground. By the time of the Flemish masters perspective ruled depth, and the cues of texture and color, together with other devices, served to break the flat wall out to any depth the painter chose.

How size constancy arises out of our visual experience, how it acts in the twisted rooms of Adelbert Ames, Jr., and how visual perception as a whole has come more and more to be regarded as no mere peering out the window of the eye but as a process of comparison with internal patterns stored or even wired within us is the theme of this first-rate book for young people, so clear and cogent as to be a first reference for any general reader.

The lines with an arrowhead at each end that look longer when the arrowheads point inward and shorter when they point outward—the Müller-Lyer illusion—are the central test items. The illusion may be dependent on experience. Its effectiveness decreases from city folk to dwellers in the grass huts of tropical villages. We have learned from carpenters and painters alike: the depth illusion is fostered by those corners, so that we place the lines nearer or farther as we have learned from so many pictures and so many corner views.

An illusion is not hard to define: it is a perception that requires correction, once we gain information. Modern artists—Piet Mondrian, Robert Rauschenberg, Maurits C. Escher and Saul Steinberg—continue teaching all of us the ways of seeing. There is no end to learning how to see.

TOPSY-TURVIES: PICTURES TO STRETCH THE IMAGINATION, by Mitsumasa Anno. John Weatherhill, Inc. ($3.50). UPSIDE-DOWNERS: MORE PICTURES TO STRETCH THE IMAGINATION, by Mitsumasa Anno. John Weatherhill, Inc. ($3.95). Two populations of colorful tiny folk roam these wry books. In *Topsy-Turvies,* which is totally wordless, the gnomish fellows occupy a series of strange landscapes, many scaled by artifacts of our world such as paint tubes and toy cars. The scenes are presented with artful ambiguities of perspective and a duplication of viewpoint and of gravity. Stairs go forever up—or is it down? Ceilings are also floors, and ramps hesitate. The watercolors are nearly all quite beautiful and rich in detail. *Upside-Downers* finds its people in a deck of playing cards, from which flock richly costumed medieval courtiers and jokers. They bring with them the strong sense of symmetry expressed in the cards. The playing-card book holds closer to its theme, but its small verses are perhaps less witty than the wordless pages of *Topsy-Turvies.* These are two books of rare imagination; they are sure to engage children in the task of interpreting the artist's unbounded cosmos.

LENS AND SHUTTER: AN INTRODUCTION TO PHOTOGRAPHY, by Harvey Weiss. Young Scott Books ($5.50). PHOTOGRAPHER'S HANDBOOK, by the editors of Time-Life Books ($1.50). SPECIAL PROBLEMS, by the editors of Time-Life Books ($9.95). The sunburst of interest by young people in the art and craft of photography is served by these three books, quite distinct in level and purpose. *Lens and Shutter,* whose author is a well-known sculptor who has written similar books for beginners in the arts from collage to pottery, surveys the technique and samples the art in an open, brief text accompanied by many splendid photographs: from the Matthew Brady cameramen to Walker Evans, from the Canyon de Chelly to a frog worriedly clinging to a pencil. Weiss seeks to tell what makes good pictures no less than how to mix Dektol. The result is a good overall treatment for any would-be beginner, complete with the worthwhile hint to buy your gear at a specialized camera shop, where you can make friends with people who can aid you. Schools, clubs and young readers who are on the brink of photography will find the book a real help. Its technical directions are clear and honest; they probably fall just short of providing enough detail to enable anyone to do it all without further advice.

Photographer's Handbook is quite different, although overlapping. It is a terse little spiral-bound brochure that covers picture-taking and film-processing in the home darkroom step by step; it is always knowing and detailed, with excellent lists of films, developers and the like, given by trade name with specifications. There is no effort toward motivation—you have to have made up your mind—or toward examination of the art. It is an admirable companion to your second camera or your first darkroom.

The pictures taken up in *Special Problems* are not for wide emulation. The book is a marvelous insider's account of how to get the impossible photograph. Is the picture beyond reach because the action is too fast to stop? Does intelligibility demand the ultimate in black-and-white harshness? Did the camera back have a light leak? Here you will find how the professionals diagnosed the problem and brought back successful pictures by a splendid mixture of technical mastery and thoughtful innovation. One section treats instruction in photography. This is a book for those who admire or aspire to a kind of work beyond the scope of any temporary darkroom. It is beautifully illustrated; see Billy Kidd at top speed yet sharp in color, or a barefoot young fisherman in black and white.

