SCIENTIFIC AMERICAN

GERM-FREE LAMB

SIXTY CENTS

July 1964

$$R(t) = e^{-\lambda t}$$

$t = 2.5$ hours

$\lambda = \frac{0.048}{\text{million hours}}$

$$R(2.5) = 2.7183^{-0.048(2.5)\times 10^{-6}}$$

$$R(2.5) = .99999988$$

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A-1907

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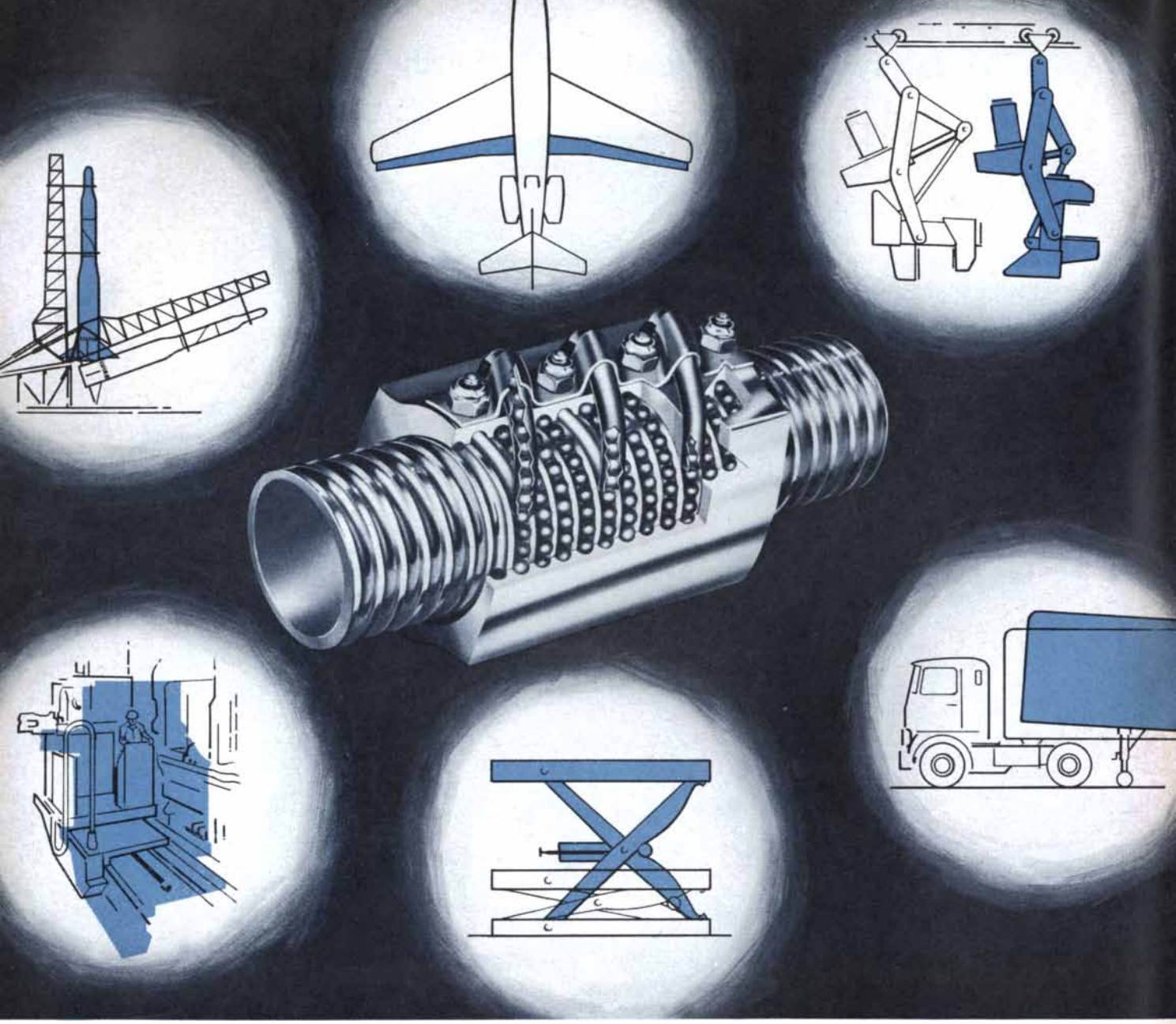

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Established 1845 **SCIENTIFIC AMERICAN** July 1964 Volume 211 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows a lamb in a cage surrounded by an "isolator": a sterile chamber in which animals delivered by Caesarean section under sterile conditions can be reared in the complete absence of microorganisms (see "Germ-free Isolators," page 78). Extending from the front and back of the chamber, which is made of flexible vinyl film, are long rubber gloves that enable the investigator to work inside the chamber without contaminating it; here the gloves are thrust outward by air under pressure. Sterile air enters the chamber through the hose and filter at lower right and leaves through the exhaust trap at lower left. At the right side of the chamber is an entry port in which food and supplies can be placed, sterilized and then passed into the chamber from the inside. At the back of the chamber is a manhole by means of which the experimenter can work inside the chamber by putting his head and arms into the flexible-film pullover that hangs down from the table.

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Cover painting by John Langley Howard

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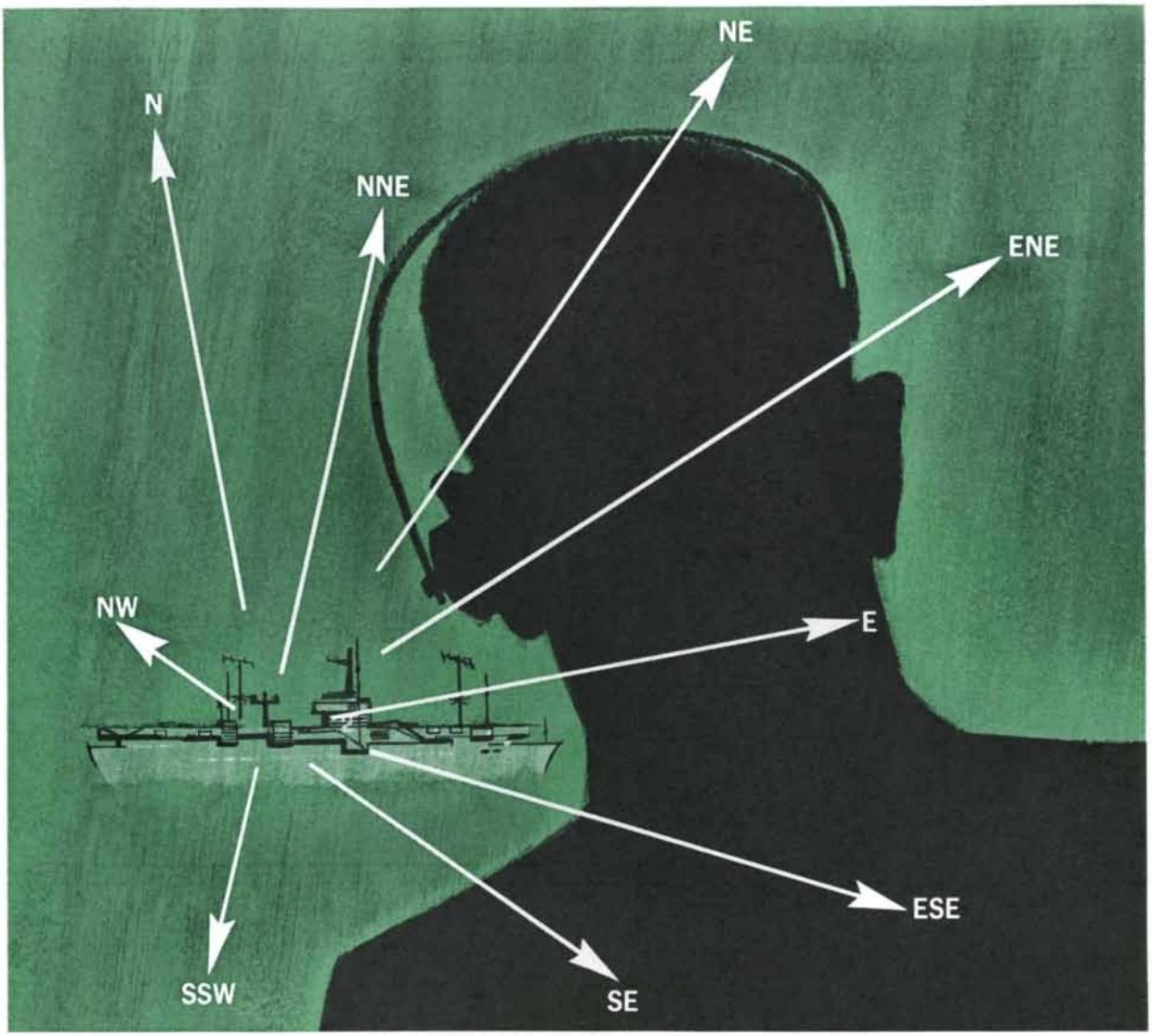

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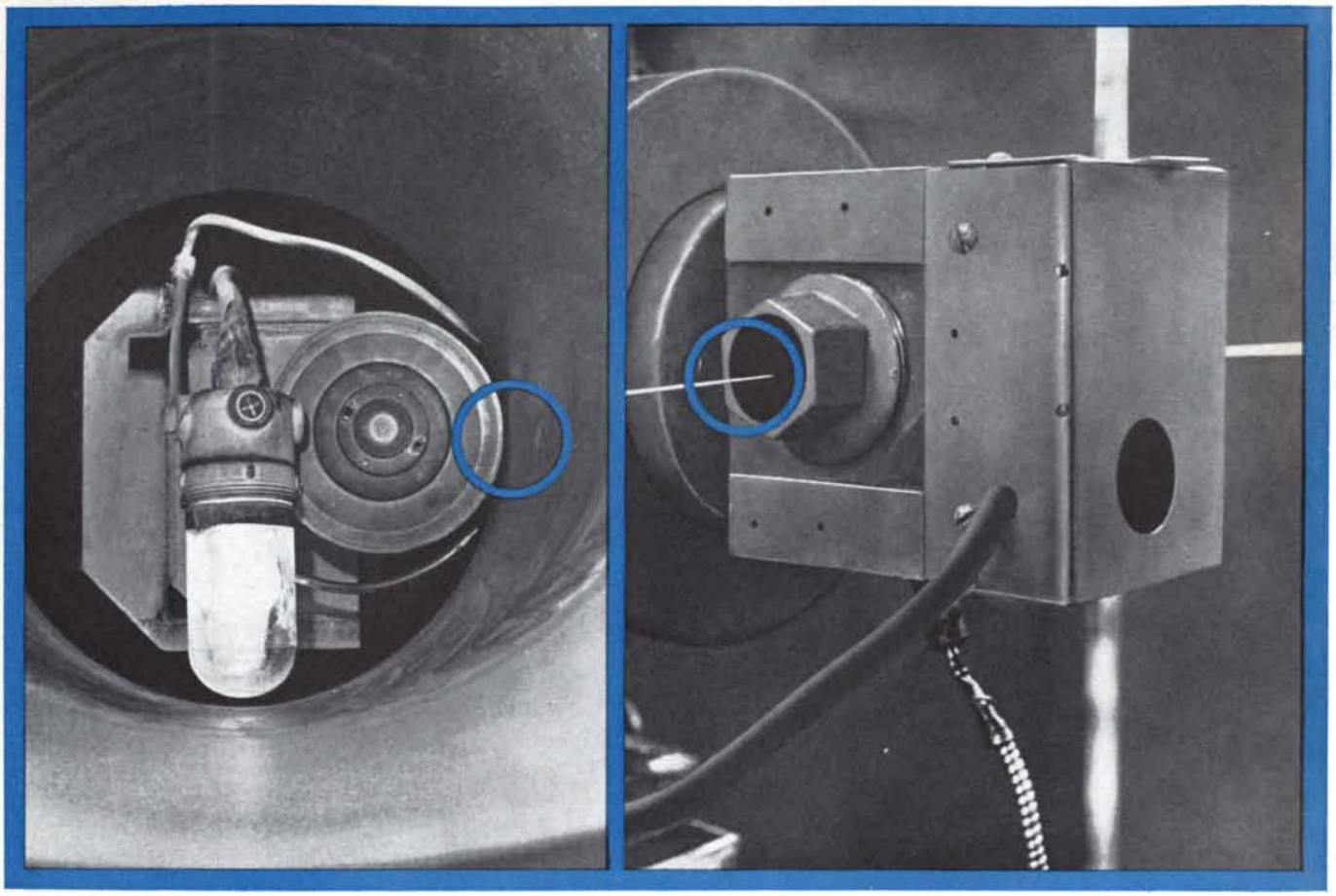
Grinding Internal Diameter

of alumina ceramic casings for the Atomic Energy Commission at Frenchtown Porcelain Co., Frenchtown, N. J., is accomplished with a series of 8-inch metal-bond wheels containing 60-, 100-, and 120-mesh diamond grit. The ID of the alumina casing is increased from 16.0 inches to 16.437 inches.

Diamond Dies

guide telephone wires through plastic insulating process. The insulating chamber at Western Electric Co., Kearny, N. J., is attached to the extruding machine. Wire enters chamber (left), passes through diamond guide die, is coated with plastic, and emerges (right) through sizing die.



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Slicing Sidewalks of New York

A diamond saw sliced New York sidewalks to make openings in pavement for 4000 new trees. Water coolant was utilized as clean, sharp cuts were made with the diamond blade. This method of cutting permitted the removal of existing concrete without breaking the adjoining pavement.

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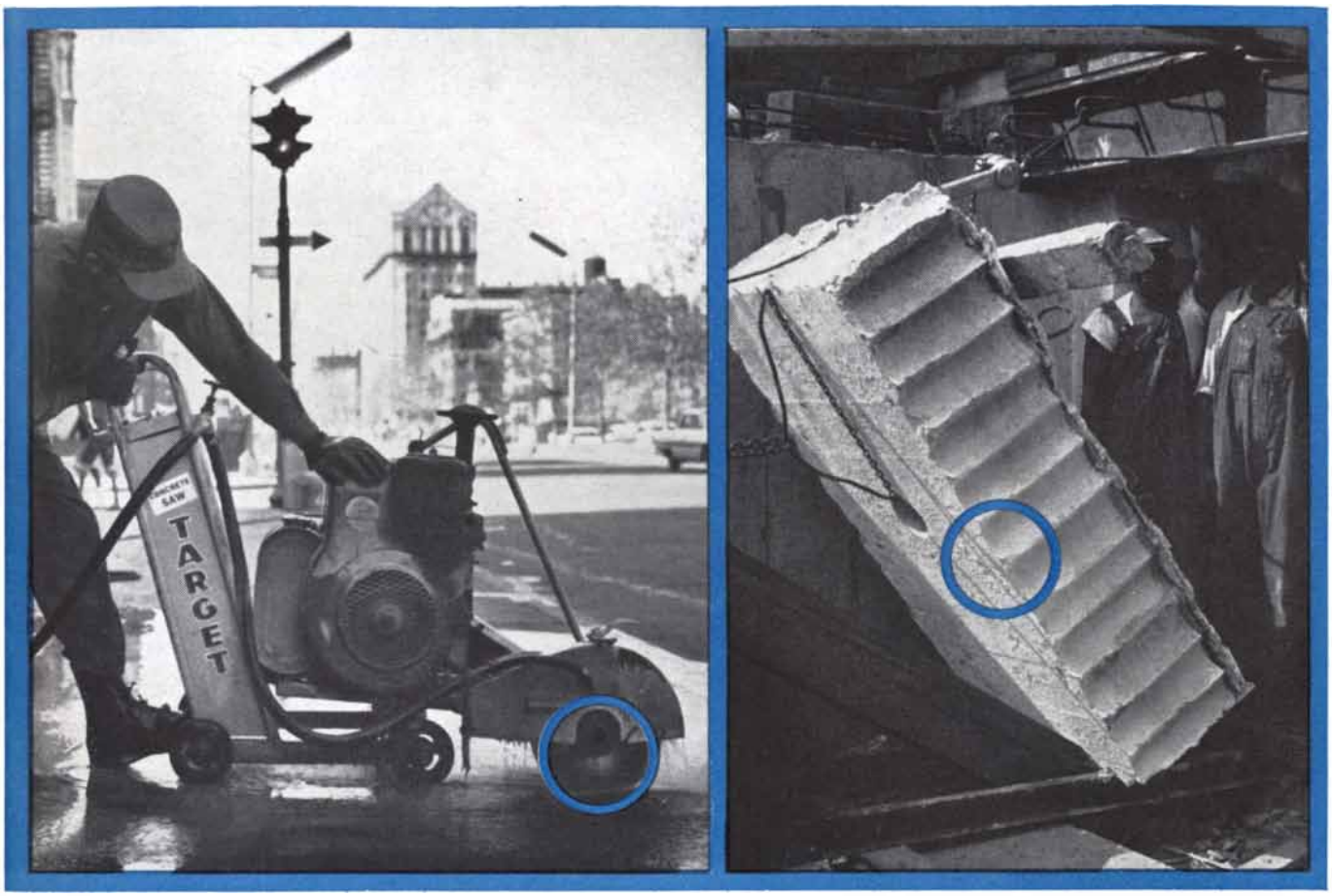
for Chicago hospital were cut into 18-inch reinforced concrete walls with 6-inch diamond bits. Each 3 x 7-foot door required about 40 holes, some of which were cut in as little as 15 minutes each. Other holes required more time because of cutting through the steel reinforcing rods.



DOING WITH DIAMONDS

Imaginative people are using industrial diamonds for all sorts of intriguing jobs—everything from cutting frozen fish sticks to sawing out fossilized dinosaur tracks.

Shown here are four more orthodox applications. Although they span several diverse industries, they still share one important detail: each job was done more quickly and more economically than before, with diamonds.

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LETTERS

Sirs:

Freeman J. Dyson's letter (April) of rebuttal to James R. Newman's review of *Interstellar Communication* (February) contains a remarkable note. Apparently science is not beholden to humanity but only to curiosity. Thus Dr. Dyson is glad to speak for a community whose "business as scientists is to search the universe and find out what is there." This sounds quite superior and recognizes no cause for restraint.

Yet an ordinary bit of uninhibited scientific curiosity will turn up all manner of unanswered questions. For instance, what would be the sociological and biological effects of a 100-megaton explosion in Times Square? Or if this is not on the current agenda of our "business as scientists," how about a study of the psychological deformations generated in a man-child reared from birth by a servomechanized computer in lieu of human parents?

The point about these elegant scientific research proposals is not that they are expensive or might disturb domestic tranquillity but that they are idiotic activities for *human* scientists. Newman was taken to task for calling stellar travel a hoax, which it may not be for bacteria or the Martian green mists, but for humans the term is perfect.

Perhaps Newman was too narrow in allowing a human bias to shape his criticism, but as a publicly supported scientist whose career *is* subordinate to human values, I am pleased to continue in his audience.

EVERETT TAFT

Institute of Science and Technology
Ann Arbor, Mich.

Sirs:

I was surprised to find in your May issue a discussion of high-voltage electricity transmission that limited itself to questions of cheapness and efficiency ["High-Voltage Power Transmission," by L. O. Barthold and H. G. Pfeiffer; SCIENTIFIC AMERICAN, May]. In the most glaring case the authors pictured three types of transmission tower and went on to evaluate them strictly as "ways to save weight and costs" for electrical companies.

This seems an excessively narrow-minded approach for *Scientific American*. Transmission towers are a very prominent part of the American landscape. At least one of the designs your authors show is even uglier than it is cheap. Surely both as scientists and as employees of General Electric your authors needed to consider high-voltage lines—well, maybe not quite aesthetically, but as the environmental factors they unquestionably are.

NOEL PERRIN

Department of English
Dartmouth College
Hanover, N.H.

Sirs:

I found the article "The Circulation of the Upper Atmosphere" by Reginald E. Newell very interesting [SCIENTIFIC AMERICAN, March]. One phenomenon described therein may well explain the long-mysterious "January thaw."

In his article Dr. Newell pointed out that there are two wind cores blowing from west to east in the winter atmosphere. One core is generally at an altitude of about 10 kilometers and the other at 60 kilometers. Late in January, however, the upper core drops down and rides on top of the lower core. This promotes relatively vigorous mixing of air from the upper atmosphere with air at the lower levels, as indicated by the downward movement of high-altitude radioactivity in late January.

The air above 15 kilometers also has a very high potential temperature (375 to 800 degrees Kelvin when compressed adiabatically to sea-level pressure). Is it possible that enough of this potentially "hot" air mixes with the normally cold polar air mass to result in the comparatively warm temperatures present in the polar air mass during the "January thaw"?

W. H. SENS

Assistant Chief Engineer
Pratt & Whitney Aircraft
East Hartford, Conn.

Sirs:

Mr. Sens's suggestion of a relation between the "January thaw" and the increased activity in the 15-to-30-kilometer region, often at the same time, is quite intriguing. I feel that the mass of air passed from the higher to the lower atmosphere is actually too small to produce the effect; even though air in the higher core up to perhaps 30 kilometers or more can move in phase with the lower core, the average vertical displacements of individual air parcels do not span the whole region. In fact, these vertical displacements are probably not more than several kilometers a month in the 15-to-30-kilometer region, so that air at 30 kilometers does not suddenly find itself in the lower atmosphere with the high potential temperature it had at 30 kilometers but rather is involved in some quasi-horizontal eddy processes that bring it down gradually with the radiation field changing its potential temperature all the time. Furthermore, although we observe that ozone is built up in the 15-to-30-kilometer region in the early spring, it is not until late spring that ozone and radioactivity values at the surface reach their maxima. However, there are undoubtedly changes in other parameters of the general circulation at the time of the January thaw, and I think it would be profitable to investigate Mr. Sens's argument from the other direction to see if the changes in temperature in the lower atmosphere are the cause of the apparent relation between the two wind systems in early spring.

REGINALD E. NEWELL

Massachusetts Institute of Technology
Cambridge, Mass.

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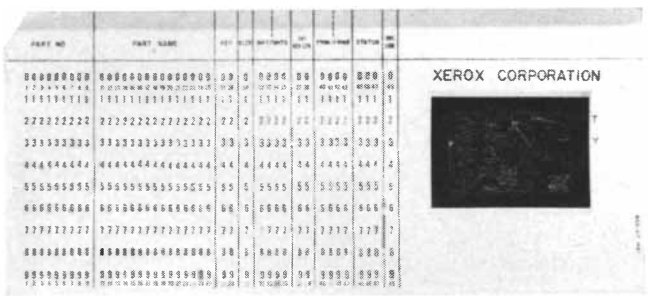

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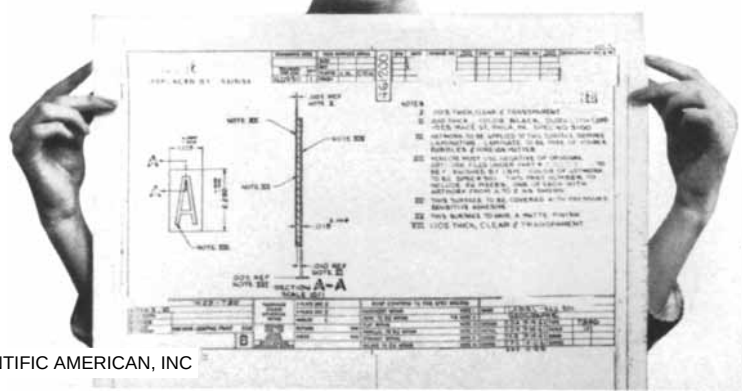

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1914: "Those in charge of the Wanamaker transatlantic expedition must surely find encouragement in the remarkable performance of Reinhold Boehm, the German aviator who at Johannisthal on July 11 achieved the feat of flying continuously for 24 hours and 12 minutes. Boehm covered about 1,350 miles at an average speed of 47¼ miles an hour."

"Prof. Capitan now finds that prehistoric man was able to model in clay with considerable artistic skill. We are already familiar with the remarkable cave drawings of animals which were made at such epochs, but this appears to be the first time that we have evidence of models in relief. He found these in a cave in the Ariège district of France, and two bisons are thus reproduced in high relief. There are also engraved animals upon stones, which seem to date from the Magdalenian epoch, or about 30,000 years ago. Animals instead of men were probably drawn for purposes of incantation, so as to give power over the animals, some of which are shown pierced with an arrow."

"The March number of *Le Radium* contains a paper by A. H. Pfund of Johns Hopkins University, in which he describes some preliminary tests he has made of a new apparatus for measuring the light of a star. The work was done at the Allegheny Observatory with the Keeler 30-inch reflector. In the focus of the telescope was placed either of two small blackened disks which formed the junction of a thermo-circuit. The wires used for the thermo-element were enclosed in an evacuated capsule closed at one end by a plate of fluorite and substituted for the eye-piece of the telescope. The thermo-current was measured by a moving-coil galvanometer. The sensitiveness of the arrangement was such that a candle at a distance of eight miles would give a deflection of one millimeter. The deflections obtained from celestial objects were: Vega, 7.5 millimeters; Jupiter, 3.0; Altair, 2.0. The author hopes, by using a more sensitive galvanometer and other materials for his thermo-elements, to increase the sensitiveness considerably and in this way to open up a new field of astrophysical research."

"The world's largest ship was recently launched at Hamburg. She was christened *Bismarck* by the German Emperor before a notable gathering. The new liner is 955 feet in length, 100 feet in beam and of 60,000 tons displacement. She is designed to maintain an average speed of about 23.5 knots."

JULY, 1864: "The Commissioner of Agriculture makes the following statements in relation to tobacco:—'Tobacco acts as a sedative, calming the nervous system and inviting to repose; but when used to excess, it produces nausea, debility and sometimes death. Its active principle, which is procured either by distilling or burning its leaves, is a deadly poison. Its medicinal properties are very doubtful. The opinions of medical authors on this point are diametrically opposite. There can be no doubt, however, that the excessive use of it often shortens human life.'"