SCIENCE PROJECTS THAT MAKE SENSE, by A. Harris Stone. Illustrated by Mel Furukawa. The McCall Publishing Company ($4.95). Here we have some 20 simple experiments, each one described briefly in two pages for young readers with the aid of large, attractive and detailed ink drawings, many of which have surprising scale and viewpoint. The range of suggestions is sampled by the making of Braille characters with a pin, painting an orange blue and listening to passing cars with eyes closed. The experiments require and repay consid-

erable energy and thought but need very little special equipment. The most original task is to direct a friend at a distance of six feet or more where to poise his hand so that a penny he holds will fall into a cup. Try it, first with two eyes, then with one eye, then with two advisers standing in different places, each using one eye. Does it work in a mirror? This winning book is directed to experimenters in the early grades by the ingenious and tireless author of many similar works for sixth-grade savants.

Physics

TOWERS, by David Webster. The Natural History Press ($4.95). They stand tall against gravity, all of them: dandelions and the Statue of Liberty, television antennas and a ketchup bottle, rockets, the celebrated leaning tower, a giraffe and a basketball center. This fresh look at a feature of the world continues and improves the author's string of excellent books for young readers. It has a brief, questioning text and fascinating, diverse photographs. "Men have always built towers," the book begins. The author himself has managed to build one pound of clay into a tower 28 inches high. Can you beat his record? You will need a tower with a round section, a tapering form, a hollow interior and disks cut out of the walls here and there. Or try soda straws joined by pins. A five-foot soda-straw tower, secure against even the hurricane winds made by fanning a large piece of cardboard, is an engineering project for the classroom or the home. Man's tallest structures are the television towers of our Great Plains, lacy steel columns secured by long guy wires. Their chancy erection is shown in detail, with an instructive account of the reasons for the main features of their design. One can marvel at and mourn the tallest of them all, a North Dakota giant 2,060 feet tall, more than twice as high as the Eiffel Tower. It was brought down by a helicopter collision. Mystery towers are shown in some 20 pages at the end of the book, towers whose purpose and nature are left to the now penetrating eye of the reader.

UNDERSTANDING LIGHTNING, by Martin A. Uman. Bek Technical Publications Inc., Carnegie, Pa. ($6.50). Organized as discursive and well-illustrated answers to some 30 questions repeatedly put to the author by lay and scientist audiences alike, this small book gives a readable account (at the high school level) of our present incomplete knowledge about this awesome phenomenon. The book presents remarkable photographs, some of which were taken by amateurs. (It is not at all hard to do.) One such picture shows ribbon lightning, the glow widened by the wind blowing the heated air column sideways between the repeated strokes of a single flash. Another remarkable picture, taken at the first of all thermonuclear explosions, shows five simultaneous flashes of induced lightning branching upward from the ground to reach the clouds above that huge fireball! The basic electrical physics, the injury statistics, the history from Benjamin Franklin's day, the practical precautionary measures, the effects on trees and barns, the mysteries such as ball lightning and conjectures such as one about the effect of eliminating lightning altogether are all part of the interesting book. Readers who enjoy watching the marvelous natural fireworks will find this book makes it even more fun.

KITES, by Wyatt Brummitt. Illustrated by Enid Kotschnig. Golden Press ($1.25). STICK-PAPER AIRPLANES, by Robert H. Steidl. Abelard-Schuman ($4.95). Anyone who has 10 thumbs or who flinches from diagrammed instructions will not enjoy these books. For the happy many they are two delightful introductions to silent flight. *Kites,* a colorful pocket-sized paperback, compact of folklore, history, expert diagnostic advice and clear diagrams, is a bargain entry into the delight and struggle of the kite-builder. Not for the casual string-puller, it starts at the beginning but quickly flies off to kites that lift cameras and measure the altitude. See San Francisco's ruins, photographed after the great fire by an airborne camera held up by a train of 17 enormous kites! The book is a little gem of up-to-date exposition: it identifies sources of supplies, lists other books and generally spans the taut world of kites. It calls for confident readers who are not beginners with either words or tools. *Stick-Paper Airplanes,* a larger paperback, presents the concepts and know-how needed for the building of 50 distinct variants of a new kind of small aircraft, the author's own development. Each elegant glider is based on lift and guiding surfaces made of stiff paper mounted—how variously!—on a stick keel, made preferably of balsa wood. The plans are detailed mechanical drawings.