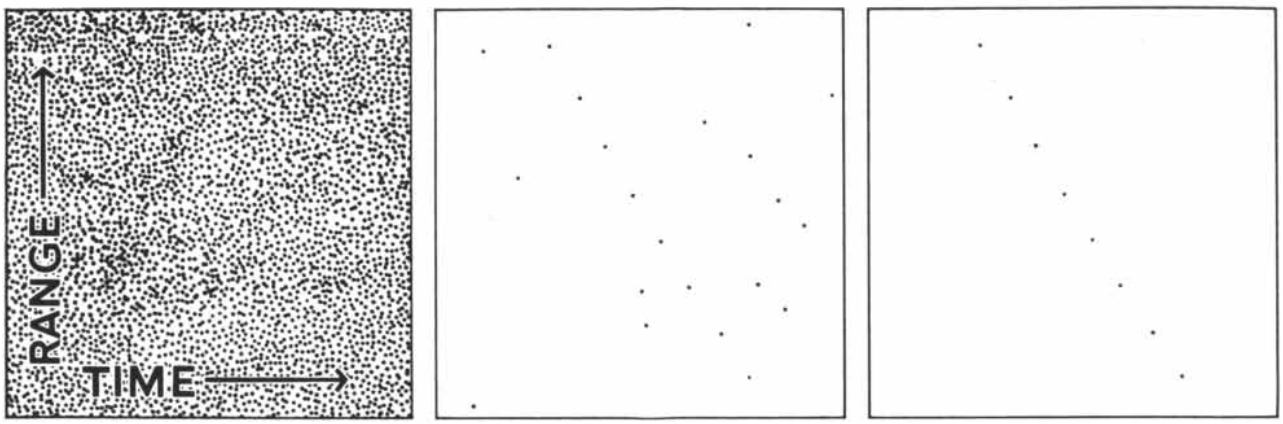
"The July number of *Silliman's Journal* contains the last in a series of articles by H. A. Newton on the 'November Star-shower.' In these articles Prof. Newton has traced the history of this startling phenomenon from the first record of its appearance in A.D. 902 and has discussed at length its most probable cause. He comes to the conclusion that there is a ring of small planets revolving around the sun; that the planets are distributed very unevenly in the ring, there being a small section of the ring where the bodies are numerous, with a few stragglers scattered along the rest of its circuit; that the earth passes through the ring every year, and each year in a new place; and that it passes through that part of the ring in which the planets are most numerous once in about 33 years."

"The possibility of procuring a substitute for ebony and ivory has become an important question now that these materials command such extravagant prices. M. Ghoulston Ghislain has brought before the French Academy a substance which he asserts answers this

A 30-second
Report from

BELL LABORATORIES

Charts show 30-second real-time elimination by computers of noise from radar range data: left, raw data; middle, first stage of filtering; right, noise-free space target trajectory.



(NOISE & space target) (noise & **SPACE TARGET**) **(SPACE TARGET)**

Space objects can be tracked by sending radar pulses and observing reflections. But such reflections are accompanied by thousands of "noise" signals from the sky and from the radar receiver itself—especially when the threshold of detection is set low enough to pick up very small or very distant objects. For accurate tracking it is essential, of course, to distinguish reliably between the target signals and the noise.

A new data processing system developed at Bell Laboratories performs this separation of "real" signals from "noise" signals, and does it in two steps.

In the first step, a computer compares the received pulses following each transmitted pulse with those following the next succeeding transmitted pulse. Those received pulses of the first train are then retained which have corresponding pulses in the succeeding train; the others are rejected. Such correlated data result in the information shown in the middle chart.

In the second step, another computer compares the correlated data resulting from the transmitted pulses constituting one "look" at a given section of the sky with the correlated data on subsequent "looks" for the same section of the sky (although enlarged somewhat to allow for motion of the space object), again checking for correlation and when none is found rejecting the data. The third chart shows the resultant noise-free data of a space target moving through the sky.

The data processing system operates continuously and in "real time"—i.e., it processes the data immediately as they arrive from the radar. A human being performing the calculations carried out during the 30 seconds depicted above would require three weeks.

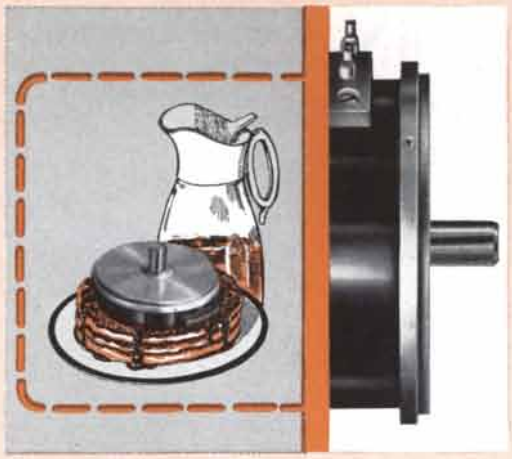
For this military project, engineers at Bell Laboratories, working closely with engineers of the Univac Division of Sperry Rand Corporation, designed and programmed the computers. Because of the demanding requirements of reliability and speed, they developed for it new high-performance semiconductor and magnetic memory components. The two groups combined talents with engineers of the Western Electric Co., the manufacturing unit of the Bell System, to build prototype computers. BELL TELEPHONE LABORATORIES. World center of communications research and development.

purpose completely. He produced it by the following method. Take 60 per cent of the powder of marine plants, 15 per cent of glue and an equal quantity of coal tar; boil till thoroughly mixed; dry in an oven at a temperature of 300 degrees Fah. till it becomes plastic. The compound will assume the appearance of ivory by being heated in an aqueous solution of caustic potash and allowed to macerate for several hours in diluted sulphuric acid; after which subject it to the action of chlorine or chloride of lime, repeating the operation till it becomes perfectly white."

"At a late meeting of the Munich Academy of Sciences, Baron Liebig presented an interesting paper on certain experiments he had made with an apparatus constructed at the expense of the King of Bavaria for estimating the amount of oxygen in various bodies. These experiments prove that not only is oxygen disengaged from the atmosphere by plants, but also in considerable quantities by the decomposition of water in the bodies of carnivorous animals. Baron Liebig is of the opinion that this fact will throw new light on the phenomena—at present so little understood—of nutrition and digestion."

"Lartet and Christy have found in caves in central France a floor-breccia containing bones of the reindeer and other animals, ashes, fragments of charcoal, flint chippings, weapons and utensils of reindeer bones and horns, and slabs of stone having the forms of animals scratched upon them. Among the remains of the reindeer several vertebræ are sometimes found united, and also jointed bones with their parts still in connection, showing that the animals must have lived in the region. There is no written record of the existence of the reindeer or of a sub-arctic climate in what is now temperate Europe."

"Harvey's theory of the circulation of the blood, or rather the causes of the circulation, is beginning to be disputed; for blushing, sudden paleness of the face, flushing and chillness of the body frequently occur without any disturbance or modification of the heart's action. The steady movement of the blood in the capillaries, the circulation through the liver without the intervention of any propulsive force, the fact that after death the arteries are usually found empty, among other things, cannot be accounted for on the hypothesis that the heart is the sole mover of the blood."



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4-gang unit composed of 4 trig function pancake sections. (1) 1.01 tan $\theta/1 \pm \tan\theta$, (2) sine ± 90°, (3) cos ± 90°, each 0.015% peak-to-peak conformity; (4) load corrected linear @ 0.01% conformity, only 2½" long.

THE AUTHORS

HERBERT H. HYMAN and PAUL B. SHEATSLEY ("Attitudes toward Desegregation") are public opinion experts who have collaborated for many years. One of their many joint efforts is the continuing survey described in the present article, which is a sequel to an article with the same title that appeared in the December 1956 issue of SCIENTIFIC AMERICAN. Hyman and Sheatsley carried out their survey on behalf of the National Opinion Research Center of the University of Chicago. Hyman is professor of sociology at Columbia University, where he received a Ph.D. in social psychology in 1942. He has been associated with the National Opinion Research Center since 1947 and has conducted public opinion surveys for the Center and for the government in the U.S., Germany, Japan, Norway and Turkey. He is a past president of the American Association for Public Opinion Research. A graduate of Princeton University and a former journalist, Sheatsley directed the Eastern office of the National Opinion Research Center from 1942 until last year, when he moved to Chicago to assume direction of its Survey Research Service. He is currently secretary of the American Association for Public Opinion Research.

DEREK H. FENDER ("Control Mechanisms of the Eye") is associate professor of biology and electrical engineering at the California Institute of Technology. A native of England, Fender was educated at Henley-on-Thames Grammar School and the University of Reading, where he received a B.Sc. in the physical sciences in 1939. He acquired another B.Sc. as well as a Ph.D., both in physics, from Reading in 1947 and 1956 respectively. During World War II Fender served as a major in the Royal Corps of Signals; after the war he became senior lecturer on radio ballistics and control systems at the Royal Military College of Science in Shrivenham. In 1953 he joined the Reading faculty as lecturer in physiological optics and cybernetics. He transferred his research on problems of visual perception to Cal Tech in 1961.

K. L. FRANKLIN ("Radio Waves from Jupiter") is an astronomer on the staff of the American Museum–Hayden Planetarium in New York. A graduate of the University of California at Berkeley, Franklin spent two years as an assistant astronomer at the Lick Observatory before returning to Berkeley in 1950 to resume graduate study; he received a Ph.D. in astronomy there in 1953. After working for a year with Otto Struve at Berkeley's Leuschner Observatory, Franklin was awarded a postdoctoral fellowship to study radio astronomy in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. In 1955 he and a colleague at the Carnegie Institution, Bernard F. Burke, discovered the radiation from Jupiter discussed in this article. Franklin joined the American Museum–Hayden Planetarium in 1956 because, he writes, "I believed its staff was beginning to do an excellent job in responsible public education, and I was impressed by its organization for this purpose. I thought I might be able to do more in the long run to aid the cause and advance of astronomy by being with this institution than I might do in more traditional employment."

ELWYN L. SIMONS ("The Early Relatives of Man") is associate professor of geology at Yale University and curator of vertebrate paleontology at Yale's Peabody Museum of Natural History. Simons received a B.A. in biology from Rice University in 1953 and a Ph.D. in vertebrate paleontology from Princeton University in 1956. He went to England in 1956 as a Marshall scholar to study with Joseph Weiner (the exposer of the Piltdown fraud) and Sir Wilfred Le Gros Clark at the University of Oxford, where he received a D.Phil. in 1959 for his dissertation on primate evolution. After short teaching stints at Princeton and the University of Pennsylvania, Simons joined the Yale faculty in 1960. He has since led six teaching and research expeditions for Yale, three to Wyoming and three to Egypt.

RAPHAEL H. LEVEY ("The Thymus Hormone") is a resident in surgery at the Massachusetts General Hospital in Boston. He also does research on the immunological role of the thymus gland in the department of surgery of the Harvard Medical School. A graduate of Princeton University, where he investigated biological clocks with Colin S. Pittendrigh and the morphogenesis of mushrooms with John Tyler Bonner, Levey received an M.D. from the Harvard Medical School in 1959. From 1961 to 1963 he was on the staff of the National Cancer Institute in Bethesda,

Md., where the work reported in this article was begun.

P. C. TREXLER ("Germ-free Isolators") is associate professor of microbiology and immunology and research associate professor of surgery at the Albert Einstein College of Medicine of Yeshiva University. He is at present on leave of absence and serving as director of research at two laboratories seeking to develop better equipment for germ-free research: the Snyder Laboratories in New Philadelphia, Ohio, and the Gnotobiotic Research Foundation in North Wilmington, Mass. Trexler was graduated from the University of Notre Dame in 1934 and received an M.S. in bacteriology there in 1936. He did research for a year at the Harvard Medical School before becoming a member of the Notre Dame faculty in 1939. He left Notre Dame to take up his present post in 1962.

MICHAEL D. COE ("The Chinampas of Mexico") is associate professor of anthropology at Yale University. He is also adviser to Harvard University's Robert Woods Bliss Collection of pre-Columbian art at Dumbarton Oaks. A native of New York, Coe received an A.B. and a Ph.D. in anthropology from Harvard in 1950 and 1959 respectively. After teaching for a year at the University of Tennessee he went to Yale in 1960. Since 1957 Coe has concentrated on the development of early civilizations in Central America. He has excavated and traveled extensively in Mexico, British Honduras, Costa Rica and Guatemala. His interest in the chinampa problem, he writes, "was the by-product of a busman's holiday in Mexico City in the summer of 1962, when I became convinced that the 'floating garden' theory was all wet."

DON L. BUNKER ("Computer Experiments in Chemistry") does research at the University of California's Los Alamos Scientific Laboratory in New Mexico. Bunker received a B.S. in chemistry from Antioch College in 1953 and a Ph.D., also in chemistry, from the California Institute of Technology in 1957. He has been at Los Alamos since 1957.

JULES HENRY, who in this issue reviews *Human Behavior: An Inventory of Scientific Findings*, by Bernard Berelson and Gary A. Steiner, is professor of anthropology at Washington University.

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Attitudes toward Desegregation

Presenting a sequel to an article of the same title that appeared in this magazine in 1956. The findings indicate a steady rise in support of integration among whites in both North and South

by Herbert H. Hyman and Paul B. Sheatsley

Nearly eight years ago—in December, 1956—we summarized in these pages the main findings of 14 years of investigation by the National Opinion Research Center at the University of Chicago on the attitudes of white Americans toward Negro Americans. Those findings showed that a majority of white persons in the North favored racial integration of public schools, believed there should be no racial discrimination in public transportation and said they would have no objection to living near Negroes of their own income and educational status. In the South a majority of whites opposed each of these views.

Another finding, however, was that since 1942, when the studies had begun, white opinion in both the North and the South had moved steadily and in some cases strikingly toward the acceptance of integration. Underlying this long-term trend, it appeared from the surveys, were fundamental changes in old beliefs about the Negro—such as that he is innately inferior to whites—and a continued influx of better-educated and more tolerant young people into the population of white adults.

A retrospective look now makes it seem that at the time of our earlier article the pace of events in the area of race relations was slow, at least compared with the pace of events since 1956. Even then, however, school-integration conflicts in small communities such as Clinton and Oliver Springs in Tennessee, Clay and Sturgis in Kentucky and Mansfield in Texas had led to episodes of violence and drawn national attention. Since then developments have come frequently and dramatically: in 1957 the Little Rock conflict, the first Civil Rights Act to be passed by Congress since the Reconstruction and the first demands for school integration in the North; in 1960 the first "sit-in," which was conducted by Negro college students in Greensboro, N.C., and led to a wave of similar demonstrations in both Southern and Northern cities; in 1962 the riots at Oxford, Miss., and last year the march on Washington.

The pace and scope of the Negro protest movement have provoked intensified resistance to integration in some quarters and may even have alienated many whites who are basically sympathetic to the aspirations of Negroes. The surprisingly strong showing of George C. Wallace, the segregationist governor of Alabama, in several Presidential primaries this spring has been interpreted by some analysts as reflecting just such a reaction.

In the light of these developments it is reasonable to ask if the generally optimistic conclusions we drew in our 1956 article are still tenable and if the long-term trend toward the acceptance of integration has been halted or perhaps even reversed. We have a basis for providing some answers to those questions. Last year the National Opinion Research Center, aided by a grant from the Whitney Foundation, was able to make three surveys (in June, November and December) repeating some of the questions asked in the surveys on which the 1956 article was based. The new findings provide a measure of two significant things: the actual shifts in the attitudes of white adults as a result of the eventful developments in race relations since 1956, and the trends of opinion on integration over a span of more than two decades.

Before we discuss these findings we shall briefly describe how the surveys were made. Each survey was designed to include a representative sample of the nation's adult white population and for that purpose involved interviews with 1,200 to 1,500 individuals. The interviewers were white people trained for the task and living in the sample areas. Each interview resulted in a punched card containing the answers and pertinent information about the person interviewed: age, sex, education, place of residence and so on. In this way the National Opinion Research Center was able to compare the opinions of various groups, such as the elderly and the youthful, the highly educated and the poorly educated, and many others.

In discussing the findings we shall use the terms "South" and "North." "South" refers to three regions as defined by the Bureau of the Census: the South Atlantic region (Delaware, Maryland, the District of Columbia, Virginia,

West Virginia, North Carolina, South Carolina, Georgia and Florida), the East South Central region (Kentucky, Tennessee, Alabama and Mississippi) and the West South Central region (Arkansas, Louisiana, Oklahoma and Texas). "North" refers to the rest of the country except for Alaska and Hawaii, where no interviews were conducted. Finally, we wish to emphasize that what we have sought to investigate over these 22 years is the trend of white opinion on racial integration. That is why the findings we shall discuss pertain only to the opinions of white adults and do not include the views of the more than 10 million Negro adults in the nation.

The dramatic changes throughout the nation are illustrated by the findings about school segregation, based on the question "Do you think white students and Negro students should go to the same schools or to separate schools?" In 1942 fewer than a third of all whites favored the integration of schools. The attitudes of Southern whites at that time were about as close to unanimity as one ever comes in surveys of the U.S. public: only 2 percent expressed support for integration. Among Northerners in that period integration also represented a minority view, endorsed by only 40 percent of white adults.

By 1956, two years after the Supreme Court decision against racial segregation in public schools, national approval of integrated schools had risen to approximately half of the total white population; in the North it had become the majority view, endorsed by three out of five white adults. Even the South was far from immune to the changing situation. Earlier only one person in 50 had favored school integration; in 1956 the proportion was one in seven. The most recent figures now show not only that the long-term trend has continued but also that in the South it has accelerated. Today a substantial majority of all white Americans endorse school integration. In the North the figure has continued its steady climb and now stands at approximately three out of every four adults. But whereas in the 14 years from 1942 to 1956 the proportion of Southern whites who accepted this principle rose only from 2 percent to 14 percent, the proportion has now risen to 30 percent in just seven years since that time.

That these are real changes rather than accidental results reflecting unreliability of the sampling method is indicated by other findings. In spite of the errors inherent in all sampling procedures, which may run as high as three or four percentage points in samples of the size used in these surveys, the figures for the total white population, in three separate surveys in 1956 and in three other separate surveys last year, did not vary by more than one percentage point. Even the findings for the separate regions, based on smaller numbers and therefore subject to an even larger sampling error, are highly stable.

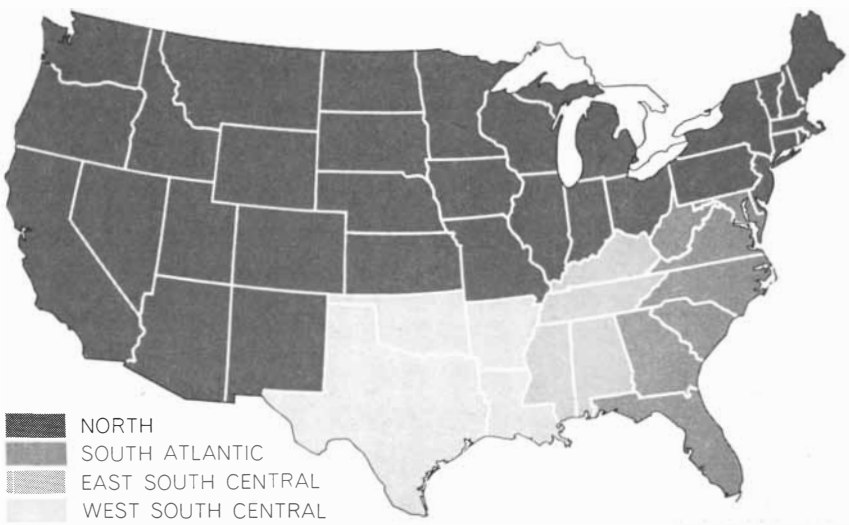
The surveys repeated in 1956 and 1963 also establish that the changes in national opinion on this question represent long-term trends that are not easily modified by specific—even by highly dramatic—events. The survey last November was conducted within a week after the assassination of President Kennedy, but the national findings remained unchanged in spite of any soul-searching that may have been occurring in the North or the South. In 1956, between the June and September surveys, the attention of the nation had been focused on the first violent crises over school integration in a number of small towns in the border states and in Texas. Again the figures showed no change. The overall picture is thus one of a massive trend, unbroken by the particular news events of the day.

What accounts for the steady and strong rise in support for school integration? One important factor would seem to be the conversion of segregationists. The size of the "Don't know" vote in opinion surveys can be taken as a crude but fair measure of the intensity of the public's views. If large numbers report themselves as undecided, the opinions of the remainder are often lightly held. Conversely, if almost everybody has an opinion on the issue, it is probable that opinions are strong.

It could have been expected that in 1942–12 years before the Supreme Court decision and long before the great ferment in civil rights–a considerable number of Americans would have been undecided on the question of school integration. On most issues put to the U.S. public in surveys it is common to find that 10 percent or more of those interviewed are undecided. Yet in 1942 the "Don't know" group on the question of school integration amounted to no more than 4 percent of the total.

That group has remained at about 4 percent since 1942. Therefore the increased support for school integration cannot have come significantly from the ranks of the undecided, leaving the number of staunch segregationists virtually unchanged; nor can it be argued that a number of segregationists have become doubtful of their position and have moved into the ranks of the undecided. The greatly increased support for integration must have come mainly from segregationists who switched to the opposite camp.

There are other indications of the public's strong involvement in the issue of race relations. In last December's survey, prior to any specific questions about integration, respondents were asked: "What, in your opinion, are some of the most important problems facing the United States today?" More people mentioned civil rights and race relations than mentioned any other problem. Similarly, when respondents were asked



NORTH AND SOUTH are differentiated according to the usage in the findings presented in the accompanying article. The South consists of three regions (*lighter grays*) as defined by the Bureau of the Census. The North is the rest of the nation except for Alaska and Hawaii.

YEAR	EVENT
1954	Supreme Court decision against school segregation
1955	Court ruling on school integration "with all deliberate speed" Federal order barring segregation in interstate transportation
1956	School integration conflict, Clinton, Tenn.
1957	First Civil Rights Act since Reconstruction; Little Rock conflict
1958	First use of Civil Rights Act in Negro voting case
1959	Closing of public schools in Prince Edward County, Va.
1960	Second Civil Rights Act; Start of "sit-in" movement, Greensboro, N.C.
1961	Freedom rides
1962	James Meredith at University of Mississippi
1963	March on Washington
1964	Congressional debate on third and strongest Civil Rights Act Supreme Court order on reopening Prince Edward County schools

MAJOR EVENTS in the field of race relations during the past decade are listed chronologically. They indicate the background against which opinions of whites were formed.

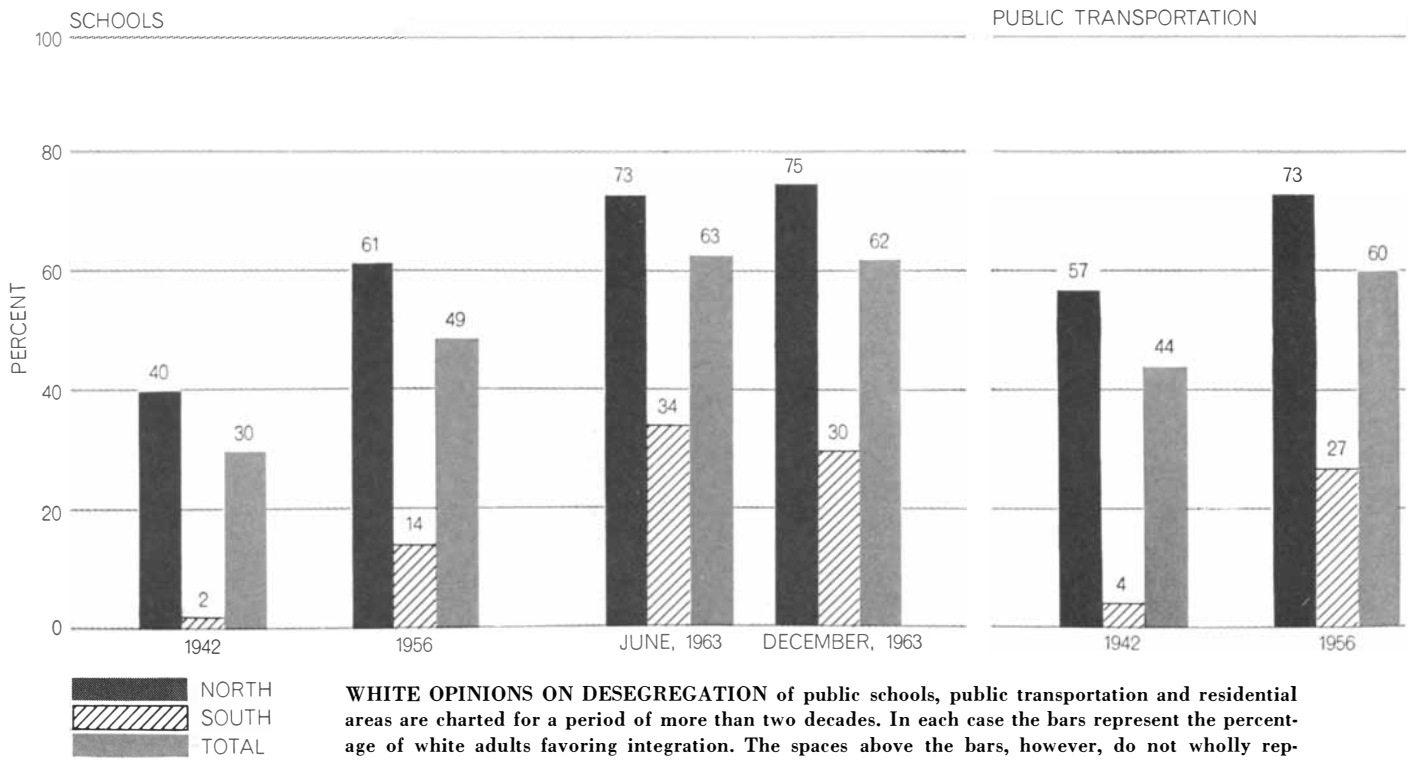
to rate their degree of interest in a number of public issues, there were more people reporting themselves "very interested" in Negro-white relations than in Cuba or the forthcoming Presidential election.

In sum, the long-term trend toward school integration seems to be moving with considerable force. It has not been reversed even by highly dramatic events. Moreover, integration has been achieving its gains by converting persons with strongly held opposing views.

The problems of Negro-white relations involve many issues other than the integration of schools. For two of these—the integration of neighborhoods and of public transportation—detailed data are available on the trend of public opinion over the 22 years. The question asked concerning neighborhoods was: "If a Negro with the same income and education as you have moved into your block, would it make any difference to you?" The question was asked in this way to eliminate the factor of social class from the discussion and leave the respondent confronted only with the issue of his potential neighbor's color. Since the answer "It would make a difference" could include people who would positively welcome a Negro neighbor, supplementary questions clarified any ambiguity in the matter. The question asked about transportation was: "Generally speaking, do you think there should be separate sections for Negroes on streetcars and buses?"

On these questions the same fundamental trends and underlying processes appear as in opinions on school integration. Opinion has remained highly crystallized, with fewer than 4 percent unable to decide. And although these questions were asked in only one of the 1956 surveys, so that it was not possible to judge the impact of short-run events at that time, the fact that there was little change between June and December of last year again suggests that attitudes are not greatly modified by such events.

The main findings, which are presented in more detail in the illustration below, are that support of residential integration rose from 35 percent in 1942 to 64 percent at the end of last year among all whites; that for Northern whites the increase was from 42 percent to 70 percent and for Southern whites



WHITE OPINIONS ON DESEGREGATION of public schools, public transportation and residential areas are charted for a period of more than two decades. In each case the bars represent the percentage of white adults favoring integration. The spaces above the bars, however, do not wholly rep-

from 12 percent to 51 percent, and that during the same period of more than two decades approval of integrated public transportation rose from 44 to 78 percent among all whites, 57 to 88 percent among Northern whites and 4 to 51 percent among Southern whites.

The uniformities in the long-term trends in both the South and the North should not be allowed to obscure certain regional differences in the pattern of opinion on schools, neighborhoods and transportation. For example, the North has been consistently less amenable to residential integration than to integration of public transportation, and the shift in the North over the 22 years has been smallest on the residential issue. Presumably these attitudes reflect the fact that in most of the North whites maintain a social distance from Negroes, although allowing them the legal right to use the same public facilities. This social pattern has contributed to the existence of *de facto* school segregation in the North, even though the great majority of white Northerners are now opposed to school segregation in principle. The pattern is illustrated by the comment of a retired mason in a town in eastern Pennsylvania. After expressing approval of integrated schools and transportation, he said he would object if a Negro of equal education and income moved into his block. He added: "I believe in equality, but not that much."

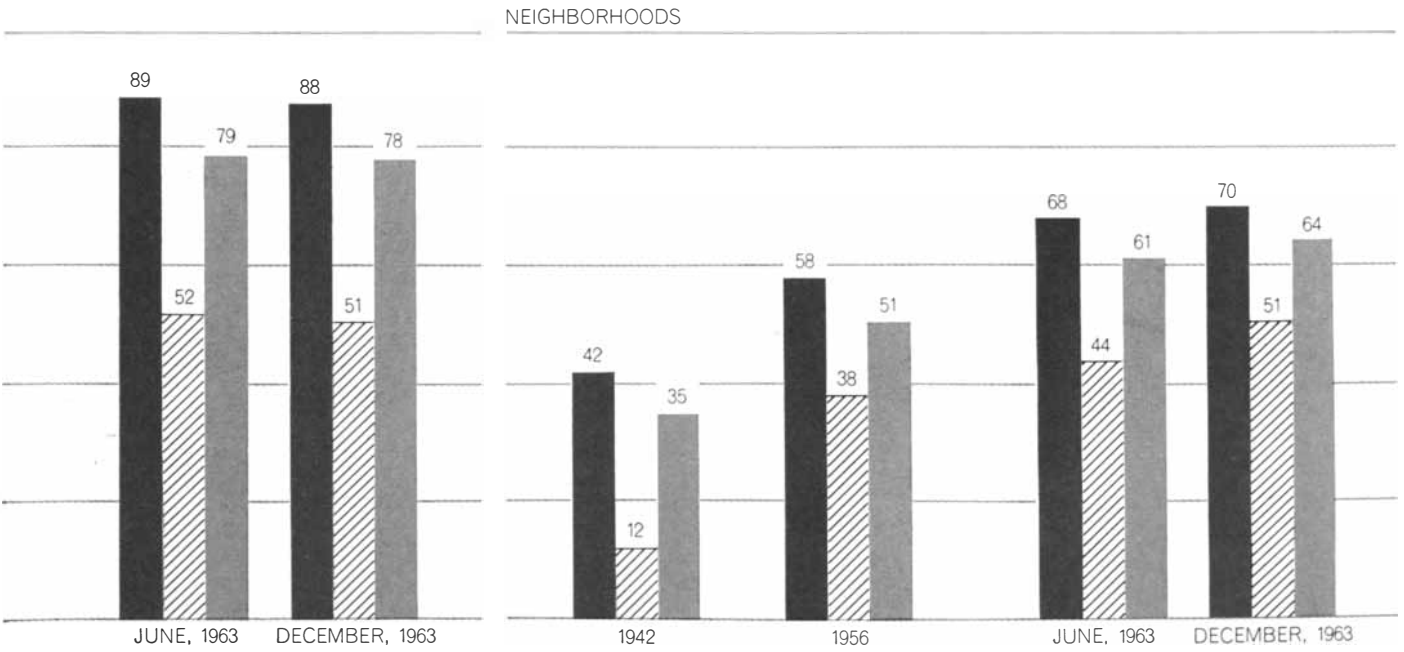
Having discussed the broad findings of the surveys of the National Opinion Research Center since 1942, we turn to some interpretive remarks and to certain aspects of the findings, particularly as they pertain to views about the integration of schools. We shall first discuss the validity of the responses on which the findings are based. Then we shall examine in some detail opinions about the intelligence of Negroes; the correlation between the support of school integration and the degree of school integration existing in the community; the views of Northerners who have lived in the South and of Southerners who have lived in the North; the correlation between degree of education and support for integration, and the attitudes of different age groups.

It is sometimes argued that in public opinion surveys the respondents do not always reveal their true opinions but instead tend to give the answers they think are expected of them. According to this argument some of the opinion supporting integration is of this character because integration is now fashionable. In our view it is unlikely that such factors inhibited many of the respondents in the surveys we are discussing. The surveys show a substantial number of individuals, even in the North, who express opposition to integration, and the magnitude of the opposition is highest in just those spheres where independent evidence would lead one to expect it: the schools in the South and housing in the North.

On many other questions asked in the most recent surveys white respondents freely expressed opposition to full integration or voiced criticism of Negroes. An example is provided by a question asked last December: "Do you think there should be laws against marriages between Negroes and whites?" To this 80 percent of Southern whites and 53 percent of Northern whites answered affirmatively.

Furthermore, many of the respondents seem to take full account of the moral issues involved and still end up on the segregationist side. For example, a mother in North Carolina gave this response to the question about school integration: "I have mixed emotions. I think they deserve the right, but when I think of my own children going with them, I don't know.... Well, I guess I'd say separate schools."

That the demonstrated decline in support of segregation reflects changes in fundamental beliefs is suggested by the long-term trend in white opinion about the inherent intelligence and educability of Negroes. On several occasions since 1942 the National Opinion Research Center has asked the question:



resent persons opposed to integration, for on each issue about 4 percent of the respondents were undecided. Two other surveys in 1956 and one in 1963 produced results consistent with those shown, indicating the reliability of the sampling. The 1963 survey also showed that dramatic events, such as the assassination of President Kennedy, had little effect on the trend of opinion about integration.

"In general, do you think that Negroes are as intelligent as white people—that is, can they learn things just as well if they are given the same education and training?" In the responses to that question there has been a striking change. In 1942 only 50 percent of Northern whites answered "Yes." Today the figure has risen to 80 percent. In the South today a substantial majority credits Negroes with equal intelligence, in contrast with only 21 percent in 1942.

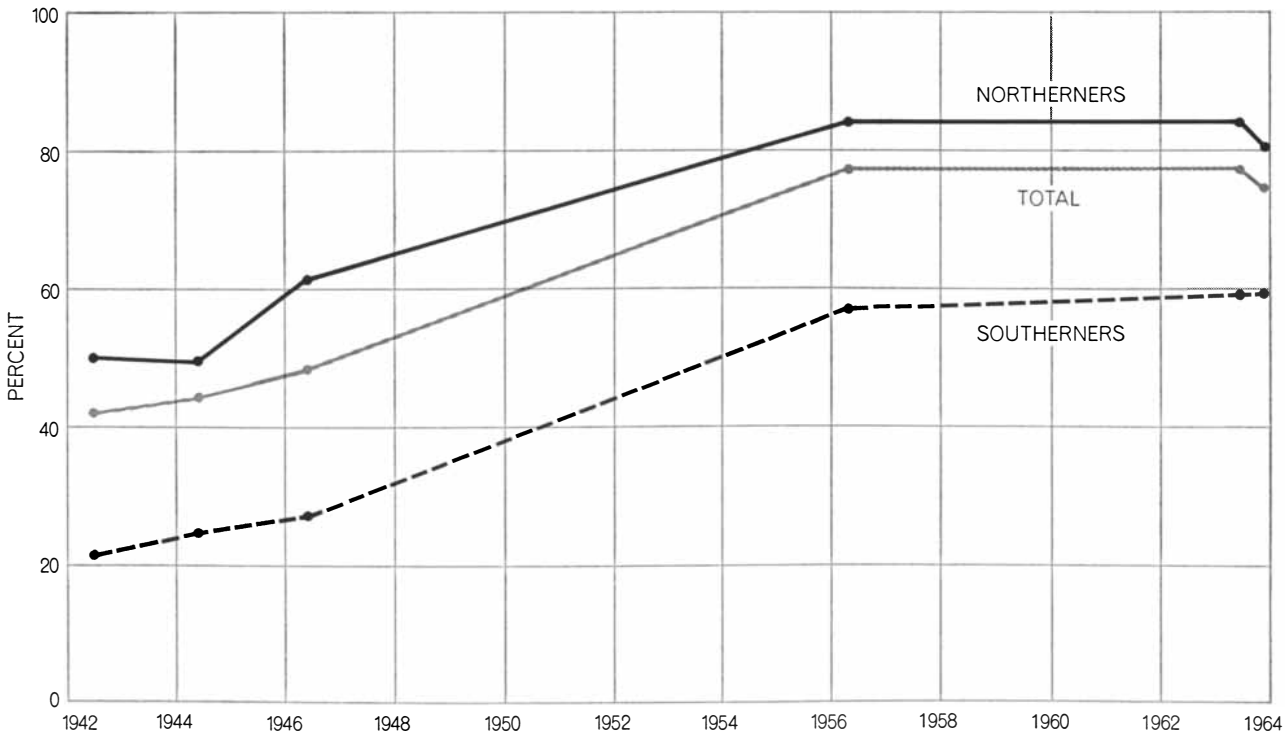
This revolutionary change in belief goes far to explain the increased acceptance of school integration over the past two decades. It has undermined one of the most stubborn arguments formerly offered by whites for segregated schools. The illustration on the opposite page shows the relation between belief in the educability of Negroes and the support of integrated schools in the 1956 and 1963 surveys. As one might expect, those who regard the Negro's intelligence as equal to the white's are much more likely to favor integrated schools than those who regard the Negro as inferior in intelligence. There is more than this, however, to be said. Belief in the equal intelligence of Negroes, after rising steadily for 14 years, leveled off in 1956 and has remained stable since then. Support of integrated schools, however, has continued to rise. Plainly there are forces at work in the growing support for the integration of schools other than belief in the educability of Negroes.

Attitudes on school integration vary according to the degree of integration existing in a given area. This becomes apparent when one looks at particular Southern areas instead of regarding "the South" as a homogeneous region, as we have in this discussion up to now. The occurrence of racial crises in some Southern communities but not in others and the varying degrees of official compliance with Federal law suggest that there are large differences within the region. Our surveys bear this out. We divided our sample of Southern localities into three groups according to the amount of integration in the public schools: those with considerable integration, those with token integration and those that remain completely segregated. Since few Southern communities fall into the first classification, respondents living in those areas constitute a tiny fraction of the total, and the sampling error of this particular statistic could be substantial. To give greater strength to the findings we have pooled the results of the surveys in June and December, 1963, and as another check we have compared responses made when the Gallup Poll, at our request, asked Southern whites the question on school integration in June, 1963.

In Southern districts where considerable integration of schools has taken place 54 percent of white adults favor integration; in districts where token integration has occurred, 38 percent express favorable attitudes, and in segregated districts 28 percent favor integration. There is obviously some parallel between public opinion and official action, but which came first? In the desegregated areas did integration come about in response to a more favorable public opinion or did the more favorable public opinion develop only after the official act of desegregation?

Close analysis of the current findings, compared with those of the 1956 surveys, leads us to the conclusion that in those parts of the South where some measure of school integration has taken place official action has *preceded* public sentiment, and public sentiment has then attempted to accommodate itself to the new situation.

In the 1956 surveys of those Southern districts that had already achieved some integration of schools only 31 percent of white adults expressed approval of the idea. By 1963 the number of such communities had been increased by those



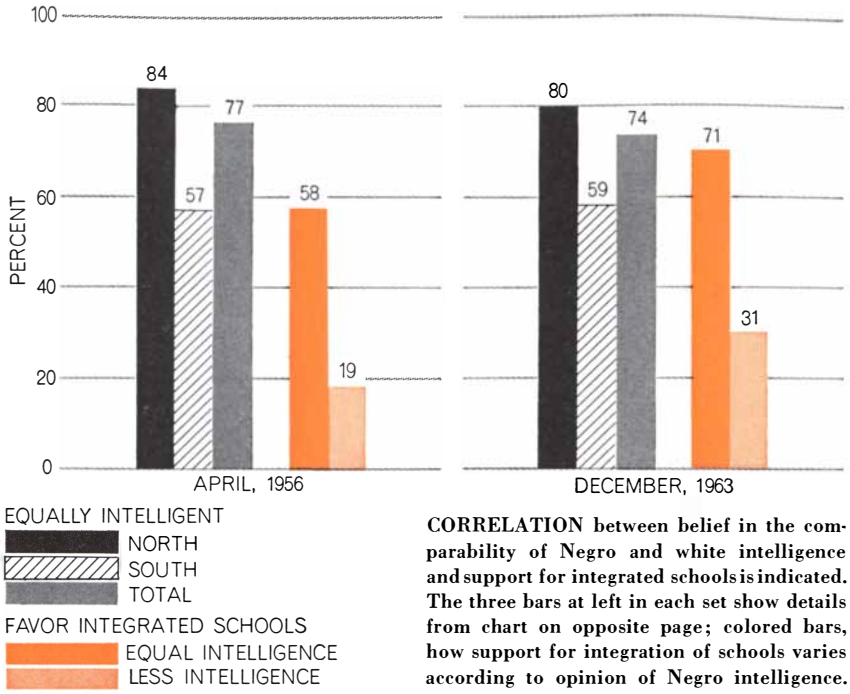
INTELLIGENCE OF NEGROES in the opinion of whites is the subject of this chart. A series of polls in which whites were asked if they believed Negroes to be as intelligent and educable as whites produced the percentages of affirmative responses shown here.

districts that only belatedly and reluctantly accepted a measure of integration; in our current sample more than half of the Southern respondents living in communities now classified as integrated to any degree experienced such integration only within the past year, and none of those in areas of considerable integration were exposed to such a level of integration before 1962. One might expect as a result that the proportion approving integration would be even lower than it was seven years ago. Instead approval of integration has risen in such areas from less than a third in 1956 to more than half of their white population today.

Similarly, it was found in 1956 that only 4 percent of white adults in Southern segregated districts favored the integration of schools. Since then some of these communities have reluctantly adopted a measure of integration, so that the segregated districts that remain might be described as the hard core of segregation. Within this hard core, however, approval of school integration has now risen to 28 percent of the white public. Thus even in the extreme segregationist areas of the South the tides of opinion are moving toward integration, and in the more progressive areas it seems that official action in itself is contributing to the speed and magnitude of popular change.

In this connection it is relevant to cite the results of the following question, asked repeatedly over the years by the Gallup Poll and included in the National Opinion Research Center survey of June, 1963: "Do you think the day will ever come in the South when whites and Negroes will be going to the same schools, eating in the same restaurants and generally sharing the same public accommodations?" In South and North alike, whether the community has segregated or integrated schools, more than three-quarters of the white adults believe that integration is bound to come. In contrast, only 53 percent of the respondents felt that way in 1957. Apparently the pattern is that as official action works to bury what is already regarded as a lost cause, public acceptance of integration increases because opinions are readjusted to the inevitable reality.

Data from the 1963 surveys also enable us to compare opinions in Northern communities that vary in the extent to which Negro and white children attend the same schools. As we have noted, such segregation in the North stems largely from patterns of residential housing rather than from law, but the



CORRELATION between belief in the comparability of Negro and white intelligence and support for integrated schools is indicated. The three bars at left in each set show details from chart on opposite page; colored bars, how support for integration of schools varies according to opinion of Negro intelligence.

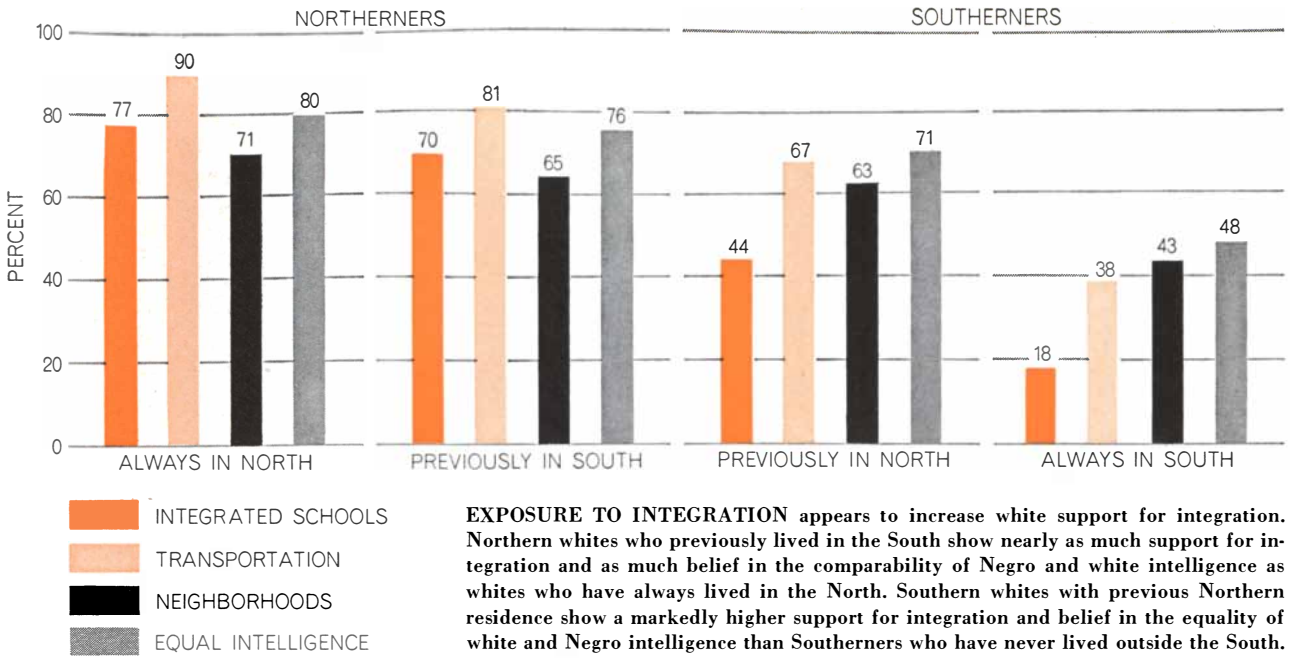
comparisons with the South are nonetheless of interest. Again we find greater support for integration where integration actually exists and greater support for segregation where there is no integration. In both types of community, however, the overall level of support is much greater in the North than in the South. Among Northern whites living in districts that have segregated schools 65 percent favor integration; in Northern areas where schools are considerably integrated 83 percent favor the policy.

A similar pattern of support for integration growing with exposure to integrated situations appears in the findings about people who have moved between North and South. The top illustration on the next page compares the opinions of four groups: Northerners who have never lived in the South, Northerners who once lived in the South, Southerners who have never lived in the North and Southerners who did at one time live in the North. From the comparison it is apparent that Northerners who once lived in the South differ very little in their views from Northerners who have never been exposed to Southern life. They are only slightly less favorable to integration. In striking contrast, those Southerners who have previously lived in the North differ greatly from those who have always lived in the South. Except on the issue of school integration, the attitudes of Southerners with a history of earlier residence in the North are much closer to those of Northerners than to those of their fellow Southerners. Even on school integration the difference is substantial.

The influence of geographical mobility on Southern opinion may well account for a considerable part of the gross change in Southern attitudes over the recent decades. Although the rate of movement from South to North exceeds the rate from North to South, the Southern migrants represent a relatively small proportion of the Northern population, whereas among Southerners today a considerably larger proportion have had some Northern exposure. Thus the net effect of migration is to strengthen support for integration.

As for the relation between amount of education and support of integration, both the 1956 and the 1963 surveys showed that the better-educated groups, North and South, were more favorable to integration of schools and public transportation than people of less education were. Between the two surveys, however, all subgroups have become more favorable to integration [*see bottom illustration on next page*]. Since the number of cases in the South is small, and since the subgroup estimates are subject to a larger sampling error, we have pooled the two recent surveys.

The most dramatic change of opinion has occurred in the best-educated segment of the Southern white population, where the proportion in favor of inte-

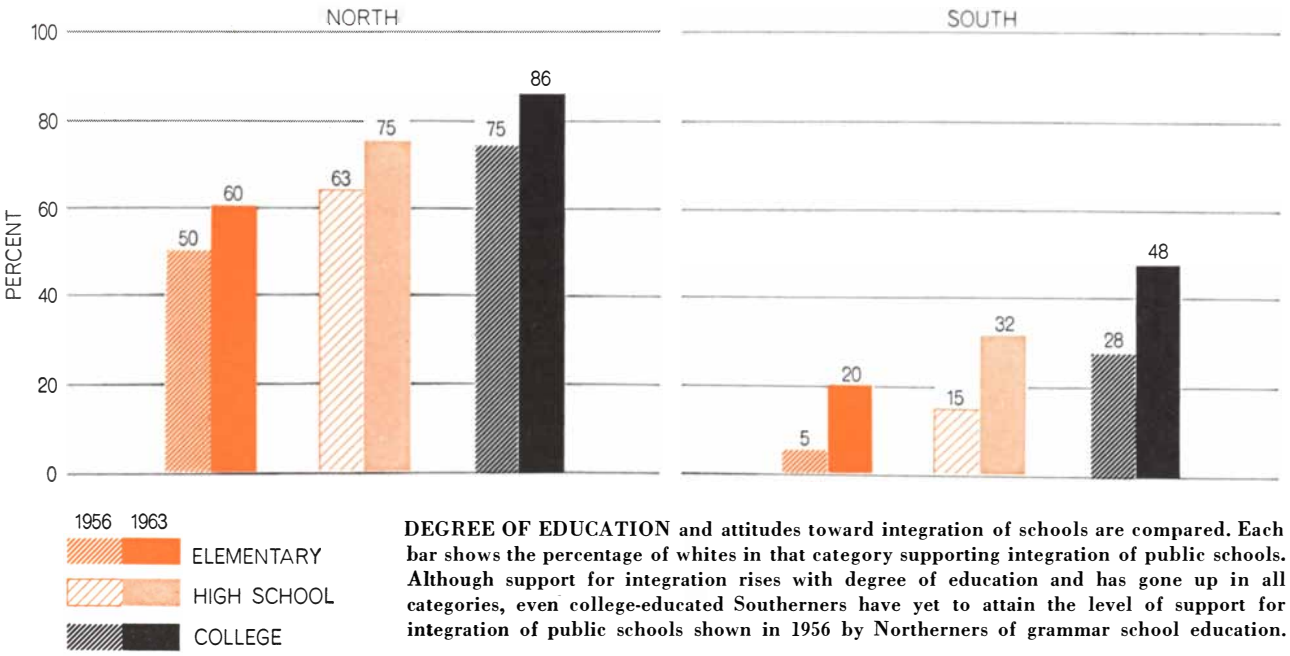


EXPOSURE TO INTEGRATION appears to increase white support for integration. Northern whites who previously lived in the South show nearly as much support for integration and as much belief in the comparability of Negro and white intelligence as whites who have always lived in the North. Southern whites with previous Northern residence show a markedly higher support for integration and belief in the equality of white and Negro intelligence than Southerners who have never lived outside the South.

gration has increased from only about a fourth to almost half. Lest formal education appear to be a decisive factor, however, note that in 1963 the best-educated white Southerners were not as favorably inclined to integration as the least-educated white Northerners, and that by 1963 those Southerners had not yet reached the level of opinion already exhibited in 1956 by poorly educated Northerners.

In 1956 it was found that the segment of the white population represented by people 65 and older, in both the North and the South, was least favorable to integration, and the same finding is documented in the recent surveys. One would expect this result on the basis of education alone; inasmuch as the expansion of educational opportunity is a development of recent decades, the oldest adults are less likely than the younger ones to have had advanced schooling. Indeed, some of the long-term trends in attitudes toward segregation may simply represent the passing of the oldest generation and its replacement in the population by younger individuals of greater tolerance. The persistence of the difference in attitudes between the oldest group and younger groups would help to account for the further changes in public opinion in more recent years and would augur still more change in the future.

Since the analysis of differences between age groups is so relevant to an understanding of long-term opinion trends, the sample in last December's survey was designed to double the number of interviews with the youngest adults—those from 21 to 24. These extra interviews were not included in the tabulations except for this particular



DEGREE OF EDUCATION and attitudes toward integration of schools are compared. Each bar shows the percentage of whites in that category supporting integration of public schools. Although support for integration rises with degree of education and has gone up in all categories, even college-educated Southerners have yet to attain the level of support for integration of public schools shown in 1956 by Northerners of grammar school education.

analysis, but by using them here we can place greater confidence in our findings for this age group, which otherwise would account for only a small portion of the national sample. In this way we are able to provide more evidence for a new finding that appeared in the survey of June, 1963, but then could be regarded only as suggestive. The finding, which is reflected in the illustration on this page, is that whereas in 1956 the youngest adults were the most favorable to school integration, by 1963 the pattern—at least for the South—seemed to have changed. Although they were never as prosegregationist as the older age groups, the 21-to-24-year-olds appeared in the recent surveys to be less favorable to the integration of schools than the adults aged 25 to 44. The difference is admittedly small and could conceivably be due to sample variation. But the finding appeared in all of last year's surveys; unless it is disproved by subsequent studies one must accept as valid the evidence that the youngest adults are relatively less tolerant than formerly, in spite of the fact that on the average they are more highly educated.