Earth and Skies

SECRETS IN STONES, by Rose Wyler and Gerald Ames. Photographs by Gerald Ames. Four Winds Press ($4.75). Easy enough and brief enough for the nine-year-olds at whom it is aimed, this small, attractive book has something to say to any beginner in geology. Its logic is so clear and yet so closely folded into the context that the book is a genuine aid to learning. The photographs too—close-ups of pebbles or of sneakers, longer shots of bedded strata or of young climbers—grow into the text; they are not only ornaments but also clues. Geology begins by looking for bedrock. That is where stones—pieces of the earth—come from. Stones are sometimes mixed; they must have come from different kinds of bedrock. If the stones are rounded, they are worn. These bald and inescapable conclusions move naturally and quietly out of the simple sentences. Crystals in rock (crystals you can grow yourself), worn grains of sand (shown by the hand lens), chemistry (if only the hiss of vinegar on limestone) and fossils that you might find (or that a museum has collected)—all play a role. On every page the child is there, thoughtful, cheerful, thinking and acting. You see him or her, and you share the act and its inference. Few books attain such quality in such simple form.

CONTINENTAL DRIFT: A STUDY OF THE EARTH'S MOVING SURFACE, by Don Tarling and Maureen Tarling. Doubleday & Company, Inc. ($1.45). Geology has metamorphosed into a young worldwide science from a mature regional compendium within the past decade. Every reader of *Scientific American* has had a chance to watch the rise of the new view: the drifting continents, the spreading sea floor, the earthquake sources lined up at the great plate seams where material flows down into the depths. Here is a brief account of the entire viewpoint, qualitative but careful, intended as a summary-introduction for the student scientist and the general reader. The fundamental suggestion of drift is as old as modern science. The first workers fitted the jigsaw puzzle of the continental forms; now geologists have painted a colorful picture on the jigsaw pieces, a picture geological, magnetic and paleontological that fits even better, although a few elements are still awry. All of this is well described, without neglecting its meaning for the origins of ores, and for the cause and perhaps even the cure of earthquakes. Basic to all is the driving force, very probably slow convection currents deep within the earth's hot mantle. This hidden flow is still not known in its full three-dimensional splendor, nor do we yet have the

wit for quantitative prediction. The two English authors (Maureen is not a geologist but a writer) are confident that the general picture is now in our hands; with maps and drawings they give a clear story both of what we know and how we know it. They are, so to speak, conservatives, rejecting both the notion that the entire skin of the earth has slid around the spinning core and the one that the entire earth has substantially expanded, at least within the past billion years. It is a picture of grandeur, simply described, calm and underplayed throughout.

THE ANTARCTIC, by H. G. R. King. Arco Publishing Company, Inc. ($9.95). The Arctic is a frozen hollow, the Antarctic an icy bump. That bump is a continent, where men now live under international treaty. The ice cap, the land, the climate, the remarkable life on ice, rock and sea, the way men too manage to move and to live, the islands on the fringe and their great fisheries, even the laws that bind men in the Antarctic, are the fabric of this book. It has been woven out of map, photograph and word by the information officer of the Scott Polar Research Institute at the University of Cambridge. There are aircraft and surface vehicles—Russian, Japanese, American, British—in color photographs. There are the icebergs and penguins, the isotherms around the coldest spot on earth, the chill tables and the whale catches. There is the history too: Shackleton's 1907 motor tractor and the weather log of Scott's party the day they reached the Pole. The book is a full, clear guide in nontechnical language to the Antarctic as a whole. Young people beyond the sixth grade will find it a solid companion to armchair exploration at any level of interest. The author is rightly enthusiastic about the way men cooperate in the Antarctic for knowledge, beyond the frontiers of language and nation. A bit of the frost has entered his clear account of whaling, though. He sees the senseless and greedy slaughter of the blue whale, the largest animal ever to live on the earth, merely as threatening "total eclipse of the Antarctic's only staple industry."