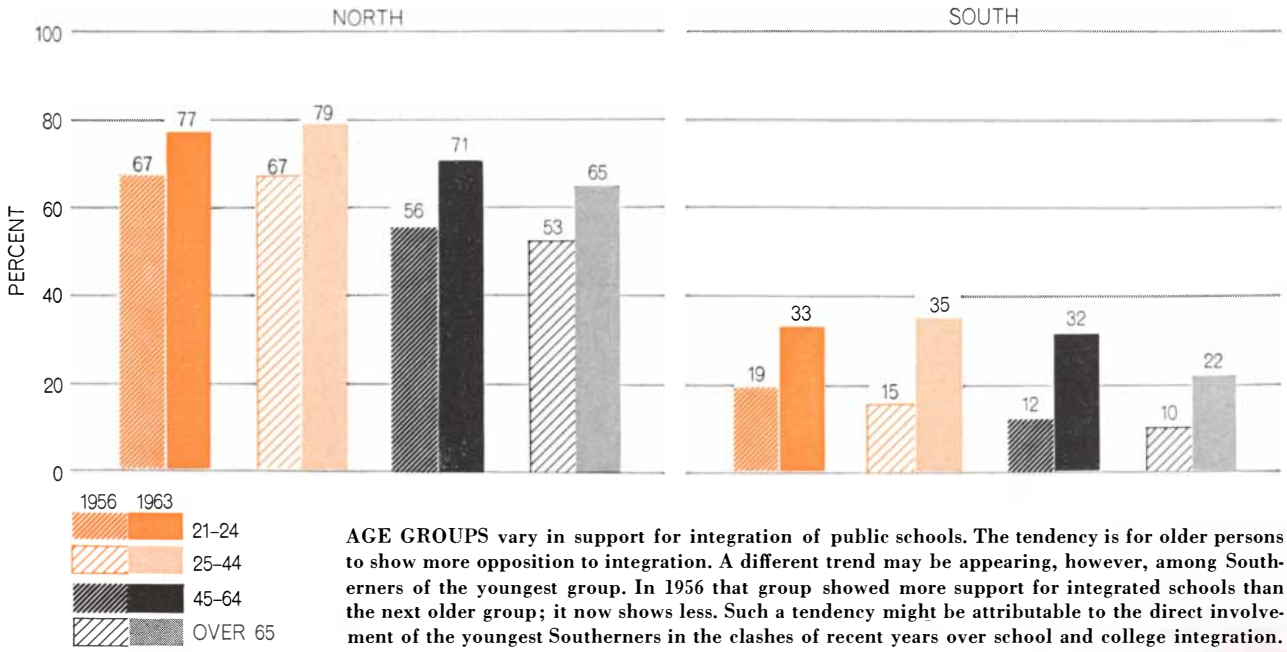
The members of the youngest group in 1956 have, of course, now aged sufficiently to be included in the present 25-to-44 group and have added their earlier quantum of tolerance to that older group's attitudes. Those who are now in the 21-to-24 group were still children in 1956 and so were not included in the surveys of that time. But why, having arrived at the status of young adults, do they not exhibit the larger measure of tolerance characteristic of the equivalent age group in earlier years?

That the phenomenon is clearly evident only in the South suggests an explanation, because this newest group of young Southern adults has lived through experiences quite different from those of the generation of young adults studied in 1956. They have spent their high school and college years in the stormy decade since the Supreme Court decision, and it is they who have been most closely associated with the crises and dislocations that have accompanied the transition to integration in various communities. Actually few of them appear to have suffered directly from these events. They were asked "In what ways have you or any members of your family been affected by integration?" More than four-fifths reported no effects. It is noteworthy, however, that not a single Southerner of this age group spontaneously reported any kind of favorable effect, whereas among Northerners of the same age 5 percent volunteered an answer describing the personal effects of integration in favorable terms.

Plainly the conflicts of integration have had a great immediacy for the young Southerners. The issue of civil rights is more salient for them than for the older groups in our Southern sample. More of them spontaneously mention race relations as the biggest problem facing the country today. The youngest Southerners are more likely than the next older group to express themselves as believing the Negro protest movement is "violent" rather than "peaceful" and to voice the opinion that demonstrations and protests have "hurt the cause" of Negroes.

Other questions substantiate the likelihood that a change of attitude has occurred among young Southern adults. When asked if their views have remained the same in recent years or have become more favorable or less favorable to integration, it is this youngest group that is more likely than others to report both a change in attitude and a shift away from a favorable opinion. For example, the youngest adults in the South say they have shifted almost two to one against integration in recent years. The older groups report less change of attitude, and when it occurs, the shifts are about equal in both directions.

Apart from this tendency, about the extent or permanence of which we cannot yet be sure, it appears that the attitudes of white Americans of both the North and the South are continuing to shift toward greater acceptance of integration. We cannot be certain that future events will not reverse the course. But the unbroken trend of the past 20 years, and particularly its acceleration in the past decade of intensified controversy, suggest that integration will not be easily halted. In the minds and hearts of the majority of Americans the principle of integration seems already to have been won. The issues that remain are how soon and in what ways the principle is to be implemented.



AGE GROUPS vary in support for integration of public schools. The tendency is for older persons to show more opposition to integration. A different trend may be appearing, however, among Southerners of the youngest group. In 1956 that group showed more support for integrated schools than the next older group; it now shows less. Such a tendency might be attributable to the direct involvement of the youngest Southerners in the clashes of recent years over school and college integration.

CONTROL MECHANISMS OF THE EYE

The control system whereby the eye tracks a target is investigated by an engineering technique, systems analysis, and is found to be a servomechanism in which retinal-image motion serves as feedback

by Derek H. Fender

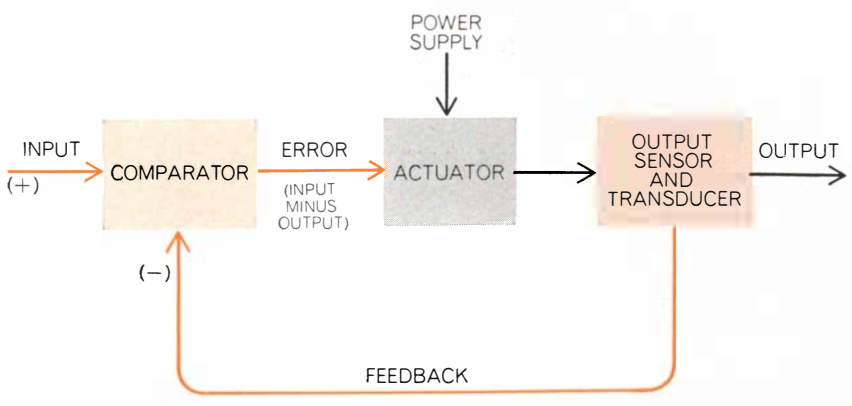
When a biologist seeks to understand how a particular mechanism in a living organism works, he often begins by dissecting the structure and analyzing the interrelation of its parts. In the study of some biological mechanisms this approach is ineffective; it may be better to examine the mechanism "from the outside" as it performs its normal functions. Here the engineering technique known as systems analysis can be useful. The investigator measures the responses of a functional unit to some simple and well-defined stimulus, and the relation between stimulus and response reveals the presence of certain classes of elements in the unit. It thus provides a clue to the makeup of the system, and with this clue the biologist can now look for the elements of the mechanism and describe its operation with more confidence.

In this article I shall discuss an application of systems analysis to the investigation of human vision, in particular to the processes whereby the eye fixes on and tracks an object in its field of view. I shall be considering the eye not as a camera but as a mechanical system: a servomechanism. Engineers define a servomechanism as a device that controls some variable physical quantity in a special way: by comparing its actual value with a desired reference value. It uses the difference between the two to drive an actuator that in turn adjusts the variable to correspond with the reference. The reference value is the input signal and the controlled quantity is the output signal; the basic principle of the servomechanism is a "feedback" from output to input [*see illustration below*].

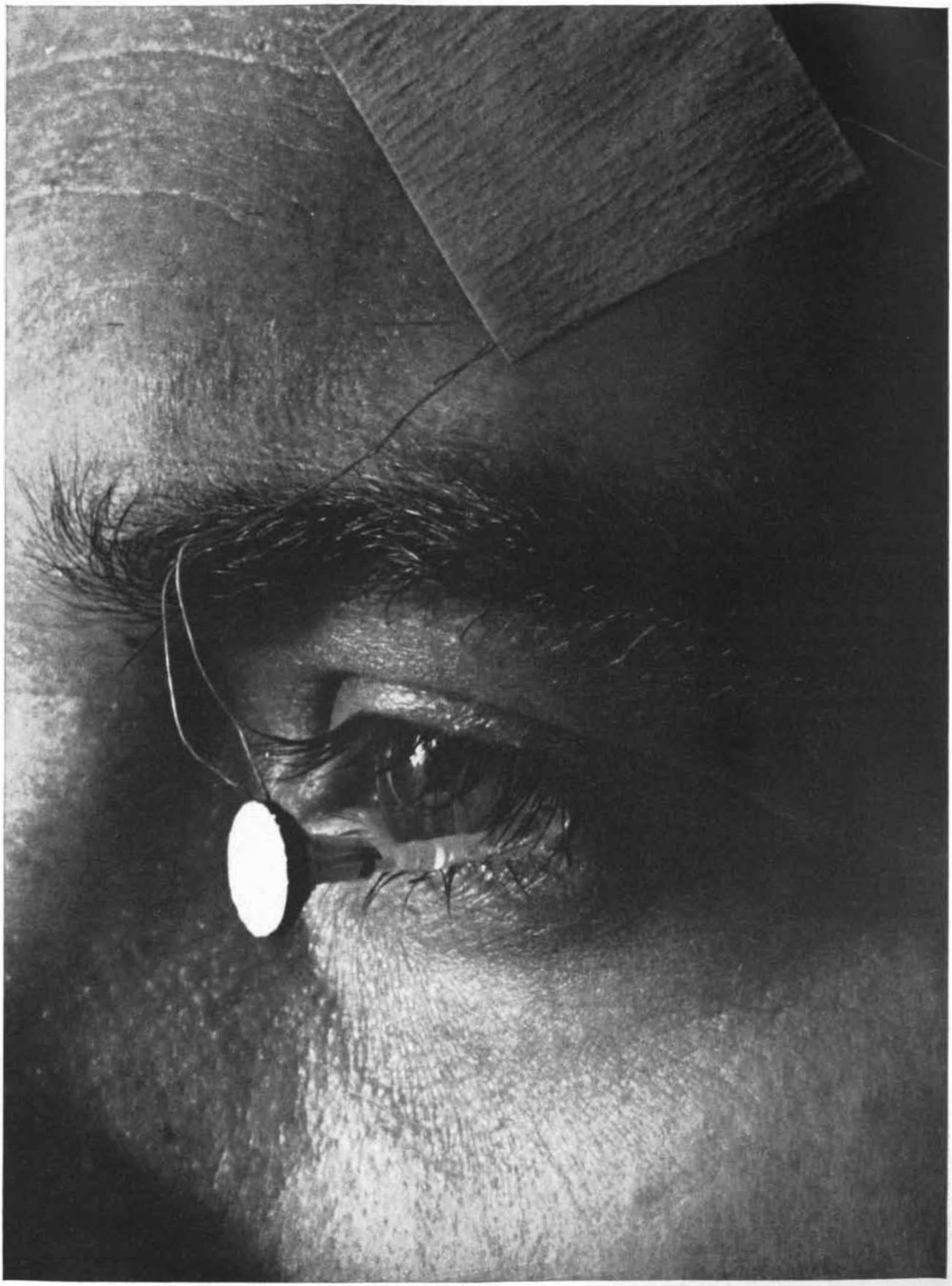
The servomechanism monitors its own performance and makes corrections as required either to conform with a change in the input signal or to compensate for an external disturbance of the output. The power-steering mechanism of a modern automobile is a good example of a servomechanism. The reference, or input, signal is provided by the position of the steering wheel; the output variable is the position of the front wheels. When input and output differ, the difference causes a hydraulic actuator to move the front wheels. When the driver rotates the steering wheel, the wheels take up a new position; when a pothole deflects the wheels, the servomechanism quickly returns them to the desired position.

The human body is a collection of servomechanisms. Feedback control systems regulate body temperature and the constitution of body fluids; they vary the flow of blood to the organs and extremities and adjust the rate of breathing to the level of physical activity. The joints have "proprioceptors" that measure the flexure of an extremity and feed back a signal to be compared with the reference, or "command," nerve signals from the brain. Some feedback loops are completed outside the body. For example, a man who wants to pick up an object observes with his eyes the closing gap between his hand and the object: the visual sense measures the "error" in hand position.

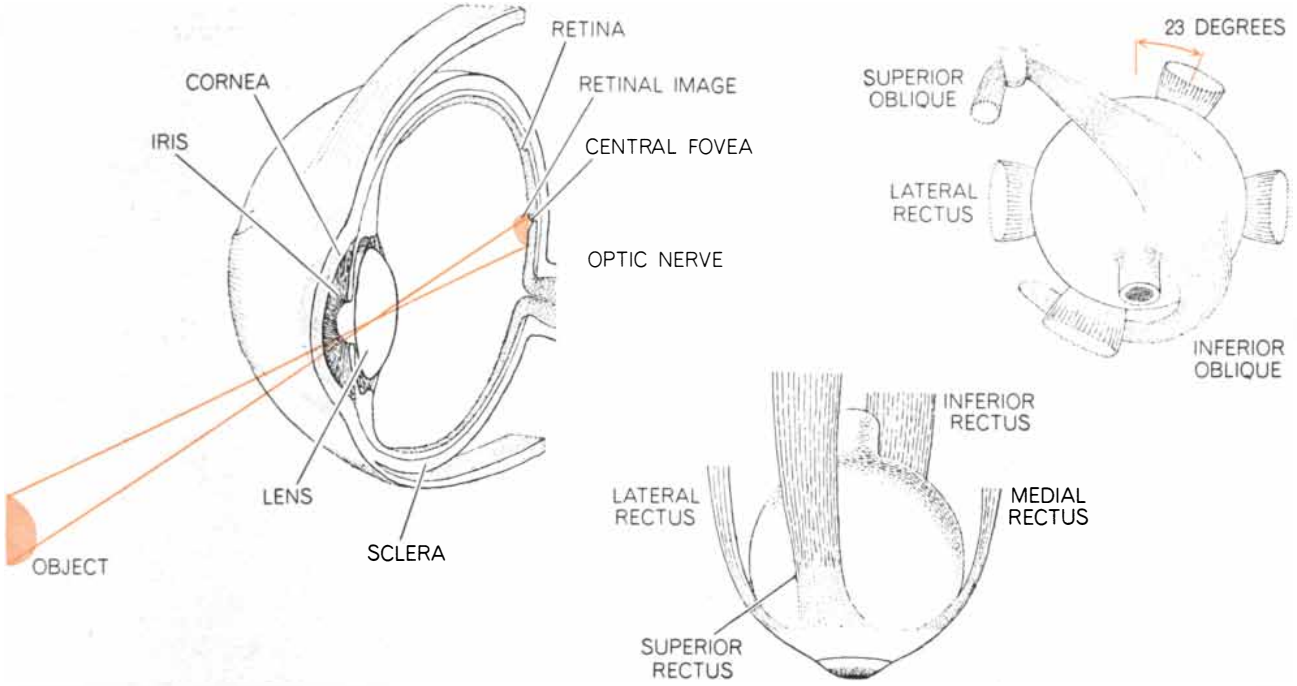
Not all of these biological control systems are equally open to investigation. Systems analysis requires that there be an input point where the stimulus can be applied and an output point where the signal regarded as the response of the system can be measured. Moreover, if it seems that the system includes a feedback loop, one must be able to change the operating conditions of that loop precisely, thus achieving the full potential of systems analysis by examining the characteristics of the "feed-forward" and feedback paths independently. These limitations have restricted the application of systems-analysis methods in human beings to a few subsystems: those in which a sensory input gives rise to motor activity. Various workers have studied feedback loops involving the control of limb



SERVOMECHANISM controls an output value by comparing it with an input, or reference, value. The sensor measures the output (a velocity, for example); the transducer states it in input terms (a voltage, perhaps) to be fed back to the comparator, where it is subtracted from the input. The resulting "error" drives the actuator to adjust the output.



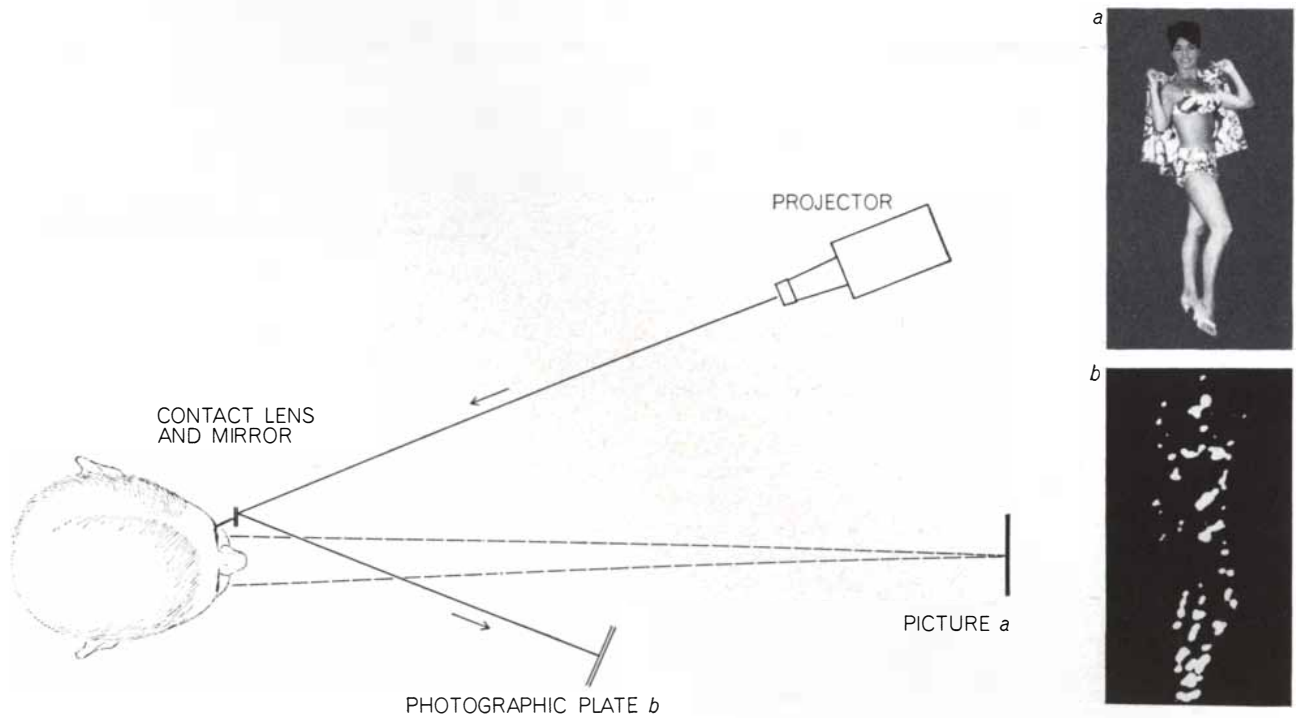
CONTACT LENS with mirror attached is mounted in the eye of George W. Beeler, Jr., one of the author's students. Light reflected from the mirror can be recorded on film to show the direction of gaze. In some experiments the mirror is made part of the optical path between the target and the eye, so that the image moves with the eye. The wires power a tiny lamp in the stem of the mirror.



CONTROL SYSTEM of the eye positions the image of an object on the central fovea, the most sensitive part of the retina (*left*). Three pairs of muscles move the eyeball. Two drawings show the right eyeball from above (*center*) and from the rear (*right*). The two pairs of recti move the visual axis from side to side and up and down; the oblique muscles roll the eyeball about the axis.

movements by proprioceptors, the control of manual movements by the eye and—perhaps most interesting of all—the eye's control of its own varied and richly interrelated movements.

The eye's optical components form the image of an external object on the retina, a screen of light-sensitive receptor cells that convert radiant energy into nerve impulses; these impulses pass along the optic nerve to the visual cortex of the brain and there generate the sensation of vision. The retinal receptors are not distributed uniformly; the cone cells, which are specialized for daylight and color vision, are most numerous and most closely packed in the fovea, a small depression at the center of the retina, and are intermingled with the twilight-vision reds and therefore more widely spaced toward the retina's periphery.



DIRECTION OF GAZE is recorded by a beam of light reflected from the contact-lens mirror. As the eye moves and lingers over a scene (*a*) the reflected beam exposes corresponding areas on the film (*b*); the resulting light spots indicate where the eye looked.

The fovea, then, is the part of the retina capable of the sharpest vision. It is not a large area; the image of a thumbnail viewed at arm's length just about covers it. To examine an object closely a person moves his eyes so that the image of the object falls on corresponding areas of his two foveas.

Three pairs of muscles rotate the eye in its socket. The medial and lateral recti move the visual axis from side to side, the superior and inferior recti move the axis up and down and the superior and inferior obliques roll the eyeball about the visual axis. It is a servomechanism that controls these muscles to position the image of an object on the fovea. Each pair of muscles receives signals proportional to the displacement of the interesting part of the image from the fovea, and the muscles then act together to move the eyeball in such a way as to reduce the displacement to zero. Retinal-image displacement is used as a feedback signal; in this instance the eye operates as what an engineer would call a simple position servomechanism.

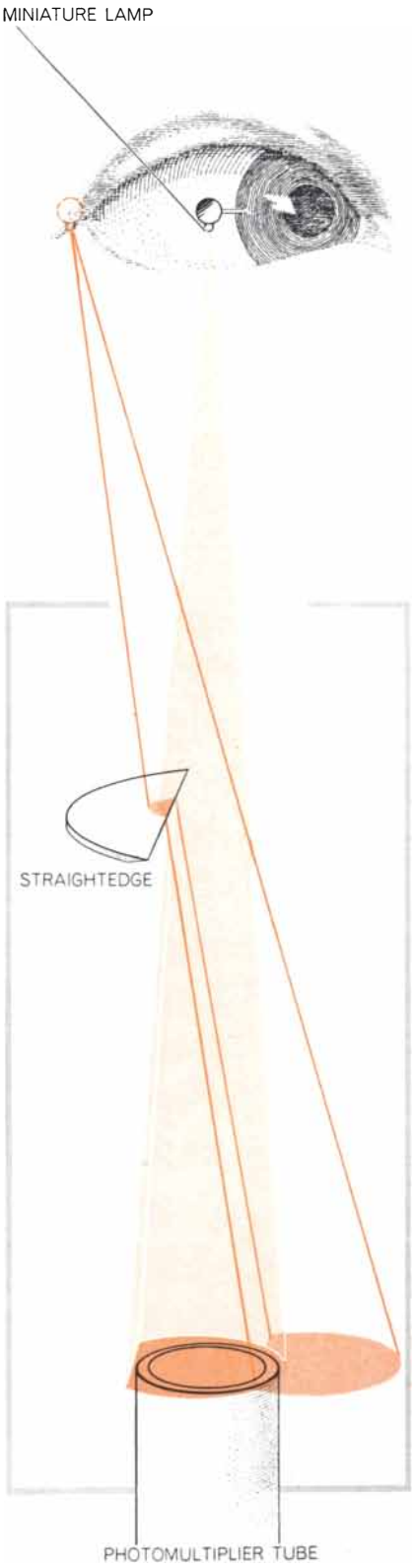
This is far from being the only feedback control system of the eye. Depth perception, for example, requires that images of an object be formed on corresponding areas of the retina in each eye. There is a control system that brings the eyes to the correct angle of convergence—a system that appears to be quite distinct from the mechanism governing the general direction of gaze but that operates through the same set of muscles. The image must also be focused sharply on the retina. Since the distance between the lens and the retina is fixed, focusing is achieved by changes in the thickness, and therefore in the focal length, of the lens. Here too it is a feedback control mechanism that adjusts this state of "accommodation" of the lens.

There is an interesting relation between the convergence and accommodation systems. One might expect that the angle of convergence would provide the visual system with information for calculating the distance of an object and then setting the focal length for a sharp image, rather like a coupled range finder on a camera. Instead the accommodative mechanism has a steady "hunting" motion superimposed on it that continually lengthens and shortens the focal length of the lens. Depending on the location of the object being viewed, a change in one direction will improve an out-of-focus image and a change in the other direction will worsen it; this information is fed back to steer accommodation in the direction of the sharpest focus. Once the correct lens thickness is found, information about it is fed across to the convergence mechanism. The two systems are separate and distinct in their modes of control but are cross-linked: information derived by one is fed into the other.

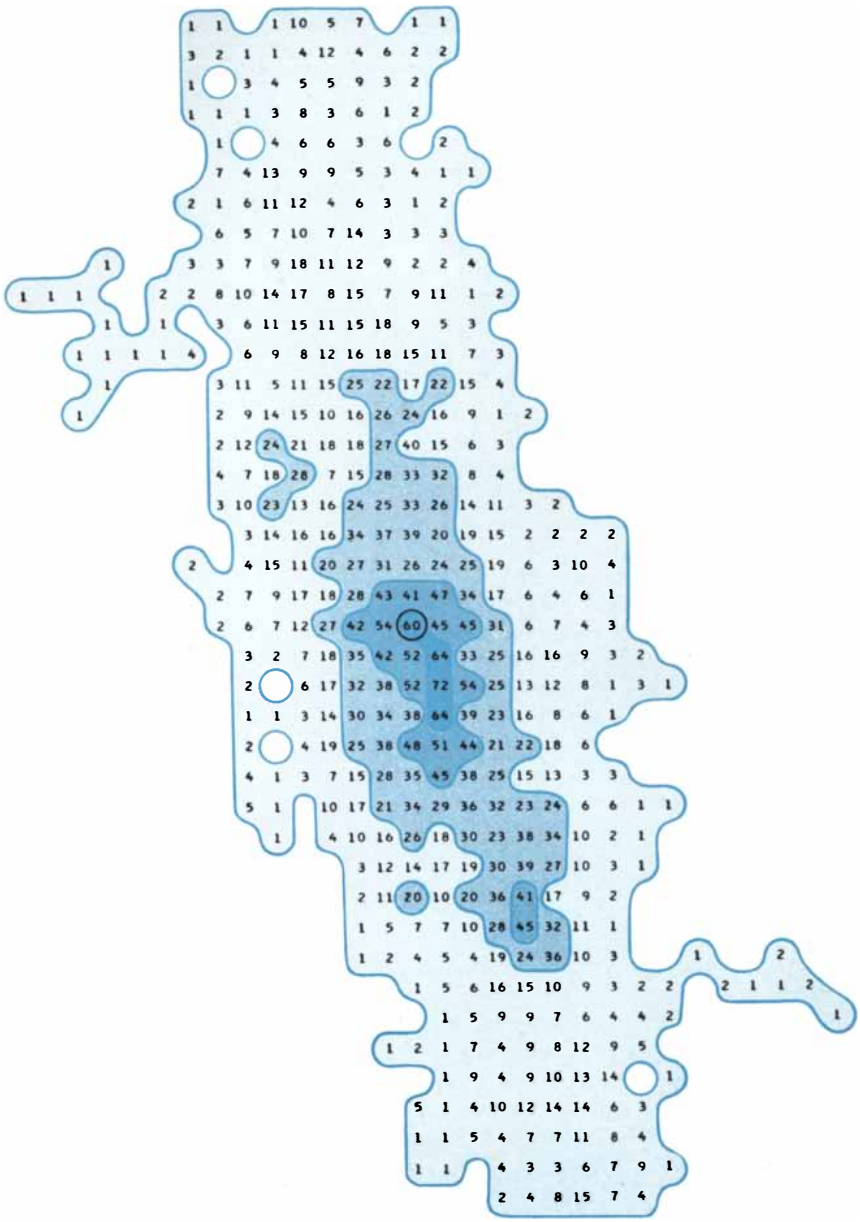
Still another feedback mechanism changes the diameter of the pupil. It measures the average illumination of the retina and activates the muscles of the iris to minimize variations in the brightness of the retinal image. This mechanism is linked in turn to the accommodative system, because when the focal length of the lens increases, the pupil must enlarge to keep the brightness of the image constant. Finally, there is even a control circuit that moves the eyelids out of the way when the gaze is directed upward. The visual pathway, then, is composed of a number of interconnected feedback systems. Each has been examined separately and, as I have indicated, some work has been done on the interactions among the various mechanisms. Let us now consider the eye's positioning and tracking system in some detail.

Some 60 years ago E. B. A. Delabarre of Brown University used a plaster cast of the cornea to fasten lightweight levers to his own eye and record its motion. Since then a number of less painful techniques have been developed. Large eye motions can be recorded by photographing the reflection of a light from the corneal surface. Another method relies on the fact that the eyeball has a small electric charge, and its slow movements can therefore be measured by electrodes placed around the eye socket. In 1925 Gösta Dohlman of the University of Uppsala in Sweden attached a mirror to a subject's eye with a rubber suction cup, so that a beam of light reflected from the mirror would trace the movements of the eyeball. In more recent adaptations of this technique, including those we have developed in my laboratory at the California Institute of Technology, the mirror is mounted on a contact lens.

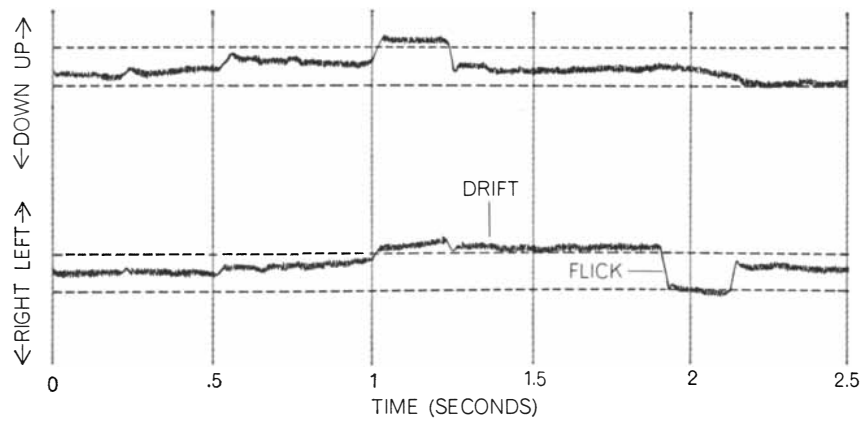
Such a mirror, together with a simple projection system and a photographic plate, provides a record of how the eye examines a scene [*see bottom illustration on opposite page*]. The subject's eyes wander over the picture, hovering selectively at certain points. The mirror moves with the direction of gaze, reflecting the beam of light, which builds up exposures at corresponding points on the photographic plate. When the resulting



PHOTOMULTIPLIER TUBE provides a more accurate gauge of eye movement, as shown here schematically. The apparatus is so placed that when the subject's eye is farthest to his left, maximum light strikes the tube. As the eye moves right (*colored circle*) the straightedge cuts off light from the tube. The output current of the tube therefore measures the position of the eye.



CONTOUR MAP shows how the eye wanders while staring at a very small stationary object whose position and size are shown by the black circle. The vertical extent of the fixation pattern is about 3/4 degree. The numbers give the relative period of fixation at each point.



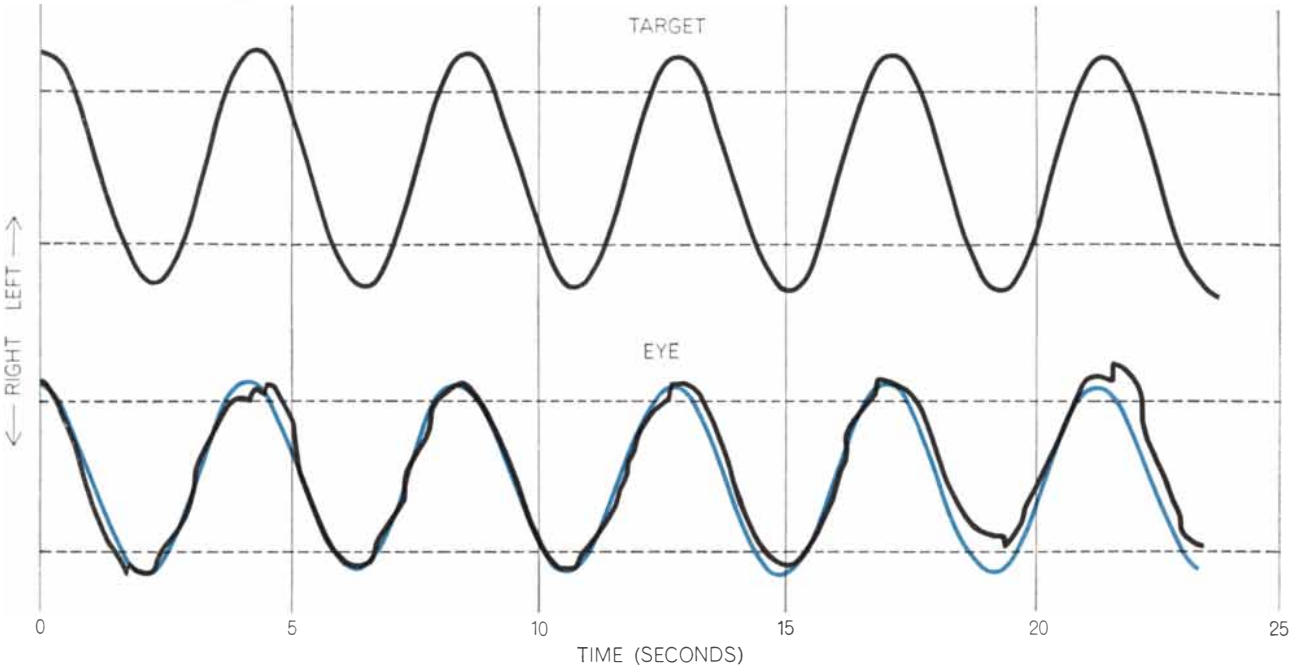
EYE MOTIONS in fixation are recorded separately. Their scale is indicated by the broken lines: distance between the two lines of each pair equals 0.1 degree of angular motion.

negative is printed, the spots of light outline the object that was being viewed and the relative amounts of visual attention accorded to various areas.

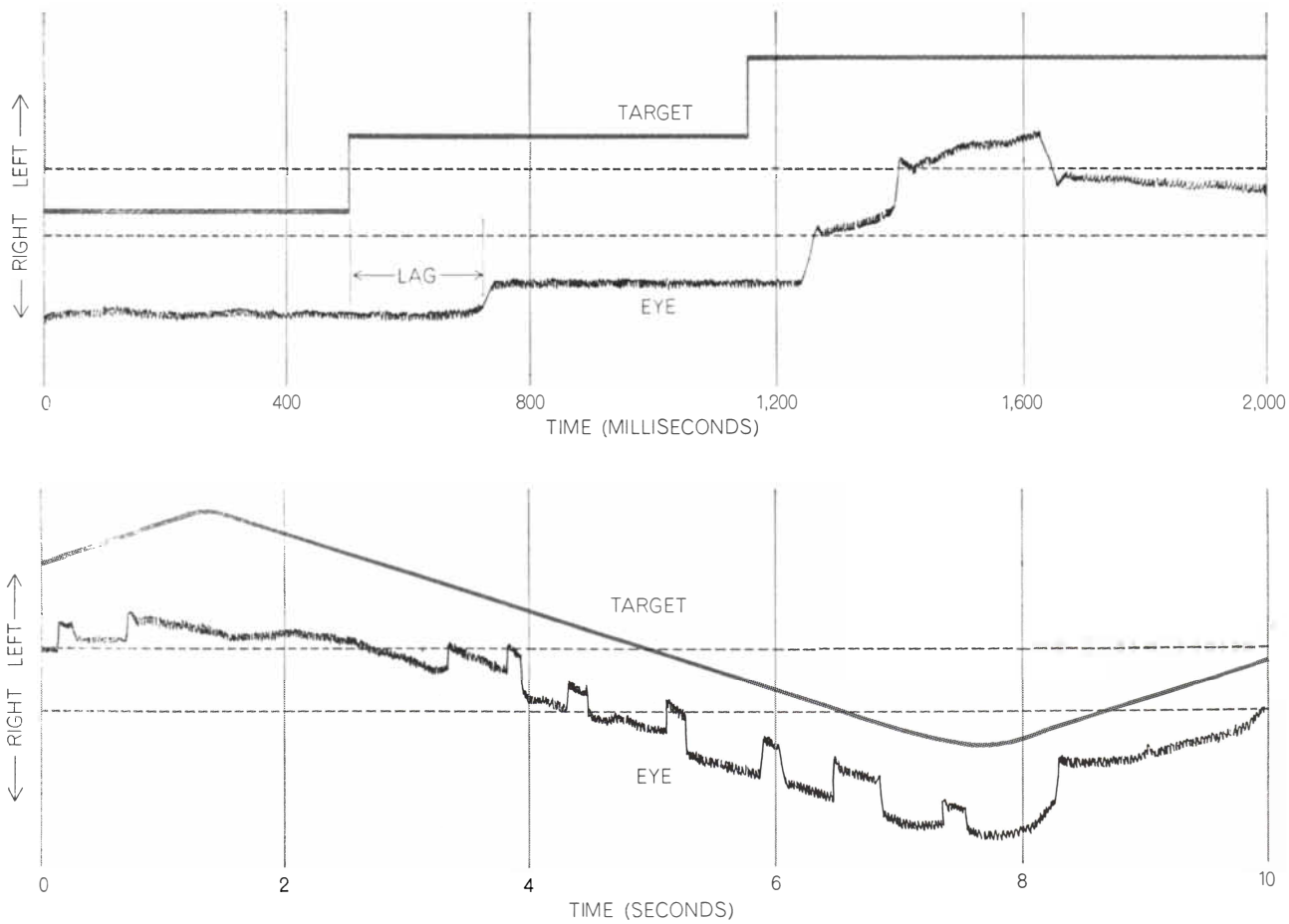
Such measurements are quite rough. To obtain data of much higher resolution and accuracy we place a tiny medical lamp in the stem of the mirror in such a way that it shines down onto a photomultiplier tube mounted perpendicularly to the subject's line of sight [*see illustration on preceding page*]. As the eye moves, the amount of light striking the tube fluctuates and the tube's output current is therefore a measure of the motion of the eye. By combining two tubes we obtain data on both the side-to-side and the up-and-down motions of the eye.

We record these data in several ways. In one method we feed the electrical signals from the photomultipliers into a computer programed to calculate the time the eye spent in each part of the visual scene and to print the results as a sheet of numbers that can be read like a contour map. The top illustration at the left is the fixation pattern recorded as a subject stared for two minutes at a small pinhole. Although he was looking at the target as carefully as possible, involuntary eye movements carried his line of vision off the target by about 1/4 degree for short periods of time (1/4 degree is the equivalent of about 1.5 millimeters at normal reading distance, or about the width of the letters on this page). Note that the area of fixation is roughly elliptical, with its major axis canted outward from the vertical. The reason is that the muscles that move the visual axis from side to side are quite sensitive and capable of precise movement, whereas the up-and-down muscles are not capable of such fine control and do not act in a vertical plane but in a plane tilted outward at 23 degrees from the vertical. This difference in degree of precision between horizontal and vertical fixation is one of the reasons why it is easier to locate a ship by searching the horizon than it is to spot an airplane by scanning the sky in vertical sweeps.

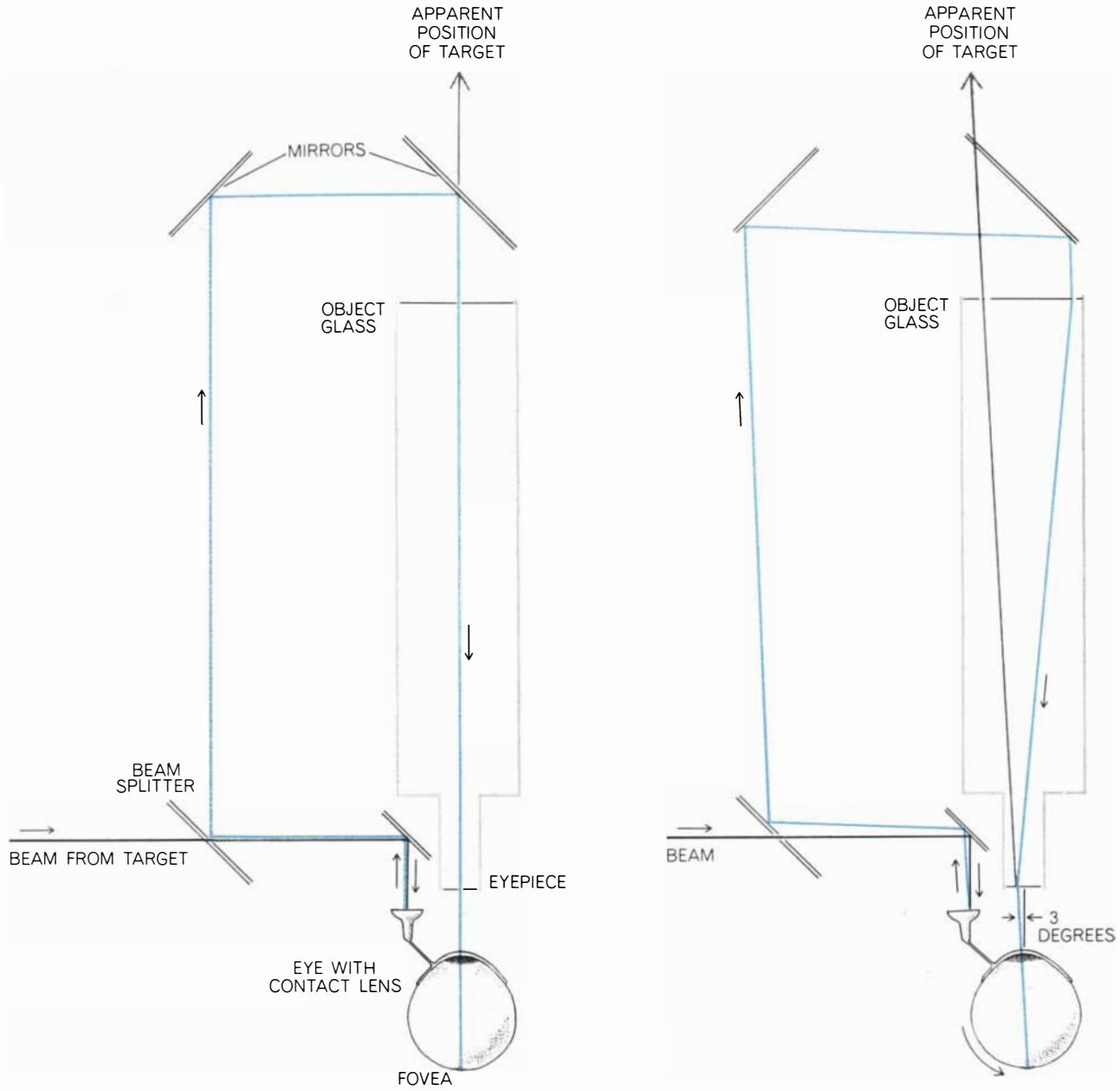
If the signals from the photomultipliers are led to recording galvanometers instead of to a computer, the side-to-side and the up-and-down components of eye motion can be recorded separately and plotted against time, as in the bottom illustration at the left. This record too is of eye movements during fixation on a stationary target, and it is now possible to see that there are two distinct eye motions. One is a slow drift of the visual axis. The other is a



SINUSOIDAL target motion is recorded (*top*) along with the total motion of the tracking eye (*lower black curve*). "Noise" is removed from the total curve to produce a true tracking curve (*color*). Its amplitude is only eight-tenths as great as that of the target curve: the system's "gain" is 0.8. The broken lines are again for scale, the distance between them equaling two degrees of motion.



STEP AND RAMP inputs are tracked in these records. In the step input (*top*) a target is moved suddenly from one place to another; the tracking system's lag is seen clearly in this case. In the ramp input (*bottom*) the target is moved across the field and back at a constant velocity. Target and eye traces have been separated for clarity. Scale lines indicate 0.1 degree of motion.



STABILIZED-IMAGE DEVICE causes the target image to remain at the same point on the retina regardless of the movements of the eye. The target, a pinpoint of light from a projector off to the left, reaches the eye only by an optical path that includes the contact-lens mirror. Here the target is stationary. The subject first sees it (*drawing at left*) in the center of his field of view. Even if he turns his eye three degrees to his left, the mirror moves the target so that it remains centered on his fovea (*right*).

sudden change of direction called a "flick," a remarkable motion that can accelerate the eyeball to an angular velocity of 5,000 degrees per second. The drift and flick are the motions by which the eye ordinarily tracks a target but, as this record shows, they are also "spontaneous" movements: they persist, along with a high-frequency tremor, even when the eye should be still. In other words, the eye has an output even when there is no input; in engineering terms, it has a lot of internal "noise." The spontaneous movements have to be cleared away before one can analyze the tracking movements of the eye and study their control mechanism. This is accomplished with standard mathematical procedures for detecting a signal buried in noise.

Systems analysis calls for varying the input to a feedback control system and measuring the response of the system. In the case of visual tracking the input is a visual stimulus and the response is eye movement. What we do is to move a target across the field of view in certain conventional ways. For a "sinusoidal" stimulus the target is moved from side to side at a fluctuating velocity. We also move the target suddenly from one location to another in what is called a "step function" or move it across the field at a constant velocity for a "ramp" input. In each case the movements of the subject's eye activate the photomultiplier device to trace a curve that can be compared with the target curve.

Consider the curves for a sinusoidal oscillating target movement [*see top il-*

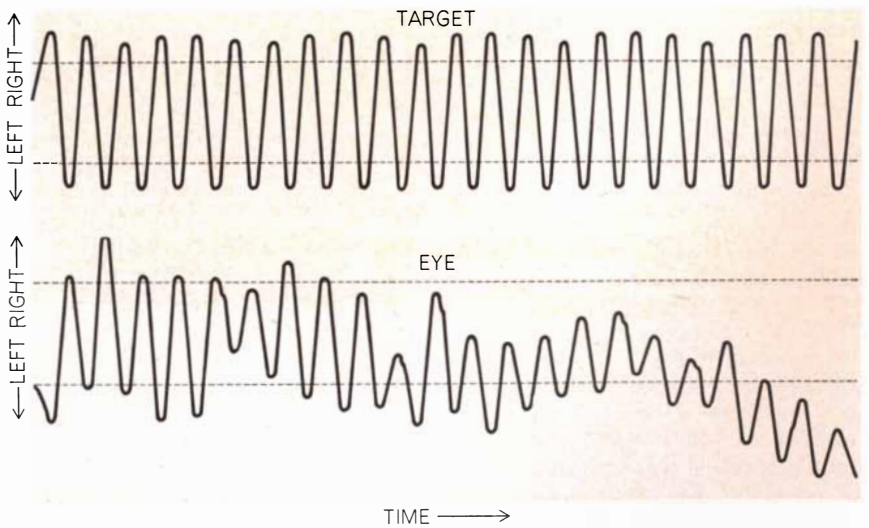
lustration on page 29]. The drifting motion provides fairly smooth tracking, but from time to time a flick is required in order to catch up. We remove the noise from the curve by calculating the sine-wave component of the output that has the same frequency as the input. Comparison of this calculated curve with the target curve shows that the amplitude of the response is not so large as that of the target motion. The ratio of the two (output amplitude divided by input amplitude) is the "gain" of the system, and in this case the gain is 0.8. In other words, the eye travels only eight-tenths as far as the target does. The gain varies sensitively with the type and velocity of target motion and with the arrangement of the feedback system; it is one of the two key characteristics one deals with in analyzing a servomechanism. The other factor is the "phase lag" of the system, the lag between input and response expressed in degrees. In the case of the sinusoidal motion illustrated, the lag is five degrees, or 1/72 of a full wavelength.

The first step in analyzing the visual position servomechanism, then, is to determine typical values for the gain and the phase lag of the system in response to various inputs. The next step is to make similar measurements after disconnecting the feedback loops in the system. The loop most readily available for experiment is the feedback generated by retinal-image motion. If this loop can be opened, the subject will receive no information concerning the motion of his own eye—information he would normally get from the displacement of the retinal image.

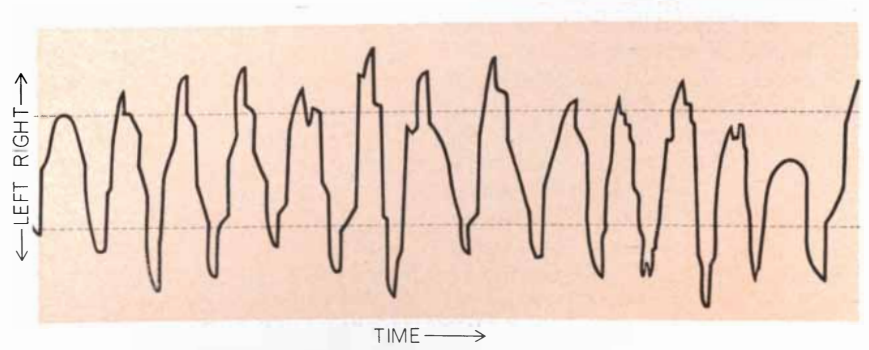
We achieve this state of affairs with an optical system that interposes the contact-lens mirror between the target and the subject's eye, so that the target moves with every movement of the eye [*see illustration on opposite page*]. Light from a projector is focused on the contact-lens mirror and is reflected from it by a series of mirrors through telescope lenses and back to the subject's eye. The subject, with his eye relaxed, sees a spot of light apparently at an infinite distance. The angular motion of the target is doubled at the contact-lens mirror but the telescope lenses correct this, so that by the time the beam emerges from the eyepiece its angular motion is exactly the same as that of the eyeball. Now an image formed on the retina will stay there no matter how the subject moves his eye; it is a "stabilized" retinal image. When the target is actually moved by the experimenter, of course, the retinal image will move, and that is how input to the system is generated. The servomechanism, in other words, will continue to receive input information but will presumably have lost a feedback loop. It will detect target motion but not eye motion, and it will be unable to monitor its own performance.

When the experiment is conducted with sinusoidal target motion in stabilized rather than normal vision, the movements of the eye still follow those of the target quite faithfully [*see upper illustration on this page*]. But the amplitude of the eye motion is now considerably greater than that of the target motion; the gain goes up to 1.8, whereas in normal vision it was only 0.8 at the same frequency. This confirms the assumption that retinal-image motion constitutes "negative" feedback, since disconnecting such a feedback loop in an amplifier always results in a considerable increase in gain. Feedback is normally negative; it is subtracted from the input value. In "positive" feedback it is added to the input, magnifying the deviation of output value from input instead of correcting it. Now, if the sign of the feedback is made positive, the result, in an amplifier, is an oscillation of the output signal. We reverse the direction of retinal-image motion by substituting reversing prisms for the mirrors in the stabilized-image apparatus and the eye responds as an amplifier does: even when the target is stationary, the gaze oscillates wildly from side to side in the motion known as nystagmus.