501 BALLOONS SAIL EAST, by Edith Battles. Photographs by Florence Harrison. Young Scott Books ($4.25). WINDS, by Mary O'Neill. Illustrated by James Barkley. Doubleday & Company, Inc. ($5.95). There are 500 children in the 230th Street School in Redondo Beach, Calif. Two of the fifth graders, Scott and Lori, conceived a way to follow the wind. Their idea was for everyone to launch a toy balloon filled with helium. They would float eastward with the prevailing winds, and a postcard tied to each balloon might bring back from far away the news of where the balloon had landed. This is the story of the project in all its detail, leading through plenty of troubles to the great day of the launch. More than 50 cards came back, the farthest—Scott's and Lori's—from across the mountains in Colorado. The book is an account of organizing a joint effort among many people, of planning, worry, effort and success. There is a checklist of what you need to do to carry out such a scheme for yourself. (For instance, read up and see movies first to figure things out, and do not forget to notify airport tower control!) The most important point, however, is not on the checklist, although it is strongly implied by this fictionalized, beautifully illustrated narrative. Why were there 501 balloons? The kids asked for 500, the round number of pupils in their school. Mr. Boone, the principal, a man as sound as he is whimsical, thought they needed 501—one balloon for him. The first task is thus to wisely choose your principal before you go to school (not to mention Miss Battles and the other teachers).

In *Winds* Mary O'Neill has made three dozen lyric poems out of her experience and knowledge. The airplane window, the types of clouds, the points of the compass have all given her topics. It is not easy to write a lyric on so objective a theme; not all are successful. The illustrator has evoked the main images clearly in his subtly colored paintings. This is a splendid mind-opener for the classroom.

THE STARS & SERENDIPITY, by Robert S. Richardson. Illustrated with photographs and drawings. Pantheon Books ($5.95). Personal, a little scoffing, quite unliterary, this book for readers of junior-high-school age (and beyond) is what the expert author would be likely to call a pretty happy business. The idea is plain: a good many important discoveries have been stumbled on, the way three princes of Ceylon (once called Serendip) were said to have done in "a silly fairy tale." (Horace Walpole's letter is here, although it does not really strengthen his definition of the word he coined.) Richardson presents about a dozen discoveries that did not make sense in his light, clear, metaphorical, slangy essays, supported by some dandy pictures. You can see Walpole's elegant library, the precession of the earth's axis as disclosed by actual photographs of star trails, the tiny dense companion of Sirius; you can read about the doubtful "canals" of Mars and the not-so-strange aberration of light, about pulsars and the red shift. All these marvels were found by searchers who were not really looking for them, again and again "by running down slight, seemingly inconsequential, deviations from prediction.... Rejoice if your results don't come out just right." Slightly weak on the side of spelling, definitely mistaken on how unusual degenerate matter is (one finds it in every atom and every chunk of metal), the book is nonetheless an enjoyable, instructive and fruitful path into astronomy or to the spirit of experimental science itself.

Technology

THE ART AND INDUSTRY OF SAND CASTLES, by Jan Adkins. Walker and Company ($4.50). "The master sandbuilder's most important gift: a romantic nature" was plainly given to artist and author Adkins, who has made his sand-colored book into a small tour de force. Part practical guide to molding in sand with old buckets, part convincing sketches of real sand castles on small rocks or by a forest of sea grass, part loving study of medieval life and times, this book is all his own. Every word of the text is hand-lettered, even the title page and the copyright notice. It is a book of sweeping views and great interiors, peopled with castlefolk of high degree and low. Let Saxons and Normans contend; for some readers the masterpiece will be the Great Sandy Wall of China, molded full eight inches high, stretching fathoms down the beach, past rocks and a curious duck. You will lose your wall to the sea in time, but "losing to the sea is the natural way of things."

THE GREAT PLANES, by James Gilbert. With special photography by the author. Grosset & Dunlap, Inc. ($14.95). Every watch has a purpose and a designer. Airplanes too have designers, and their purposes are more varied than timekeeping. Planes have abilities and foibles, consequences and careers, even tradition and memories. This well-illustrated book treats 26 of the most famous and interesting species and genera of aircraft, from the Wright Flyer to the Boeing 747, with the expertise of a lifelong aviation editor and devoted pilot.

You can read of the Loughead brothers (the name continues as "Lockheed"), who made a Detroit fortune on hydraulic brakes and spent a good bit of it before 1930 on "plywood bullets": the 197 wooden streamlined beauties, called Vega and Sirius and Orion, that they made for Hubert Wilkins and Wiley Post and Charles Lindbergh and the others. About a dozen survive; many were lost in the Spanish civil war, flying against the warplanes of the Axis. Wiley Post supercharged his Vega, named it *Winnie Mae,* got a pressure suit and probably was the first of all men to fly the jet stream, at 340 miles per hour. You can also read of the Spitfire. Behind it roars the lion voice of Churchill; its designer was the Supermarine Company's racing seaplane specialist, R. J. Mitchell, a "pipe-smoking sort of chap in baggy tweeds." A Spitfire was all metal, stressed-skin, fast, clean and expensive. There were 330,000 man-hours of labor in each one. "What was the Spitfire like to fly?... There was always a strong smell of glycol coolant.... A few strokes of the hand-primer, and you hit the starter.... The takeoff took some care. ... You were airborne very quickly.... An immediate delight was the lightness ... and quickness of the controls, and the rate of climb.... It was miraculously easy to rack up enormous G loads that sent the blood draining from your brain, so that the sky around turned gray and then black if you continued to pull on the stick." Here too are the planes of the Russian designer Alexander Yakovlev. There was a unique Russian all-woman fighter squadron with Yaks, and a Free French unit that chose the Yak-3 over any American or British lend-lease aircraft the Russians had and then took 41 Yaks back to France in 1945. Read the tale of the DC-3 (11,000 made since the model was first flown in 1936) and about the Learjet, the Moth and the Sopwith Camel.

SUITING UP FOR SPACE: THE EVOLUTION OF THE SPACE SUIT, by Lloyd Mallan. Illustrated with photographs. The John Day Company ($9.95). In 1933 a daredevil volunteer from Boston became the first man to breathe protected from low pressure by only a suit. He wore the suit designed at his prompting by the physiologist J. S. Haldane (the father of J. B. S.) and the diving engineer Robert Davis in their test chamber in England. The outside pressure went down to the equivalent of an altitude of 18 miles; Haldane feared symptoms of the "effervescence of the

blood," but the test subject felt no discomfort. Wiley Post was next; aiming at flight in the stratosphere, he wore a helmeted suit kin to the Haldane-Davis design at 50,000 feet in actual flight. The suit, amateurish and charming, is pictured here as it now sits in the Smithsonian. The word "sits" is necessary, because the suit was made to be worn only in that position. Internal pressure prevents any easy motion unless the suit is made so as not to vary in volume as elbows, knees or torso bend. That was learned rather slowly; no such suit worked (armor plate is another way, but it is hopelessly heavy) until bellows joints (originally based on the shape of the tomato worm) were developed in the early 1950's. The forces of acceleration could be beaten by counterpressure bags and tubes; the need for ventilation and cooling could be met by circulating air and water close to the skin. Now men walk on the moon in 16-layer garments that weigh (in Houston, not at Hadley Rille) 183 pounds. This unusual book is the narrative of the space suit, told in vast detail with many photographs, interviews, citations of Air Force and corporate reports, and in a cheerful, if rather excited, style at a nontechnical level.