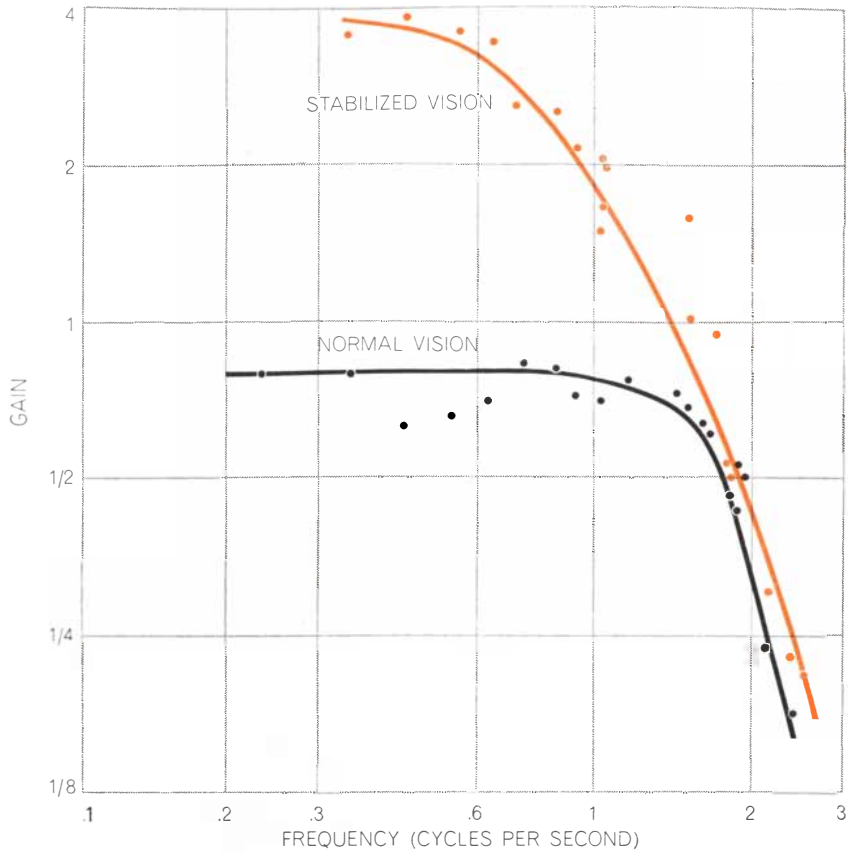
To get more information about the visual system one can alter the frequency of target motion. If the rate at which the target goes back and forth is gradually increased, the amplitude, or gain, of the tracking motion decreases in both normal and stabilized vision [*see illustration on next page*]. The eye cannot keep up with the target; it oscillates through a smaller distance



LOSS OF FEEDBACK causes an increase in gain, as in an amplifier, when retinal-image motion is eliminated in stabilized vision. (The broken lines here indicate one degree of motion.) Note that because the eye now lacks cues as to what is "straight ahead," the axis of vision drifts off to the side (this is the left eye) as the eyes do when a person faints.



POSITIVE FEEDBACK, in which output error is exaggerated, causes wild oscillation even if the target is stationary, as it is here. The broken scale lines are two degrees apart.



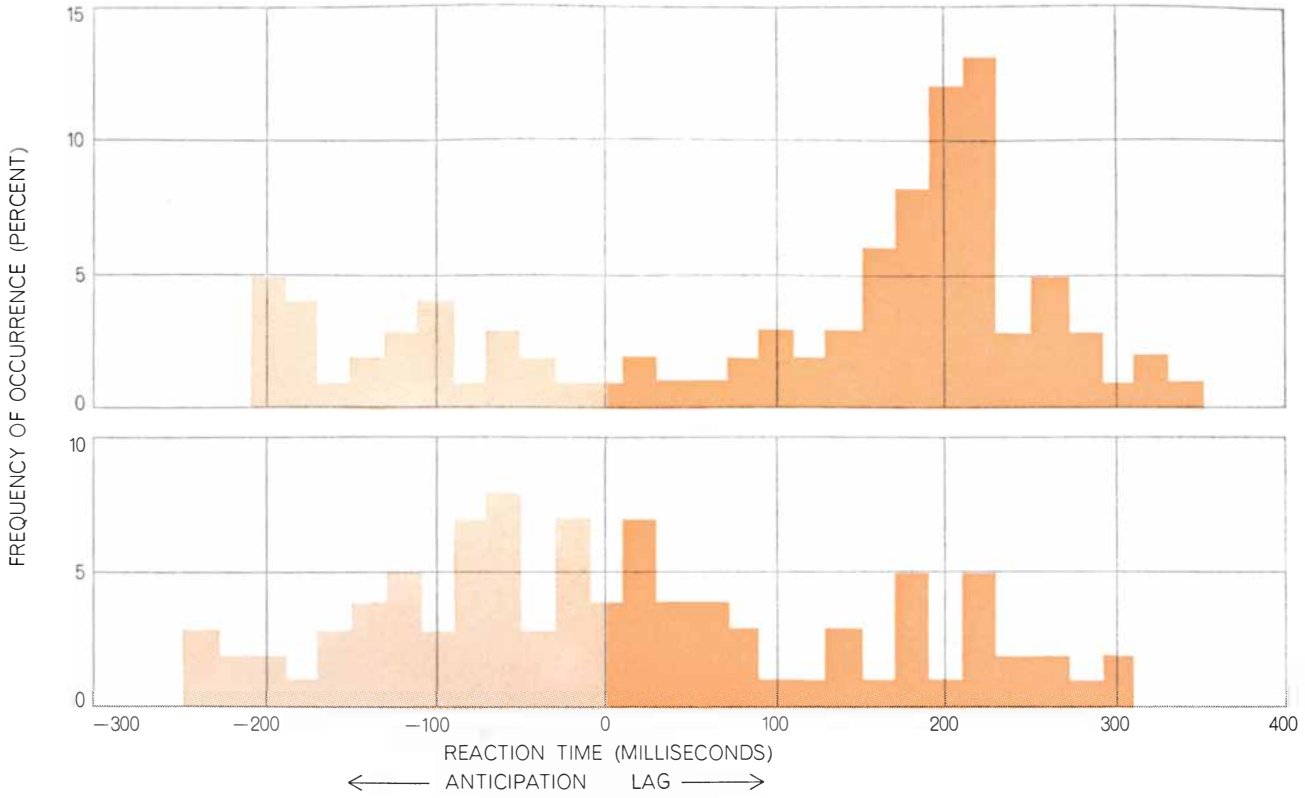
GAIN OF SYSTEM, as indicated by the amplitude of the eye-motion sine wave, decreases as the frequency of the target motion increases. The eye cannot keep up with the target.

as the target moves more quickly. (An engineer would say that the system is acting as a "low-pass filter" with a cutoff at a frequency of about three cycles per second.) This limit on the frequency attainable in tracking is not surprising; there are a number of elements in the visual pathway and each takes some time to operate. Light absorbed by the retinal receptor cells bleaches the photosensitive pigments in the cells, initiating a chemical reaction that generates electric potentials in the adjacent nerve cells; these processes take about 30 milliseconds. The potentials trigger impulses in the optic nerve that take about five milliseconds to reach the brainstem, where spontaneous eye movements are controlled. The brain takes perhaps 100 milliseconds to process the information and then sends out motor-nerve impulses that reach the eyeball muscles in another five milliseconds. So the lag between the receipt of a stimulus at the retina and the initiation of a corresponding response by the muscles is at least 150 milliseconds.

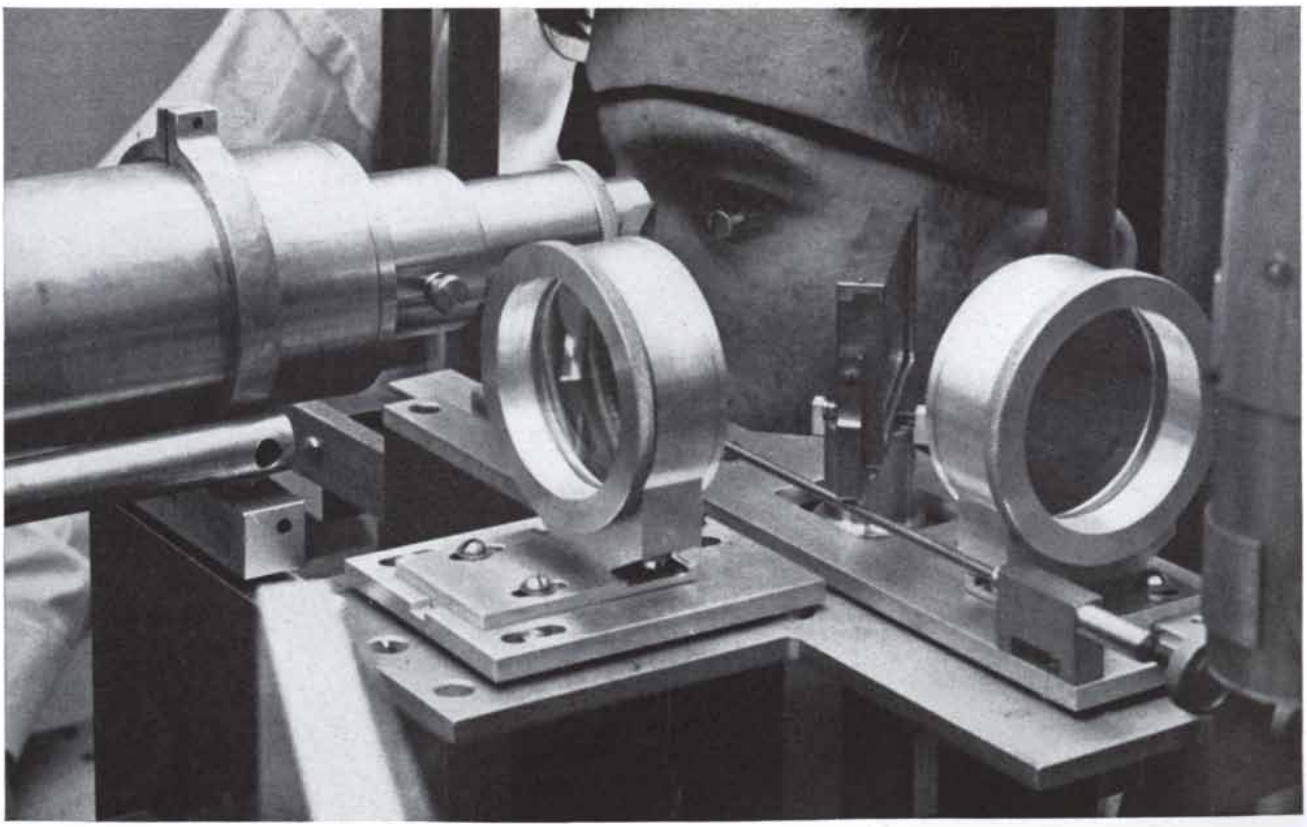
This lag is quite plain to see in the case of the step input in the lower illustration on page 29. The fact is, however, that values as large as this occur only when the target motion is irregular or unexpected. If the movement is in any way repetitive or otherwise predictable, the eye is able to keep up with it and even to anticipate it. In one series of experiments we measured the reaction times of a number of people to step movements that occurred at random and compared these with their reaction times to steps that came at regularly spaced intervals. In the case of the regular motion most of the "responses" occurred before the target moved: they were actually anticipations. This suggests strongly that the eye's control system must be doing something more than reacting to a motion; it must be predicting. There is further evidence for prediction in the sinusoidal curves at the top of page 29. Here the lag (imperceptible in the illustration) is only about six milliseconds. A mechanical system having the same gain characteristics would lag by about 50 milliseconds at this frequency if it were a "minimum phase" system capable only of responding to an input. The eye's servomechanism, then, must contain something a minimum-phase system does not have: "active" elements that allow it to calculate target motion and lock onto it. The system is not merely a tracking device but a predictor.

At this point systems analysis leads to physiological investigation. The response of the eye to target motion indicates that retinal-image displacement and velocity constitute feedback signals in the eye's control system. Are there elements right in the retina that extract these signals from the visual scene or is it done in the cortex of the brain? The eye also acts as a predictor; is this a retinal function or does it take place at higher levels? These questions can be tested by administering drugs that depress the activity of the central nervous system. A fairly light dose of a barbiturate or a tranquilizer interferes with a person's ability to predict target motion, so prediction is probably a function of the cortex. The drugs depress the velocity signal for targets presented in the fovea but not for targets moving at the outer periphery of the visual field—in the "corner of the eye." This suggests that the detection of objects approaching from the side (a faculty with considerable survival value) may be built right into the retina. And the image-displacement signal—the recognition that the target is no longer in the fovea—is quite unchanged by the drugs and is presumably retinal in origin. A biologist might therefore feel encouraged to examine the retina for nerve elements that detect the displacement of the retinal image and announce it to the brain.

The retina contains a number of kinds of nerve cell in addition to the light-sensitive rods and cones. These bipolar cells, amacrine cells and ganglia seem to be capable of more sophisticated functions than merely passing light signals on to the brain. Indeed, studies of lower animals have shown that their retinas do discriminate among visual signals and in effect filter information [see "Vision in Frogs," by W. R. A. Muntz; SCIENTIFIC AMERICAN, March], but not much is known as yet about the processing of information in the retinas of higher animals. The microscopic structure of the retina is similar to that of the brain; in fact, the retina is a part of the brain that became detached in the course of evolution. Any information that systems analysis can provide about retinal function should therefore advance the much more difficult task of understanding how the brain works.

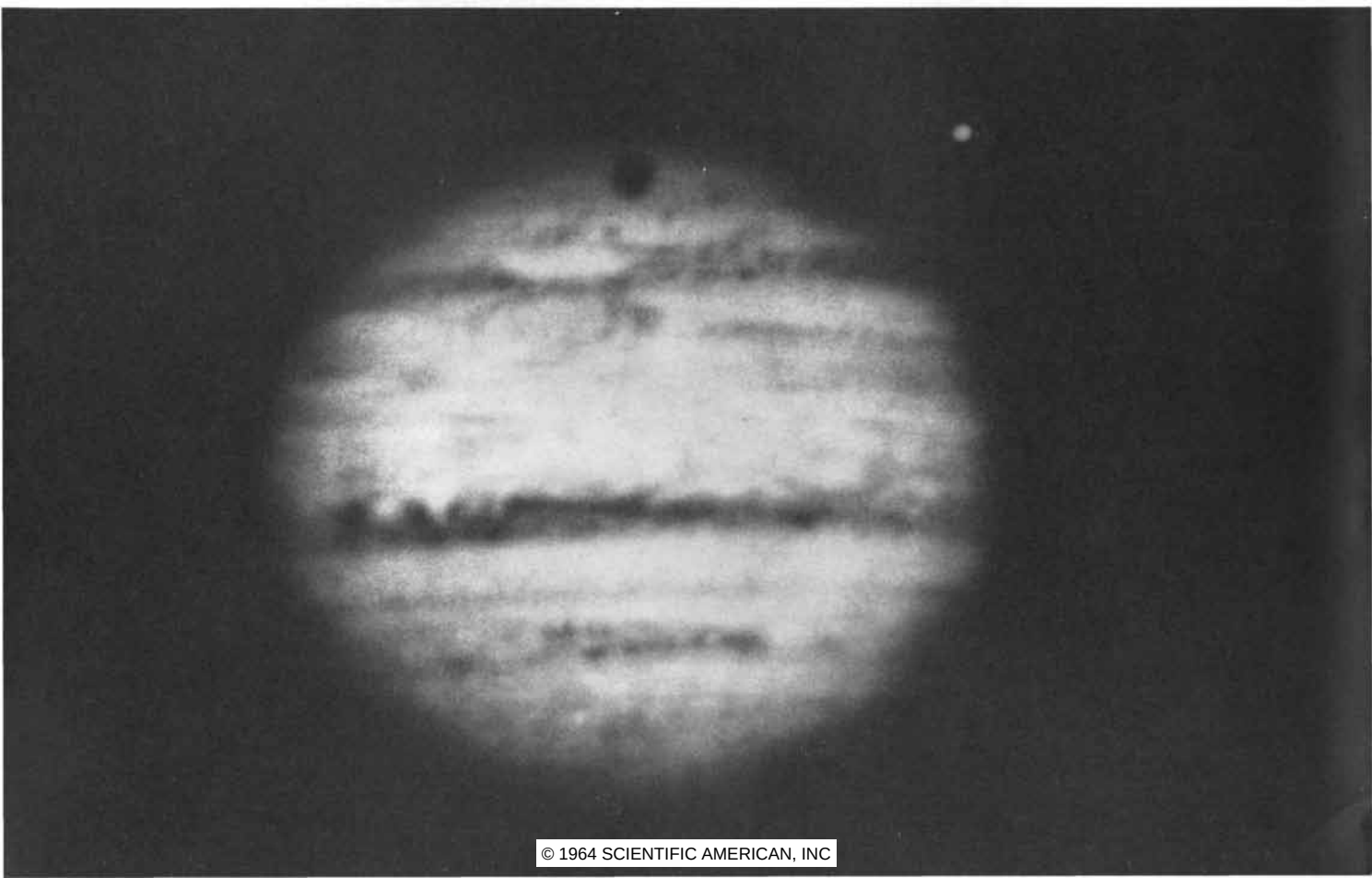


TRACKING LAG (*dark colored bars*) **is the rule when the target is moved in steps at random times** (*top*). **When the steps come in a regular time sequence** (*bottom*), **however, the eye more often anticipates target motion** (*light colored bars*). **The anticipations in the random situation are fortuitous; the eye happened, in its "noisy" wanderings, to have been where the target was going.**



OPTICAL APPARATUS diagramed on page 30 is seen in this photograph. The target beam comes from the bottom right, strikes the mirror near the eyepiece of the telescope and is reflected to the contact-lens mirror and thence around a chain of mirrors and back through the telescope to the fovea of the subject, Park S. Nobel. The photomultiplier device is out of sight below the subject's eye.

VIEWS OF JUPITER were obtained in photographs through blue and red filters in the 200-inch telescope on Palomar Mountain. In the blue light (*above*) Jupiter's Great Red Spot stands out as the large dark ellipse; the small white spot at upper right is Ganymede, one of Jupiter's satellites, whose shadow is above the Red Spot. In red light (*below*) the Red Spot is indistinct. The photographs indicate the turbulence of Jupiter's atmosphere. The atmospheric clouds are all of Jupiter that is visible from the earth.



Radio Waves from Jupiter

In 1955 the largest planet was discovered to be a source of surprisingly strong radio emissions. Now astronomers are seeking to elucidate the mechanism of the radiation

by K. L. Franklin

No other planet except the earth has contributed more to astronomical knowledge than Jupiter. It was Galileo's discovery of four moons circling Jupiter that helped to bury the ancient geocentric conception of the universe and to open men's minds to a broader view of the solar system and the universe of stars. Observations of these satellites of Jupiter later provided the basis for the first measurement of the speed of light. Now once again Jupiter has become a lively source of astronomical enlightenment through the discovery of its surprisingly powerful radio emissions.

Let us quickly review what is known about this planet. Jupiter is of course the largest planet: it is nearly two and a half times more massive than the rest of the planets put together. Its average distance from the sun is 484 million miles; its distance from the earth at its closest approach is 400 million miles. It takes about 12 terrestrial years to complete a circuit of the sun, but its rotation on its axis is remarkably rapid: its day is less than 10 hours. In spite of its great mass Jupiter is a comparatively diffuse planet: its mean density is only about 1.3 times the density of water. This is less than a fourth of the earth's mean density and about the same as the sun's. The rapidly rotating planet exhibits the marked flattening at the poles and drifting bands one would expect of a cloudy, whirling ball of low structural strength.

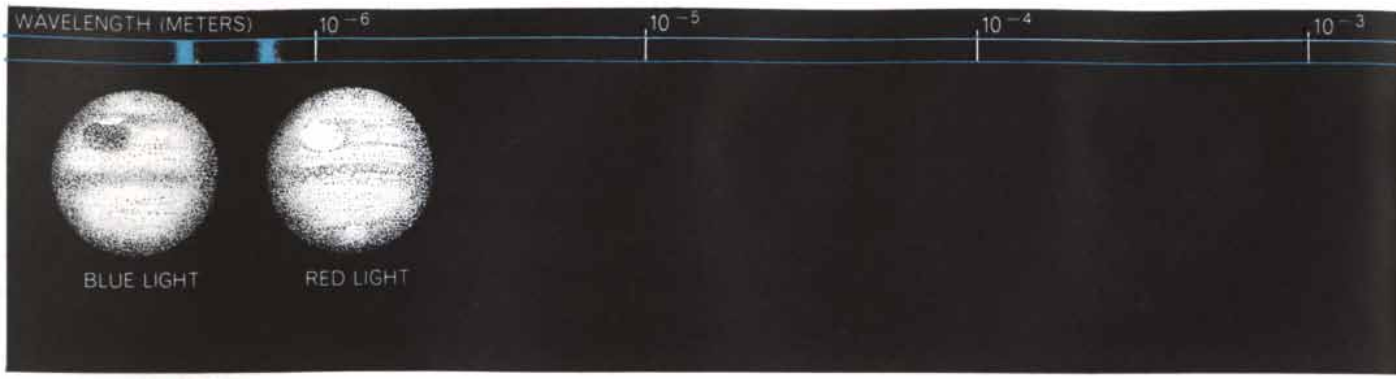
The composition of Jupiter can be deduced in a general way. The only substances in its accessible atmosphere actually detected with the spectrograph have been methane and ammonia. It must be assumed, however, that the elemental predominant constituents of the planet are hydrogen and helium, because these are the most abundant elements in the universe and Jupiter is massive enough to hold the lightest gases. Very likely the most common compounds in the planet are methane, ammonia and water. The colors that show up in Jupiter's bands—yellow, brown, red, green and blue—may indicate that various free radicals, or molecular fragments, are also a prominent part of the planet's makeup [see "The Chemistry of Jupiter," by Francis Owen Rice; SCIENTIFIC AMERICAN, June, 1956].

The structure of Jupiter is a matter of considerable debate. Some investigators argue that the planet has a core of rock about the size of the earth; others believe that the core consists of highly compressed helium and hydrogen or hydrogen compounds in a solidified metallic form. One theory holds that from the core outward there is a series of thick layers made up of ices, clouds and gases. On the other hand, it has been argued that there are no distinct surfaces but merely a gradual change of state of the material, merging from a dense solid to a less compact solid to a thick slurry to a thinning of the slurry until it becomes a thick cloud with the consistency of a blizzard and finally ends in thin cloud, vapor and gases. Because of the great force of gravity at Jupiter's surface (two and a half times that at the earth's surface) it seems most likely that the planet's gaseous outer atmosphere is a relatively thin skin about 200 miles deep.

Measurements of the infrared radiation from Jupiter's atmosphere have indicated that its temperature is about 150 degrees Kelvin, or some 200 degrees below zero Fahrenheit. With this information, and some assumptions about the most likely chemical composition of the atmosphere, Roger M. Gallet of the National Bureau of Standards has worked out models of the atmosphere's possible structure. He concludes that the cloud tops we see are made up of crystals of ammonia. Down through the cloud these gradually turn into liquid droplets; the cloud layer ends with a level bottom. Below this there may be a clear layer of gas. Below that comes another cloud layer, this time made up of water; it begins with ice crystals and turns into water droplets at the bottom of the cloud. Gallet's hypothesis predicts that near Jupiter's solid surface, if any, the temperature may be as high as 260 degrees F.

We can round out what has been learned about Jupiter from optical information with a brief description of its spectacular bands and the famous Great Red Spot [*see photographs on opposite page*]. The bands come and go; they fade and darken; they widen and become narrower by turns; they move up and down in latitude. Within them knots of cloud or other features march across the face of the planet. By timing the movement and reappearance of the distinctive features as the planet turns, observers have measured the rotation period of each of the belts. The wide belt at Jupiter's equator makes its daily rotation, on the average, in nine hours 50 minutes 13 seconds. The other belts, above and below the equatorial region, move substantially more slowly. All of them take at least five minutes longer for the daily turn, their periods ranging from nine hours 55 minutes five seconds to nine hours 55 minutes 54 seconds. There is no consistency even within a given belt; the length of its period may vary from time to time.

The only clear conclusion is that Jupiter's atmosphere must be a region



ELECTROMAGNETIC SPECTRUM of Jupiter indicates the varieties of information that can be obtained from the planet at different wavelengths of radiation. At left are two views in the optical part of the spectrum: blue, which has a wavelength of about 4,000 angstrom units, and red, which is at about 7,000 A. In these regions one obtains information like that shown in the photographs on

of great instability and turbulence. Some of the measurements indicate that in the equatorial region there are east winds blowing at about 300 miles per hour, and that in the other belts the winds blow westward at some 80 miles per hour.

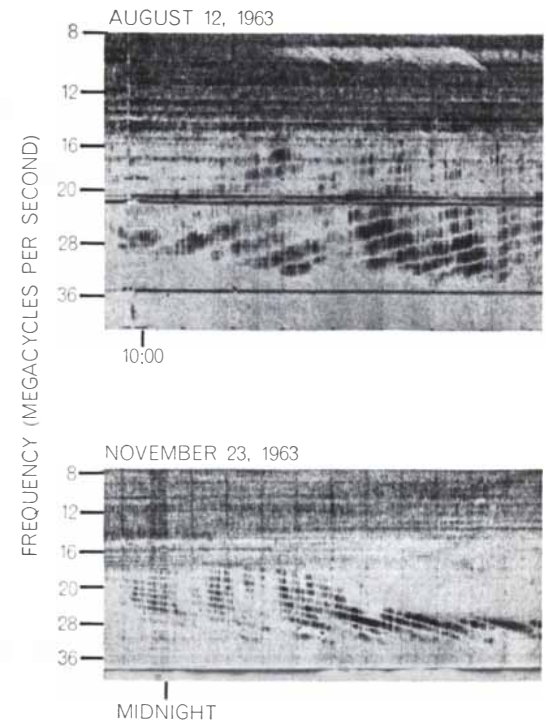
The Great Red Spot, about 30,000 miles long and 7,000 miles wide, shares the general instability of the planet's visible features. Over the century or so that it has been observed the Red Spot has varied in color and visibility, sometimes fading to gray, sometimes almost disappearing from sight. The favored explanation of the Red Spot at the moment is one proposed by Raymond Hyde of the Massachusetts Institute of Technology, who suggests that it may be a "Taylor column": a gigantic disturbance generated by a great depression or elevation in the surface of the planet below the clouds.

The new surge of interest in Jupiter began in the spring of 1955. At the Department of Terrestrial Magnetism of the Carnegie Institution of Washington the physicist Bernard F. Burke and I, then a Carnegie research fellow in radio astronomy, were making a radio survey of the sky. Our instrument, located near Seneca, Md., was a radio telescope with an antenna of the Mills cross type whose arms were more than 1,000 feet long. Capable of resolving a radio source only 2.5 degrees in diameter, the antenna gave a fine-grained view of the radio sky. It was aimed to scan a narrow strip of the sky parallel to the celestial equator as the telescope turned with the earth's rotation. The telescope searched for radio sources at a frequency of 22.2 megacycles per second, or a wavelength of about 15 meters.

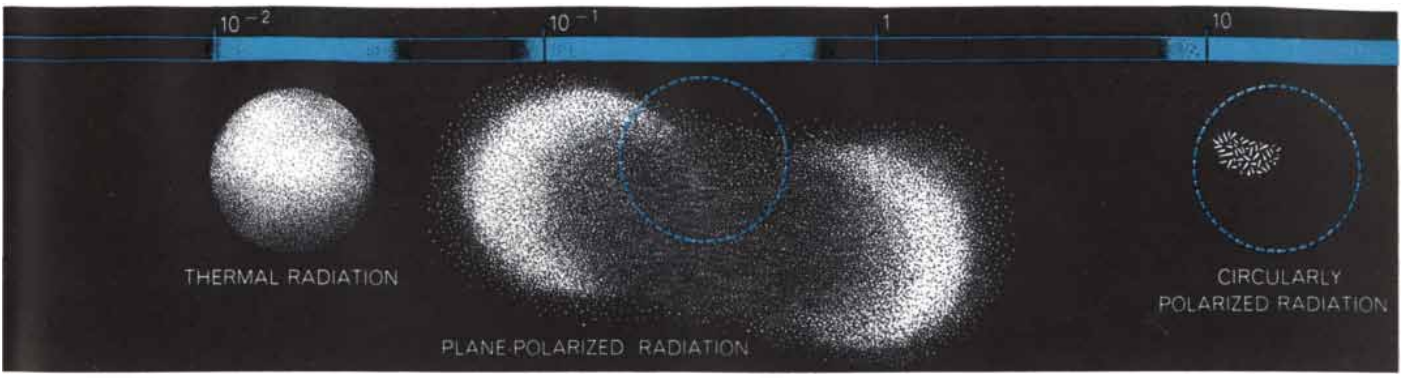
In January, 1955, a peculiar feature occasionally appeared in the tapes recording the radio waves from a certain strip in the sky. This strip included the Crab nebula, a well-known steady emitter of strong radio waves, and the Crab produced an easily recognizable record on the tape. About two hours later, on about a third of the tapes, there would be a record of many strong bursts [*see illustration on page 41*]. At first we thought this might be accidental interference from radio transmitters or electrical machinery in the vicinity of the telescope. Studying the timing of the bursts, however, Burke found that they always came at about the same interval after the reception from the Crab nebula. This suggested that the source might be an object in the sky rather than on the ground. The interval shortened slightly from day to day, indicating that the object was moving with respect to the Crab nebula and therefore might be a planet. The source of the radio bursts was then quickly located: it was the planet Jupiter.

Jupiter's bursts of radio emission turned out to be astonishingly strong: as high as 10,000 megawatts at the source. It developed that such emissions from the planet had been detected, but not identified, in earlier recordings by radio telescopes. The Australian radio astronomer C. A. Shain, looking through tapes made with his radio telescope at the Radiophysics Laboratory of the Commonwealth Scientific and Industrial Research Organization in Sydney, found Jupiter bursts in recordings going back to 1950. He had been unable to identify them with any particular source because his telescope had less resolving power than ours did.

Since the discovery of Jupiter's strong radio emissions much investigation has been concentrated on trying to discover where this noise originates and how it is produced. The first question is: Can the source, or sources, be located at specific points on the planet? If the noise does come from discrete sources near the surface of Jupiter, bursts will be received on the earth only when that part of Jupiter is facing us. Shain, analyzing the timing of the Jovian bursts in his records, found that there was certainly one discrete source of radio noise on the planet. Since then other investigators



SPECTRA OF EMISSIONS from Jupiter are photographed from records obtained by James W. Warwick of the High Altitude Observatory at Boulder, Colo. Jupiter's spectra



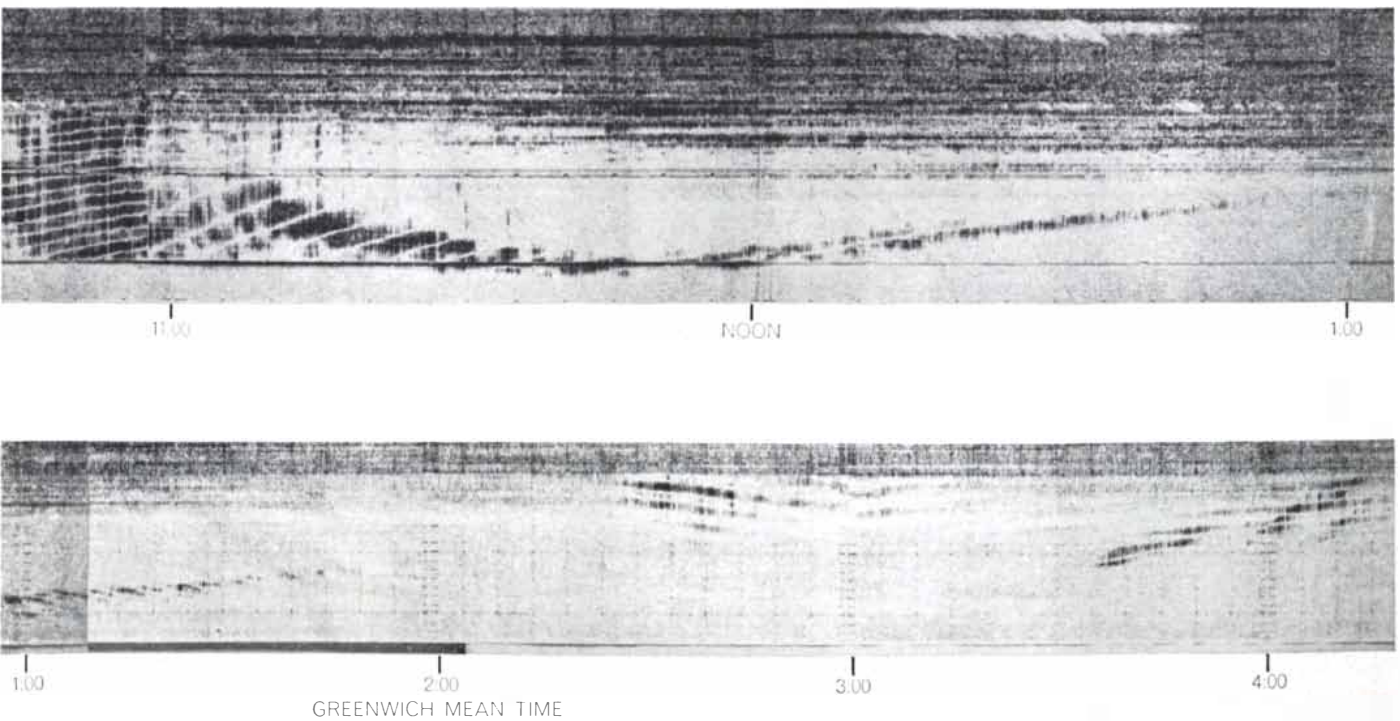
page 34. At right are three views of Jupiter as it is "seen" by radio astronomers. The first two are the regions of Jupiter's short-wave radiation: thermal, which has wavelengths measured in centimeters, and plane-polarized, which is measured in decimeters, or tenths of a meter. Last is the region of longwave radiation, circularly polarized and measured in decameters, or tens of meters.

have determined that there are probably at least four points of origin. No one has yet been able to connect any of the sources with a visible feature of the planet's surface, such as the Red Spot or some other formation.

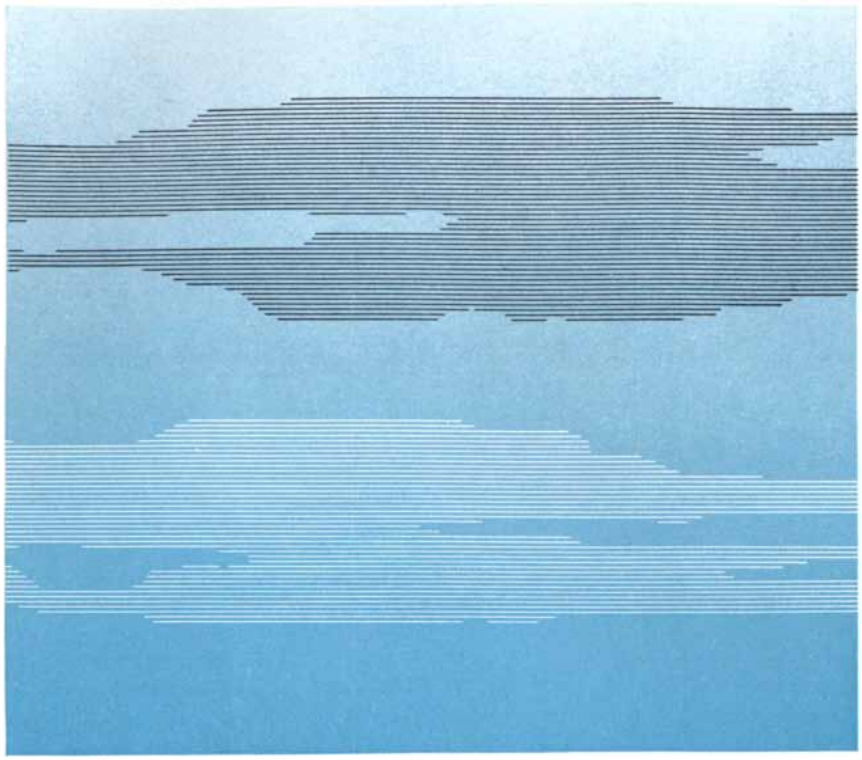
Whatever the actual sources may be, they appear to be associated in some way with the solid part of the planet, because they do not drift as the clouds do. From year to year they rotate with a period of about nine hours 55 minutes 29 seconds. I must note here that although the radio sources seem to be "associated" with the inner body of the planet, there are reasons to believe the emissions are not actually generated there.

What is the origin of the Jovian radio bursts? Many investigators have been working on the problem. The radio emissions have proved to be sporadic in their timing and highly variable in every other way. They arrive in series of rapid bursts that may last only five to 10 minutes but sometimes go on for two hours. The frequency of the radiation varies over a band between five and 40 megacycles per second, and the spectrum of each emission is highly complex. Early in the investigation both Shain in Australia and we at the Carnegie Institution discovered that the radio waves were polarized, and in a particularly complex way. Much research has been devoted to elucidating this phenomenon.

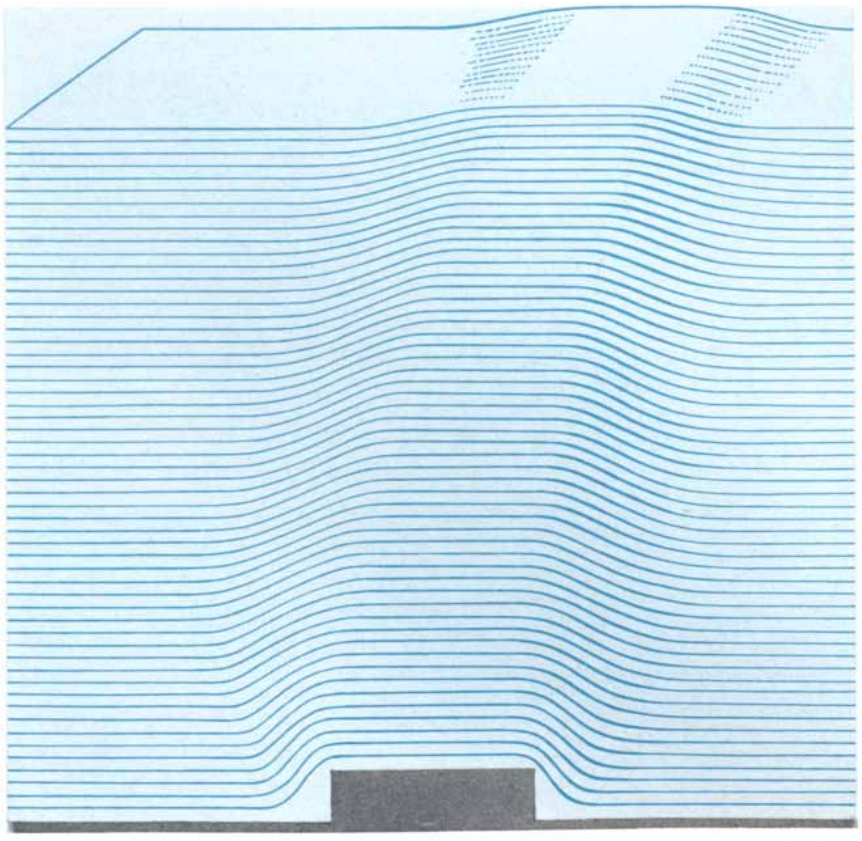
The polarization of light waves or



are the dark bands in the lower part of each photograph. Although about 100 days, or some 247 revolutions of Jupiter, separate the events shown in the two photographs, the spectra exhibit much similarity. Each changes from broad bandwidth to narrow bandwidth in a characteristic manner; at the points of maximum frequency the radio longitude of Jupiter was almost the same on the two days. The diagonal white streaks in the spectra are interferometer fringes unique to the positions of Jupiter on the two days.



JUPITER'S ATMOSPHERE is portrayed according to current hypotheses. In the upper part (*black lines*) is a cloud composed primarily of ammonia. Lower in the atmosphere is a layer of water clouds (*white lines*). The atmospheric gases, which are represented in color, are hydrogen, helium, methane and neon. They permeate Jupiter's atmosphere.

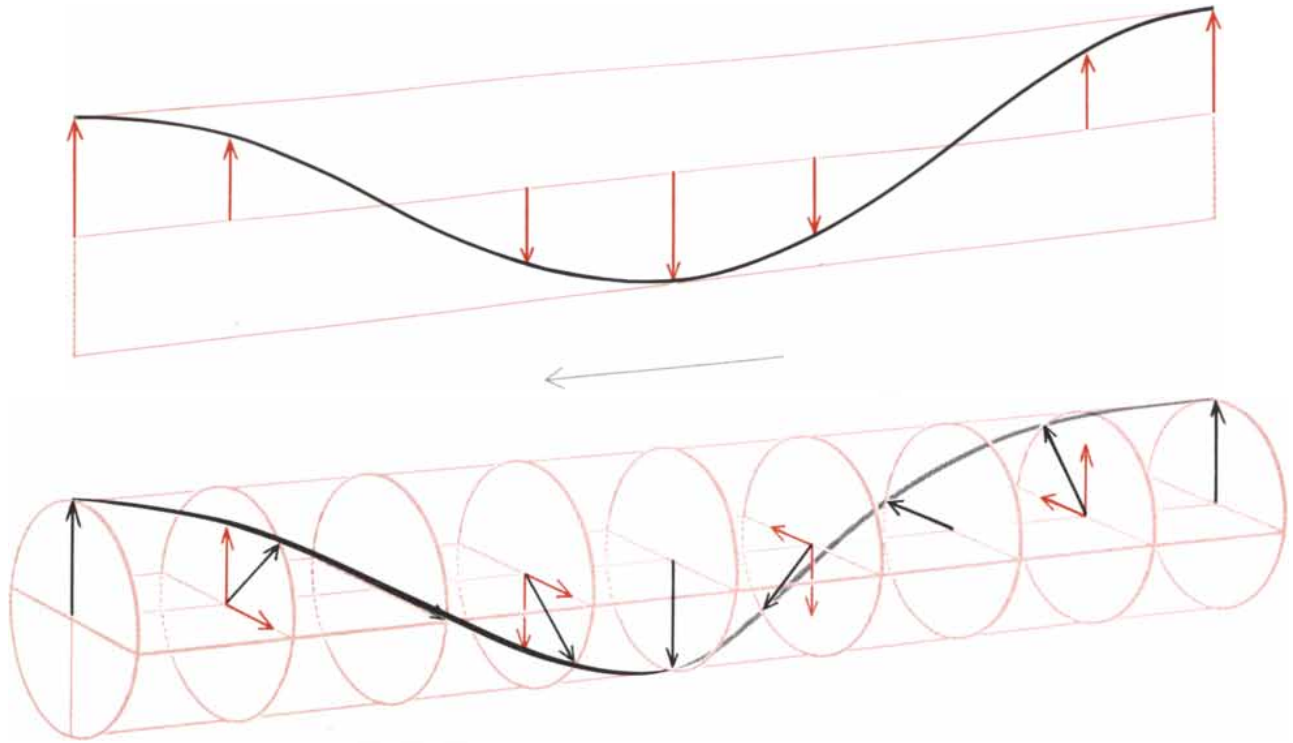


RED SPOT of Jupiter may be caused by a "Taylor column." At the surface of the planet a discontinuity (*gray*), which may be a protuberance or a depression, causes a disturbance in the air flow above it. The effect will be observable when it reaches top of the atmosphere.

radio waves might be described simply as the suppression of the waves' vibration in certain directions at right angles to their direction of travel. Thus a "plane-polarized" wave is a wave that vibrates only in one plane. We found that the radio waves from Jupiter are circularly polarized; that is, the plane of polarization rotates as the wave advances. This circular polarization could be detected by appropriate arrangement of the receiving antenna. We also found that at frequencies in the neighborhood of 20 megacycles the polarization of the waves was usually clockwise, as seen from Jupiter, but that occasionally it was counterclockwise and in some cases it seemed to be mixed. Investigators at several other laboratories also have detected the circular polarization of the Jovian radio waves, and some have found that the sense of the polarization may change from minute to minute or hour to hour.

Polarization is a welcome clue. It implies the existence of a special circumstance either in the source mechanism itself or along the path traveled by the waves. If lightning, which generates completely unpolarized waves, were the source, the observed polarization would be impressed on the radiation along the way to the earth. This might occur if the radiation were to pass through a region containing both an ionized gas and a magnetic field. Such a magneto-ionic medium will allow only one sense of polarization to pass, restricting the other completely. For a given strength of field and concentration of ions the filtering action depends on the wavelength. Waves shorter than a critical length will not be so affected; hence they will appear unpolarized. Jupiter's ionosphere may be such a filtering region. If lightning and a Jovian ionosphere were responsible, one would expect pure polarization at low frequencies and random, or perhaps confused, polarization at higher frequencies. But William M. Sherrill and M. P. Castles of the Southwest Research Institute in Texas, who have been studying Jupiter at several different radio frequencies, have found that the actual situation is just the opposite: the lower the frequency, the more mixed and variable is the polarization! This seems to argue that the Jovian radio waves do not originate below Jupiter's upper atmosphere.

Conceivably the earth's ionosphere might have something to do with the polarization of the Jovian waves coming



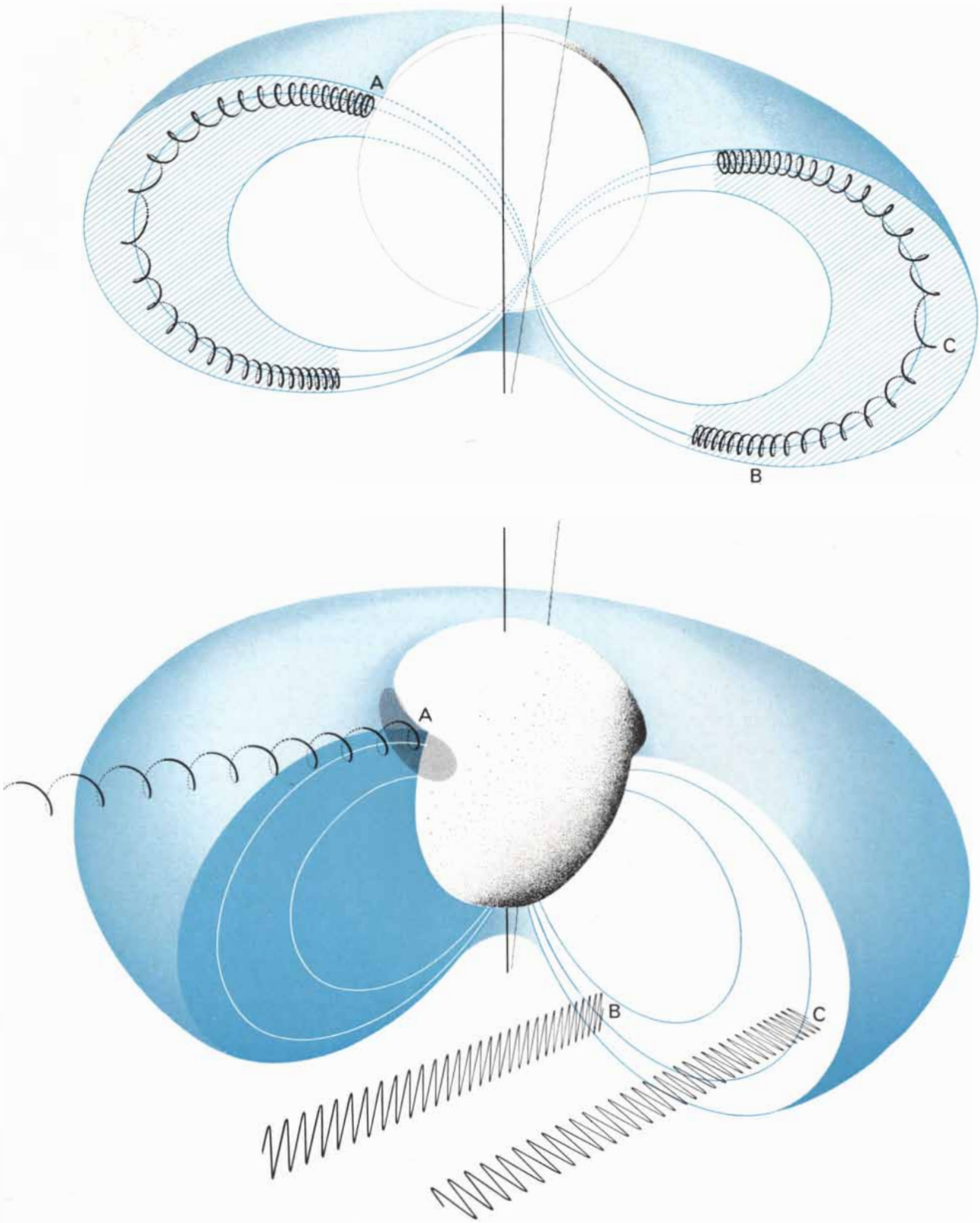
PLANE AND CIRCULAR POLARIZATION are depicted schematically. In plane polarization (*top*) the waves vibrate in a single plane, here shown as vertical. Circular polarization (*bottom*) has both vertical and horizontal components, represented by colored arrows. The resultant vectors, shown as black arrows, trace the path of a helix. In one wavelength of radiation a vector describes a circle. The gray arrow shows the direction of propagation. Both plane and circular polarization appear in radiation from Jupiter.

into our radio telescopes, but it is difficult to see how. There is some evidence, however, that our ionosphere causes a certain "twinkling" of this radiation, just as the stars twinkle in the optical part of the spectrum. Shain, observing Jupiter at a single frequency with two radio telescopes several miles apart, found that the bursts recorded at the two stations were not the same, either in timing or in sequence. He deduced from this that the patterns of bursts were probably imposed on the Jovian radiation by the earth's ionosphere; irregularities in the ionosphere might modify the radiation as it traveled along the different paths to the two stations. A number of similar cases of lack of correlation between Jovian waves received at widely separated stations have also been reported by Alex G. Smith and Thomas D. Carr of the University of Florida. They studied records made simultaneously by radio telescopes in Florida and Chile. In most instances the records were different, but there were a few occasions when identical bursts appeared at the same time in these two stations thousands of miles apart. H. J. Smith of the University of Texas and James N. Douglas of Yale University report similar findings: the bursts are sometimes identical, sometimes different at two receivers 60 miles apart on an east-west line. On several occasions a series of Jovian bursts arrived at both stations in exactly the same form but half a second later at one than at the other.

We have considered so far only Jupiter's long-wave radio emissions. They are the emissions in the low-megacycle range, that is, at wavelengths measured in decameters, or tens of meters. In 1956 Cornell H. Mayer and his associates at the Naval Research Laboratory opened up a new region of the spectrum for observing Jupiter: frequencies about 1,000 megacycles per second, or wavelengths measured in centimeters. They detected radio waves coming from Jupiter at about three centimeters. The planet's shortwave emissions were later found to range at least between three and 70 centimeters, and thus to be measurable both in centimeters and in decimeters, or tenths of a meter.

Radio astronomers at the Naval Research Laboratory and at other observatories in the U.S., Australia, France and Britain used the shortwave radiation from Jupiter as an index for estimating the temperature of the planet. A theoretical temperature can be calculated on thermodynamic principles if one assumes that the planet radiates like a black body (that is, a perfect absorber and radiator of energy). At comparatively low temperatures the radiation of energy from a body is strongest in the radio part of the spectrum. As the body becomes hotter it radiates most strongly at the infrared wavelengths, then at the red, orange, yellow and finally the blue-white wavelengths. On this basis the temperature of Jupiter might be estimated from the amount of energy received from the planet by a given radio telescope on the earth. In astronomy this temperature is called the "brightness temperature."