TRANSISTORS AND CIRCUITS: ELECTRONICS FOR YOUNG EXPERIMENTERS, by W. E. Pearce and Aaron E. Klein. Doubleday & Company, Inc. ($4.95). In a land where color television is millionfold, the struggle to make an electroscope function does not easily attract many young experimenters. This practical book of experiments and circuits is intended to provide enjoyment and understanding for boys and girls from fifth grade to junior high. It includes details for such research-like activities as charging an electroscope with a simple dry cell (by varying a capacity), which is a challenge to those, and only those, who have gained some abstract grasp of electrostatics. That activity makes no loud sound, no spark, no image. The chance that the young experimenter will try this route into the deeper part of an electrical hobby is increased if the austere pleasure can follow showier tasks. The book is accommodating: it includes an account of how to make simple electrostatic machines, of light switches using phototransistors, of several transistor radio circuits, and so on. Soldering hints and color codes accompany recipes for wrapping coils and condensers. This blend of new and old, of the packaged component and the homemade demonstration, is uncommon and hopeful. The book requires scrounging, or contact with the electronics supply trade, by mail or in person. A mail-order electronics catalogue would be a welcome accompaniment.

THE LAST WHOLE EARTH CATALOG: ACCESS TO TOOLS, by the Portola Institute. Random House ($5). A predecessor of this admirable, utilitarian and touching work was reviewed here in June, 1969. Now the publication is far-flung and famous; it presents nearly eight times as many notices of books and artifacts for the original price in an edition perhaps 50 to 100 times larger. It is ceasing out of wise principle. Never fear; it will remain a wonderfully useful tool for years, and a bright banner of hope, iconoclasm, integrity, reason and the joy of maps. Any camp, youth club, city library or high school without at least one copy has deprived itself. Buy it on its merits at a penny a page.

Mathematics

POLYHEDRON MODELS, by Magnus J. Wenninger. Cambridge University Press ($14.50). DOMEBOOK TWO, by Pacific Domes. Distributed by Random House ($4). The five Platonic solids are complete of their symmetrical kind. By mixing regular polygon faces, however, Archimedes made 13 more solids. These can be variously extended by putting cells on faces, called stellation, or by cutting away cells whenever that process can reveal new regular polygon faces within. We now know of just 75 polyhedrons (in three-space), all of whose vertexes are alike and all of whose faces are regular polygons, including the star polygons. No one knows if there are any more. Photographs of paper models of all 75 are shown in *Polyhedron Models,* with careful directions for building the intricate little structures, and some mathematical discussion. Another 25 fancy solids are thrown in for good measure, stellations mainly, with intriguing patterns of vertexes. No beginner should try the inverted snub dodecadodecahedron, encrusted with its dozen big pentagrams, but these models will lead many who have some experience deeper into the modern extensions of Plato's cool world.

Domebook carries polyhedrons into the world of human need and scale. Its first 10 large pages are mathematics, and more tables are at the end; the chief problem is spanning a sphere with a space frame of segments. The rest of the work is a folk architecture at its deepest. The myriad problems of housing technology—heat load, modeling with plastic straws, sheet-metal joints, welding vinyl, drying lumber—inform the whole. But the social context, such as organizing friends to work together, the humanity of building inspectors and the "enslavement" of mortgage payments that total 100 percent, becomes salient in the end. The entire book, a mélange of candid testimony, photographs, commentary, philosophical quotations, good sense and sharp criticism, is a product of the most endearing part of the counterculture, those who gain freedom by recognizing necessity. High school readers will get a great deal from the book, even if they never build a dome or live in the desert. A few mystics, some high on words and some on drugs, have their say, and there is a sprinkling of impolite, although generally appropriate, epithets. This publication is the second and the better of two; one hopes for more. The shortest description must be that this is an architectural manual in the spirit and style of the *Whole Earth Catalogue*.

Once Black Elk spoke: "We made these little gray houses of logs that you see, and they are square. It is a bad way to live, for there can be no power in a square." But Black Elk did not know the Pueblo.

PERPLEXING PUZZLES AND TANTALIZING TEASERS, by Martin Gardner. Illustrated by Laszlo Kubinyi. Simon and Schuster ($3.95). Martin Gardner's well-known learning and mathematical depth are worn lightly in this friendly, comical book for grade schoolers, giving the happy reader nearly 80 pages of visual, mechanical and verbal puzzles lying at the junction of logic, language and mathematics. See the three-pronged one-slot widget, its frame and holding nuts, and a crazy crate for all such undecidable objects. How can Patsy and Betsy, born within one hour to the same mother and father, not be twins?

THE MARCEL MARCEAU COUNTING BOOK, by George Mendoza. Photographed by Milton H. Greene. Doubleday & Company, Inc. ($6). The famous Mr. Bip, sailor suit and white face, floating weightlessly in astronaut's helmet or riding an invisible horse in jockey's cap, works his expressive way through 19 hats and trades. (How can a sailor list so perilously?) Each time the new hat joins its discarded predecessors in an elegant array on the pure white stage. The 20th hat is the battered old stovepipe with the insouciant rose; Mr. Bip is at last re-

vealed as himself, and the full set of hats is countably assembled before your eyes. The color photographs are beautiful, the concept is charming and Marceau is as usual the nonpareil of mime.

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I certify that the statements made by me above are correct and complete. Donald H. Miller, Jr., Vice-President and General Manager.

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AUTHORS

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BIBLIOGRAPHY

Readers interested in further reading on the subjects covered by articles in this issue may find the lists below helpful.

ATTITUDES TOWARD RACIAL INTEGRATION

THE NEGRO REVOLUTION IN AMERICA. William Brink and Louis Harris. Simon & Schuster, 1964.

SOCIAL CHANGE AND PREJUDICE INCLUDING DYNAMICS OF PREJUDICE. Bruno Bettelheim and Morris Janowitz. The Free Press of Glencoe, 1964.

THE NEGRO AMERICAN. Edited by Talcott Parsons and Kenneth B. Clark. Houghton Mifflin Company, 1966.

SIDE BY SIDE: INTEGRATED NEIGHBORHOODS IN AMERICA. Norman M. Bradburn, Seymour Sudman and Galen L. Gockel. Quadrangle Books, 1971.

WHITE ATTITUDES TOWARD BLACK PEOPLE. Angus Campbell. Institute for Social Research, University of Michigan, 1971.

THE GUM NEBULA

THE EXTENT AND EXCITATION OF THE LARGE HII REGION IN VELA-PUPPIS. Colin S. Gum in *The Observatory*, Vol. 76, No. 893, pages 150–153; August, 1956.

RADIO EMISSION FROM THE SUPERNOVA REMNANT VELA-X. D. K. Milne in *Australian Journal of Physics*, Vol. 21, No. 2, pages 201–219; April, 1968.

A PULSAR SUPERNOVA ASSOCIATION? M. I. Large, A. E. Vaughan and B. Y. Mills in *Nature*, Vol. 220, No. 5165, pages 340–341; October 26, 1968.

THE LIGHT OF THE SUPERNOVA OUTBURST. P. Morrison and L. Sartori in *The Astrophysical Journal*, Vol. 158, No. 2, Part 1, pages 541–570; November, 1969.

THE GUM NEBULA: FOSSIL STRÖMGREN SPHERE OF THE VELA X SUPERNOVA. John C. Brandt, Theodore P. Stecher, David L. Crawford and Stephen P. Maran in *The Astrophysical Journal*, Vol. 163, No. 3, Part 2, pages L99–L104; February 1, 1971.

CRYPTOBIOSIS

THE PROBLEM OF ANABIOSIS OR LATENT LIFE: HISTORY AND CURRENT CONCEPT. D. Keilin in *Proceedings of the Royal Society, Series B: Biological Sciences*, Vol. 150, No. 939, pages 149–191; March 17, 1959.

SENESCENCE, QUIESCENCE, AND CRYPTOBIOSIS. A. F. Cooper, Jr., and S. D. Van Gundy in *Plant Parasitic Nematodes, Vol. II: Cytogenetics, Host-Parasite Interactions, and Physiology*, edited by B. M. Zuckerman, W. F. Mai and R. A. Rohde. Academic Press, Inc., 1971.

CATALYSIS

ADVANCES IN CATALYSIS AND RELATED SUBJECTS. Academic Press Inc., Publishers, 1948–1970.

HETEROGENEOUS CATALYSIS. S. J. Thomson and G. Webb. John Wiley & Sons, Inc., 1968.

CATALYTIC PROCESSES AND PROVEN CATALYSTS. Charles L. Thomas. Academic Press, Inc., 1970.

MULTISTABILITY IN PERCEPTION

THE ANALYSIS OF SENSATIONS AND THE RELATION OF THE PHYSICAL TO THE PSYCHICAL. Ernst Mach. Dover Publications, Inc., 1959.

AMBIGUITY OF FORM: OLD AND NEW. Gerald H. Fisher in *Perception and Psychophysics*, Vol. 4, No. 3, pages 189–192; September, 1968.

TRIANGLES AS AMBIGUOUS FIGURES. Fred Attneave in *The American Journal of Psychology*, Vol. 81, No. 3, pages 447–453; September, 1968.

HOW BIRDS BREATHE

STRUCTURAL AND FUNCTIONAL ASPECTS OF THE AVIAN LUNGS AND AIR SACS. A. S. King in *International Review of General and Experimental Zoology: Vol. II*, edited by William J. L. Felts and Richard J. Harrison. Academic Press, Inc., 1964.

RESPIRATORY PHYSIOLOGY OF HOUSE SPARROWS IN RELATION TO HIGH-ALTITUDE FLIGHT. Vance A. Tucker in *The Journal of Experimental Biology*, Vol. 48, No. 1, pages 55–66; February, 1968.

A PRELIMINARY ALLOMETRIC ANALYSIS OF RESPIRATORY VARIABLES IN RESTING BIRDS. Robert C. Lasiewski and William A. Calder, Jr., in *Respiration Physiology*, Vol. 11, No. 2, pages 152–166; January, 1971.

BIRD RESPIRATION: FLOW PATTERNS IN THE DUCK LUNG. William L. Bretz and Knut Schmidt-Nielsen in *The Journal of Experimental Biology*, Vol. 54, No. 1, pages 103–118; February, 1971.

THE MOVEMENT OF GAS IN THE RESPIRATORY SYSTEM OF THE DUCK. W. L. Bretz and K. Schmidt-Nielsen in *The Journal of Experimental Biology*, in press.

THE ROTATION OF THE EARTH

THE ROTATION OF THE EARTH: A GEOPHYSICAL DISCUSSION. Walter H. Munk and Gordon J. F. Macdonald. Cambridge University Press, 1960.

THE EARTH-MOON SYSTEM. Edited by B. G. Marsden and A. G. W. Cameron. Plenum Press, 1966.

PHYSICS OF THE EARTH. Frank D. Stacey. John Wiley & Sons, Inc., 1969.

THE EARTH: ITS ORIGIN, HISTORY AND PHYSICAL CONSTITUTION. Sir Harold Jeffreys. Cambridge University Press, 1970.

EARTHQUAKE DISPLACEMENT FIELDS AND THE ROTATION OF THE EARTH. Edited by L. Mansinha, D. E. Smylie and A. E. Beck. Springer-Verlag New York, 1970.

THE TALKING DRUMS OF AFRICA

ZUR TROMMELSPRACHE BEI DEN EWE-LEUTEN. P. A. Witte in *Anthropos*, Vol. 5, No. 1, pages 50–53; January-February, 1910.

LE TAMBOUR-TÉLÉPHONE CHEZ LES INDIGÈNES DE L'AFRIQUE CENTRALE. A. Verbeken in *Congo*, Vol. 5, No. 1, pages 721–728; May, 1924.

THE DRUM LANGUAGE OF THE TUMBA PEOPLE. Roger T. Clarke in *The American Journal of Sociology*, Vol. 40, No. 1, pages 34–48; July, 1934.

THE DRUM LANGUAGE OF THE LOKELE TRIBE. John F. Carrington in *African Studies*, Vol. 3, No. 2, pages 75–88; June, 1944.

A COMPARATIVE STUDY OF THE CENTRAL AFRICAN GONG-LANGUAGES. J. F. Carrington. Bruxelles: Librairie Falk, 1949.

MATHEMATICAL GAMES

MODERN SCIENCE AND ZENO'S PARADOXES. Adolf Grünbaum. Wesleyan University Press, 1967.

THE AMATEUR SCIENTIST

PRINCIPLES OF PHYSICAL CHEMISTRY: AN INTRODUCTION TO THEIR USE IN THE BIOLOGICAL SCIENCES. Wallace S. Brey, Jr. Appleton-Century-Crofts, Inc., 1958.

OUTER SPACE PHOTOGRAPHY FOR THE AMATEUR. Henry E. Paul. Amphoto, 1960.

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