Mayer and his colleagues at the Naval Research Laboratory, on the basis of the amount of energy from Jupiter received at three centimeters by the NRL's 50-foot parabolic radio telescope, calculated the brightness temperature of the source to be about 150 degrees Kelvin. This agreed well with Jupiter's temperature as derived from infrared measurements. But as the NRL and other radio observatories measured the energy from Jupiter at other wavelengths they found the calculated temperature climbing higher and higher:

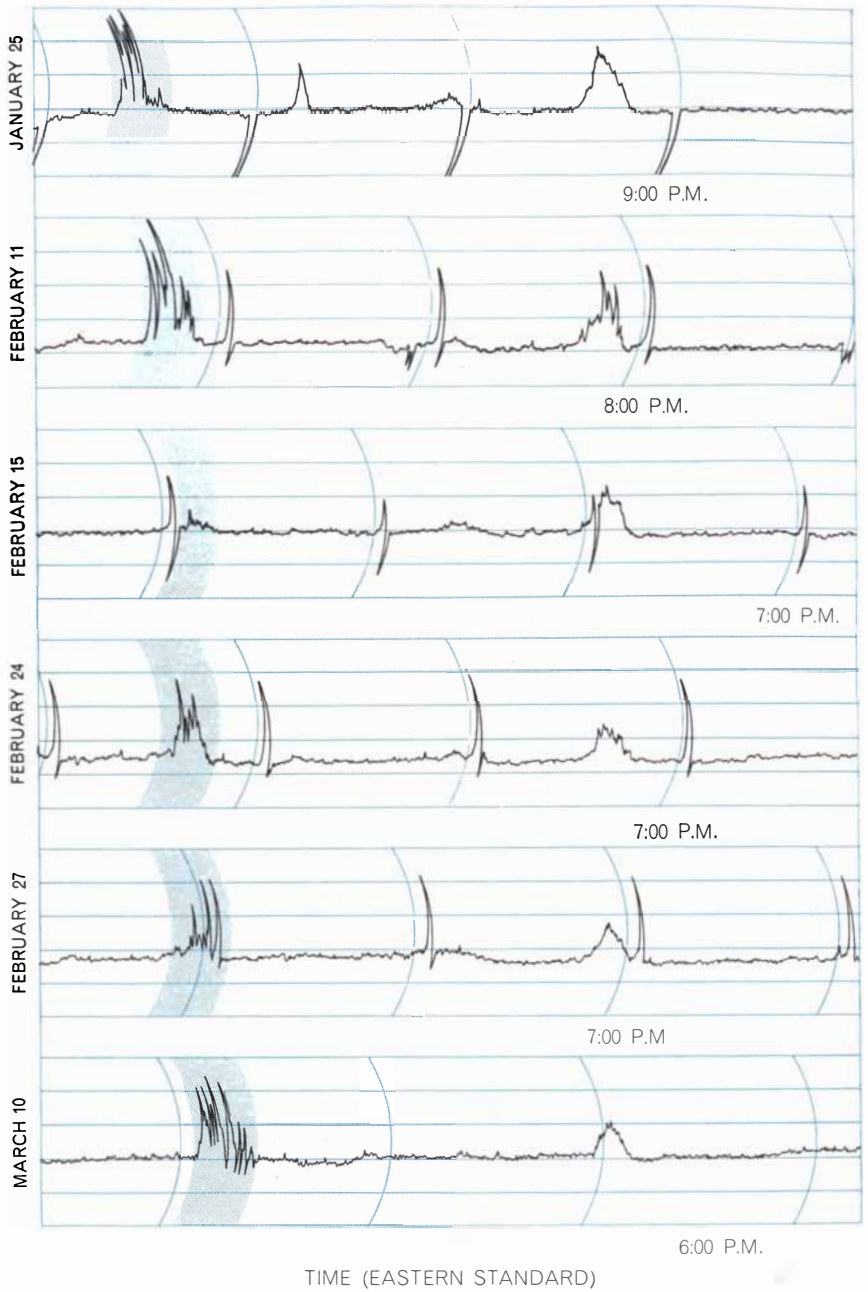


POSSIBLE ORIGINS of radio emissions from Jupiter are shown in two views of the planet and its radiation belts. At top is a cross section, in which the helices represent typical paths of high-velocity charged particles trapped in strong magnetic fields, similar to the Van Allen belts surrounding the earth, and mirrored between regions of equal field strength. These particles appear to be the source of Jupiter's plane-polarized decimetric radiation: vertical as at *B* and horizontal as at *C*. At *A* a mirror point comes close to the surface of the planet because the radiation belts are eccentric, and as a result some particles are dumped into the atmosphere. Encounters of this type may be the source of the decametric radiation, which is circularly polarized. The second view (*bottom*) shows the planet and its radiation three-dimensionally. Again the long-wave radiation, measured in decameters and circularly polarized, is shown at *A*, and typical examples of plane-polarized decimetric radiation are represented at *B* and *C*.

at 10 centimeters Jupiter's radio energy indicated a brightness temperature of nearly 600 degrees Kelvin; at 21 centimeters, 2,000 degrees K.; at 31 centimeters, 6,000 degrees K., and at 68 centimeters, 50,000 degrees K., or about 90,000 degrees Fahrenheit!

Since this was higher than the temperatures of most of the hottest stars, it was obvious that Jupiter's shortwave radiations must be generated by some energy source other than the planet's heat. Frank D. Drake of the National Radio Astronomy Observatory in Green Bank, W.Va., suggested that the radio energy at these decimetric wavelengths was generated in belts of charged particles around Jupiter, like the Van Allen belts surrounding the earth. Just as oscillating electrons in a synchrotron emit radio waves, he said, so the electrons in the Jovian belts, interacting with the planet's strong magnetic field, radiate energy in the same manner.

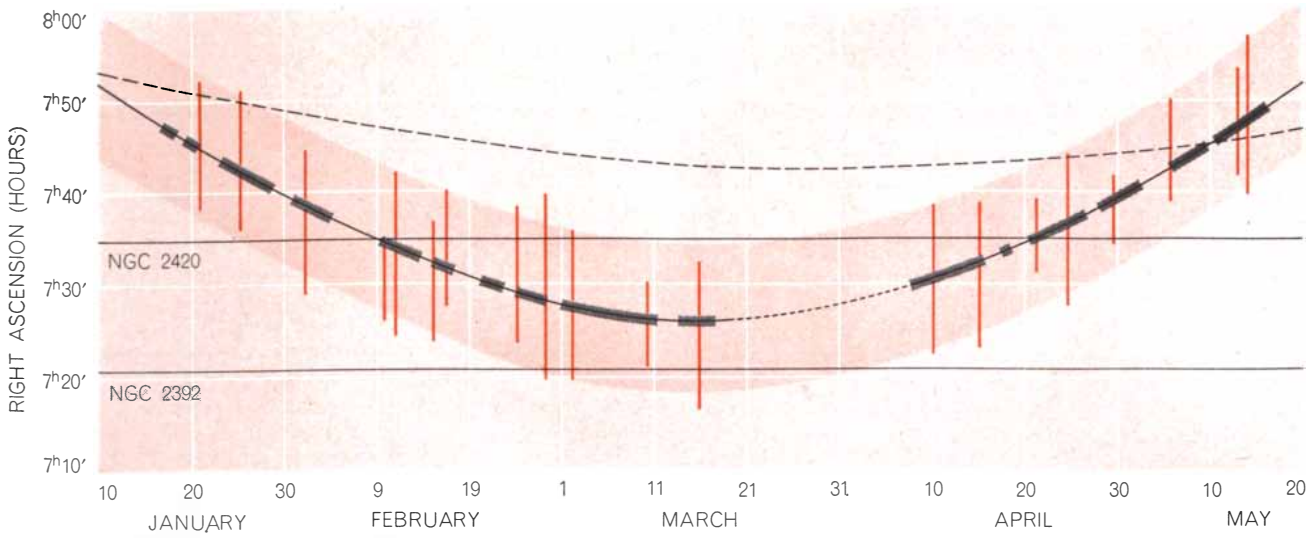
This hypothesis was soon confirmed by V. Radhakrishnan and J. A. Roberts of the California Institute of Technology. Using twin 90-foot radio telescopes mounted on rails, they found that Jupiter is ringed by a belt of radiation that extends to three times the planet's diameter—a distance including the two innermost satellites—and that this ring is tilted with respect to the Jovian equator at an angle of nine degrees. A further proof that the short radio waves from Jupiter originate in excited electrons has been found in the fact that the waves are plane-polarized, which is a characteristic of radio emissions from accelerated electrons.



RECORD OF DISCOVERY that Jupiter was a source of strong radio emissions appeared on tapes similar to those drawn here. During three months in 1955 the observers noted that on about a third of the tapes the Crab nebula's emissions, which had long been known and which appear here aligned vertically at right, were followed in about two hours by strong bursts from another source. They are depicted in color at left. The fact that the source appeared to be moving slowly in relation to the Crab nebula suggested that the source was a planet. How Jupiter was identified as source is shown in top illustration on next page.

The source of Jupiter's long-wave radiation (in the region around 20 megacycles) is still in dispute. Most investigators believe this radiation is also connected in some way with belts of particles around the planet, but they disagree as to what mechanism might generate long waves from such a source. Perhaps the most fully developed model is one offered by James W. Warwick of the High Altitude Observatory in Boulder, Colo. He suggests that Jupiter's magnetic field is arranged around the planet in an eccentric way. Particles arriving from the sun are trapped by this field and begin to move in a complex pattern. They oscillate between north and south regions of equivalent field strength as they spiral around the lines of force [*see top illustration on opposite page*]. These accelerating particles are the ones responsible for the part of the shortwave radiation that is plane-polarized and measured in decimeters.

If the magnetic field is eccentric, the atmosphere of the planet comes very close to one of the two mirror regions, the northern and southern bands where the magnetic field is strong enough to reflect the oscillating particles. As new streams of charged solar particles arrive, they act as a current to weaken the magnetic field, thus lowering the mirror regions. Part of one of these regions drops into the atmosphere, allowing the previously trapped particles to spiral into the upper atmosphere. They then cause the circularly polarized decametric energy to be emitted by the Cerenkov process—a sort of electromagnetic shock wave. The random bunching of the particles accounts for the random bursts of varying strength. Warwick's



JUPITER IS IDENTIFIED as the source of the radio bursts discovered in 1955. Jupiter's course in the sky is the curving center line; the thick portions show when the receiver was on. By plotting the bursts (*colored lines*) according to the sidereal time in which their source was in the receiver beam, observers found that the plots coincided with the right ascension of Jupiter in the sky. And the plots did not coincide with the positions of such other celestial features as the planet Uranus (*broken curve*) or the fixed objects NGC 2420 and 2392. Broken line in middle of the Jupiter curve represents a period when no observations were made.

model seems to account in a general way for the observed radio spectra from Jupiter, but other theories also have their champions.

The Jovian radio waves are providing investigators with a wide variety of interesting problems. One of the curious facts that call for explanation is the negative correlation between Jupiter's long-wave radiation and the sunspot cycle: the planet's radiation seems to be strongest when sunspot activity on the sun is quietest (as it is just now). Another mystery is an apparent change in Jupiter's rate of rotation that took place recently. Alex Smith and his colleagues, studying the records of Jovian radio bursts at the observatories in Florida and Chile, and Douglas in a study at Yale, found that the sources of the radiation abruptly changed their rate of rotation by 1.3 seconds: the daily turn took 1.3 seconds longer. Did this change occur only in the magnetic field governing the belt of electrified particles around the planet or did it reflect a change in the rotation of the planet's solid body? If the latter was the case, one must suppose that the change in angular momentum was caused by a cataclysmic event in the planet.

So far all the investigations of Jupiter's radio emissions have been conducted with radio telescopes and other instruments stationed on the earth. We look forward to more surprises when space probes begin to tune in to Jupiter from interplanetary space.

SPORADIC CHARACTER of bursts from Jupiter is evident in reproductions of recordings made during about five hours last September 28 by the author's equipment near New York. The top recording was made at a frequency of 21.04 megacycles per second; the bottom, at 21.45. It is evident that receivers on almost adjacent frequencies may receive signals at different times. A single burst of energy lasts a fraction of a second; bursts come in storms that continue for minutes or for as long as two hours.

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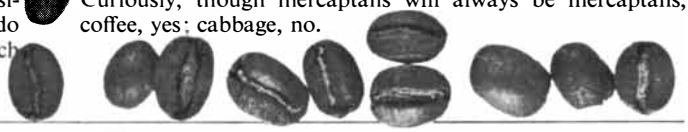
Subsequently we dropped *2-Furanmethanethiol* from the list because one of the starting materials for it had disappeared from the market. The boss took a poor view of this reason. "Thought you guys were supposed to be synthetic chemists," he said. So we made our own starting material and restored *2-Furanmethanethiol* to the list. During this operation, unfortunately, a few whiffs of the finished product got away from us. Everybody smelled it, but nobody complained. Curiously, though mercaptans will always be mercaptans, coffee, yes; cabbage, no.



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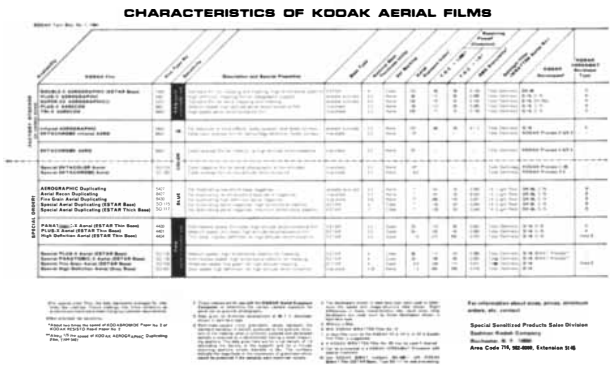
For people who might make decisions from aerial film: Almost every issue of *Photogrammetric Engineering* published by the American Society of Photogrammetry, 44 Leesburg Pike, Falls Church, Va., contains new developments on the deployment of aerial film to "look down with wisdom" in the interests of sciences and useful arts of a peaceful nature. Anybody who has toyed with the thought that aerial photography might be of assistance should ask his librarian for a pile of this too little known periodical.



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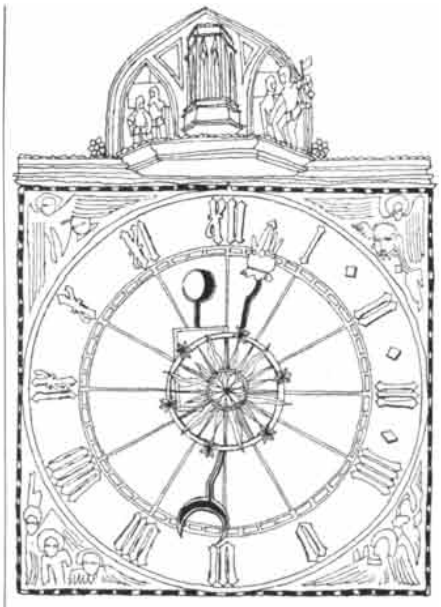

Nine More Particles

There has been no lull in the discovery of subnuclear particles, to which physicists now often refer simply as "states." Like the other states discovered in the recent past, the new ones are all strongly interacting, meaning that they respond to the "strong" force that holds together particles in the nucleus of the atom. The February issue of SCIENTIFIC AMERICAN contained a table of 82 strongly interacting particles, classified into 14 "baryon" states and eight "meson" states (see "Strongly Interacting Particles," by Geoffrey F. Chew, Murray Gell-Mann and Arthur H. Rosenfeld; SCIENTIFIC AMERICAN, February). Baryons are usually heavier than mesons and have other distinguishing characteristics.

Since this accounting a few states not listed in February now seem well established and have been joined by a few new ones. Altogether at least three baryon states and six meson states can now be added with some confidence to the February list. Only one of these nine states, the Ω^- (omega-minus baryon), which has a rest mass of 1,675 million electron volts (mev), was predicted by theory. Many of the quantum numbers needed to define the physical properties of the other eight states are still uncertain, so it is too early to tell how they fit into such classification schemes as "the eightfold way," described in the February article. There is some evidence that one of the probable new baryons, a state with a rest mass of 2,700 mev, may be the lightest member of a superfamily containing 27 members. Superfamilies of this size are allowed by the eightfold way, although the most common superfamily so far has had eight members. (The term "eightfold" actually refers not to the size of the superfamily but to a system of symmetries involving eight quantum numbers.)

The new 2,700-mev state is noteworthy in that it was produced by the six-billion-electron-volt (6-bev) electron synchrotron in Cambridge, Mass., operated jointly by Harvard University and the Massachusetts Institute of Technology. All the other new particles have been created by three large proton synchrotrons: the 6.2-bev accelerator of the University of California at Berkeley, the 33-bev alternating-gradient synchrotron at the Brookhaven National Laboratory and the similar 28-bev accelerator operated by CERN (the European Organization for Nuclear Research) in Geneva.

The third of the baryons not listed in February is a Ξ (xi) state with a rest mass of 1,810 mev. The six mesons not previously listed are three π (pi) states, two η (eta) states and one κ (kappa) state. Their rest masses in mev are 1,090, 1,220 and 1,310 for the π's, 959 and 1,410 for the η's and 1,215 for the κ.

Streptomycin and the Genetic Code

A study indicating that the antibiotic streptomycin may kill bacterial cells by flooding them with defective protein molecules has also raised questions about the validity of recently compiled genetic-code "dictionaries." These dictionaries attempt to show how the four-letter alphabet of the genetic code can be translated into the 20-letter alphabet of protein molecules, which the cell manufactures in great variety. The four letters of the genetic code are the bases adenine (A), guanine (G), cytosine (C) and either thymine (T) or uracil (U), depending on whether the code is embodied in deoxyribonucleic acid (DNA) or ribonucleic acid (RNA). The letters of the protein code are the 20 different amino acids, which link together to form polypeptide chains. It is believed that each amino acid is specified by a triplet of bases; for example, the triplet UUU specifies the amino acid phenylalanine.

It has been known for some time that antibiotics such as streptomycin can kill

bacterial cells by interfering in some way with the synthesis of proteins. It is also known that cells can become resistant to streptomycin by mutation and can even in some cases become streptomycin-dependent. (Other antibiotics that block protein synthesis include puromycin and chloramphenicol. Actinomycin blocks the synthesis of RNA from DNA.)

In recent months the search for streptomycin's site of action has been narrowed to the ribosome, the intracellular particle that presides at the synthesis of protein molecules. Protein synthesis occurs when a ribosome becomes attached to a strand of "messenger" RNA, which has previously transcribed a portion of the genetic message from much longer strands of DNA. The ribosome evidently travels along the messenger RNA, holding it in place, while smaller molecules of "soluble" RNA (sRNA) "read" the triplet code and insert the appropriate amino acid in the growing polypeptide chain.

The April issue of *Proceedings of the National Academy of Sciences* contains two independent reports indicating that streptomycin acts on the smaller of two subunits that form the complete ribosome. One report was by Julian E. Davies of the Harvard Medical School and the other by Edward C. Cox, James R. White and Joel G. Flaks, working at the University of Pennsylvania School of Medicine. The two subunits of the ribosome have the labels 30s and 50s; these designations refer to their rate of sedimentation when they are centrifuged. The two subunits can be dissociated and reassembled without loss of their biological activity.

Davies and Cox and his colleagues studied the polypeptide-synthesizing ability of hybrid ribosomes assembled from 30s and 50s subunits that had been obtained from bacterial cells that were either streptomycin-sensitive or streptomycin-resistant. The ribosomes were stimulated to produce polypeptides by being supplied with strands of synthetic messenger RNA known as poly U, a form of RNA containing only uracil (U). Such a strand normally stimulates the synthesis of polypeptide chains that contain only the amino acid phenylalanine. Davies and the Cox group found that synthesis was inhibited only when

the ribosome hybrids contained 30s subunits from a streptomycin-sensitive strain of bacteria. This implied that streptomycin sensitivity existed only in the 30s subunit of the ribosome.

A further study of the problem and a unifying hypothesis that embraces streptomycin dependence is reported in the May issue of *Proceedings of the National Academy of Sciences* by Davies in collaboration with Luigi Gorini, also of the Harvard Medical School, and Walter Gilbert of Harvard University. They restudied the polypeptides formed when ribosomes from streptomycin-sensitive bacteria were stimulated with poly U. As expected, the incorporation of phenylalanine was sharply reduced by the presence of streptomycin, but the incorporation of other amino acids (isoleucine, leucine and serine), not normally coded for by poly U, was notably enhanced. The Harvard group found further that the level of miscoding could be increased by raising the concentration of magnesium ions in the experimental system. This general miscoding attributable to excessive magnesium ions did not require the presence of streptomycin and took place even when the ribosomes were obtained from streptomycin-resistant strains of bacteria. Sensitivity of poly-U coding to the magnesium-ion level had been observed previously by Wlodzmierz Szer and Severo Ochoa of the New York University School of Medicine and throws into doubt the code assignments made in recent compilations of the genetic-code dictionary.

One conclusion to be drawn from these results is that streptomycin can cause gross misreading of the genetic code. This suggests that streptomycin may kill sensitive cells by flooding them with nonfunctional proteins. A more profound result of the Harvard study is that it will force biochemists to reexamine the sources of specificity in protein synthesis. Evidently the coding units in messenger RNA are not sufficient in themselves to guarantee that a particular amino acid will be delivered by a particular sRNA. It appears that the translation mechanism also involves the conformation of the site on the ribosome that holds the sRNA to the messenger RNA.

The authors of the Harvard study frame their hypothesis of the mechanism of streptomycin sensitivity, resistance and dependence as follows: "A modification in [the sRNA-binding] site, for example by the binding of streptomycin, permits a 'wrong' sRNA to fit so well against the messenger that a 'wrong' amino acid is entered into the polypeptide chain. A further modification, by mutation, changes the structure of the ribosomal site so that the correct sRNA is paired, whether or not streptomycin is present. Still further modification might make the site require the presence of a streptomycin molecule in order to function correctly; this would constitute a mechanism for the classical streptomycin dependence."

Preventing Mental Retardation

Massachusetts and New York are the first states to enact laws specifically designed to prevent mental retardation. The legislation requires a simple blood test of all newborn infants to detect the disease phenylketonuria (PKU), which results from a genetic defect. The PKU patient lacks an enzyme needed to utilize the amino acid phenylalanine, a constituent of all food proteins. Within 30 days after birth waste products that accumulate from the excess of phenylalanine begin to damage the brain irreversibly. Although there is no cure for the condition, a special diet low in phenylalanine can prevent mental retardation.

The testing of nearly 400,000 newborn infants in 28 states and Puerto Rico during the past two years has shown that PKU occurs about once in 10,000 births. As many as 400 children with PKU are born in the U.S. annually. The test, developed by Robert Guthrie of the New York State University School of Medicine in Buffalo, uses the "inhibition assay" principle. A sample of dried blood is placed in an agar culture medium containing a phenylalanine antagonist and spores of *Bacillus subtilis*. The antagonist normally inhibits the multiplication of the bacillus, but in the presence of blood from a baby with PKU a colony of the bacilli develops overnight. Guthrie is now applying the principle to the development of similar tests for several other genetic defects responsible for metabolic diseases.

The New York law requiring tests for PKU was passed by the 1964 Legislature and will go into effect on January 1, 1965. Massachusetts has had its law since 1963.

Galactic Magnetism

Two recent discoveries have added significantly to a small but growing fund of knowledge about the magnetic fields of galaxies. At the Mount Wilson and Palomar Observatories optical evidence of a large-scale magnetic field has been observed in the nearby spiral galaxy designated M 82. Meanwhile at the Owens Valley Radio Observatory of the California Institute of Technology radio astronomers have succeeded for the first time in determining the polarity of the magnetic field in our own galaxy.

Allan R. Sandage and William C. Miller of Mount Wilson and Palomar report their findings in *Science*. Their photographs, made in blue light with the 200-inch telescope on Palomar Mountain, reveal a previously undetected array of filaments extending as far as 13,000 light-years above and below the center of the disk of M 82. The filaments are believed to be the remnants of a violent explosion that took place at the center of this galaxy some 1.5 million years ago. Radio waves from the filaments are characteristic of synchrotron radiation, which is produced by the rapid gyration of high-energy electrons in a strong magnetic field. Light from the filaments is highly polarized, with the electric vector of the light waves perpendicular to the filamentary structure. Thus the findings indicate the existence of a more or less uniform large-scale magnetic field directed along the minor axis of M 82.

David Morris and Glenn Berge of the Owens Valley Observatory took advantage of a phenomenon known as the Faraday effect in determining the polarity, or direction, of the magnetic-field lines in our galaxy. By observing how the polarizations of radio waves from 37 known sources were changed as the waves passed through different parts of the galaxy, Morris and Berge were able to observe indirectly the galaxy's magnetic field out to a distance of about 1,000 light-years from the sun. They have found that the polarity of some segments of the galaxy's magnetic field is the reverse of that of other segments and that these reversals occur systematically with galactic longitude. In general the polarity seems to be reversed at the plane of the galactic disk.

Family Resemblance

An inquiry into the nature of all the meteorites that since 1800 have been seen to fall and have then been recovered suggests that half of them came from a single parent body. During a recent symposium on meteorites at the National Academy of Sciences, Edward Anders of the University of Chicago pointed out that more than 600 such

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meteorites have been collected, that 93 percent of them are stony rather than metallic and that more than half are chondrites that contain chondrules, or fine grains, of the mineral hypersthene. Isotope dating, Anders observed, indicates that many meteorites underwent rapid cooling somewhat more than four billion years ago. The hypersthene chondrites, however, have in common a much later cooling date: a mere 400 million years ago.

One way to account for this fact would be to assume that all the hypersthene chondrites were fragments of a single asteroid that was involved in a catastrophic collision—with consequent heating and cooling—at that late date. Searching for astronomical evidence to support this hypothesis, Anders noted that four swarms of small asteroids, comprising more than 34 individuals, are not tidily in orbit between Jupiter and Mars. Instead they follow unusually elongated paths that bring them inside the orbit of Mars. Pointing out that such eccentric travelers would be "ideal launching pads" for earthbound debris, Anders suggests that each of the four swarms represents the shattered remnants of a larger body and that one of the four is the source of all hypersthene chondrites.

Picturephone

By this month it should be possible for a New Yorker, a Chicagoan or a Washingtonian to communicate with someone in one of the other cities by televised telephoning. The device he would use is called a Picturephone and is described by the American Telephone and Telegraph Company, which developed it, as "the first dialable visual telephone system with an acceptable picture that has been brought within the range of economic feasibility." According to the company, the 275-line picture of the device presents an image equivalent to that of a picture occupying about half the height of a well-focused home television screen.

A customer wishing to use the Picturephone must be prepared to go to some extra trouble and expense. He will have to make arrangements in advance with the person he intends to call, and each of them will have to go to a particular place in his city: in New York it will be Grand Central Terminal, in Washington the National Geographic Society Building and in Chicago the Prudential Insurance Building. A typical charge will be $21 for a three-minute call between Washington and Chicago; that compares with $1.35 for a telephone conversation of the same length.

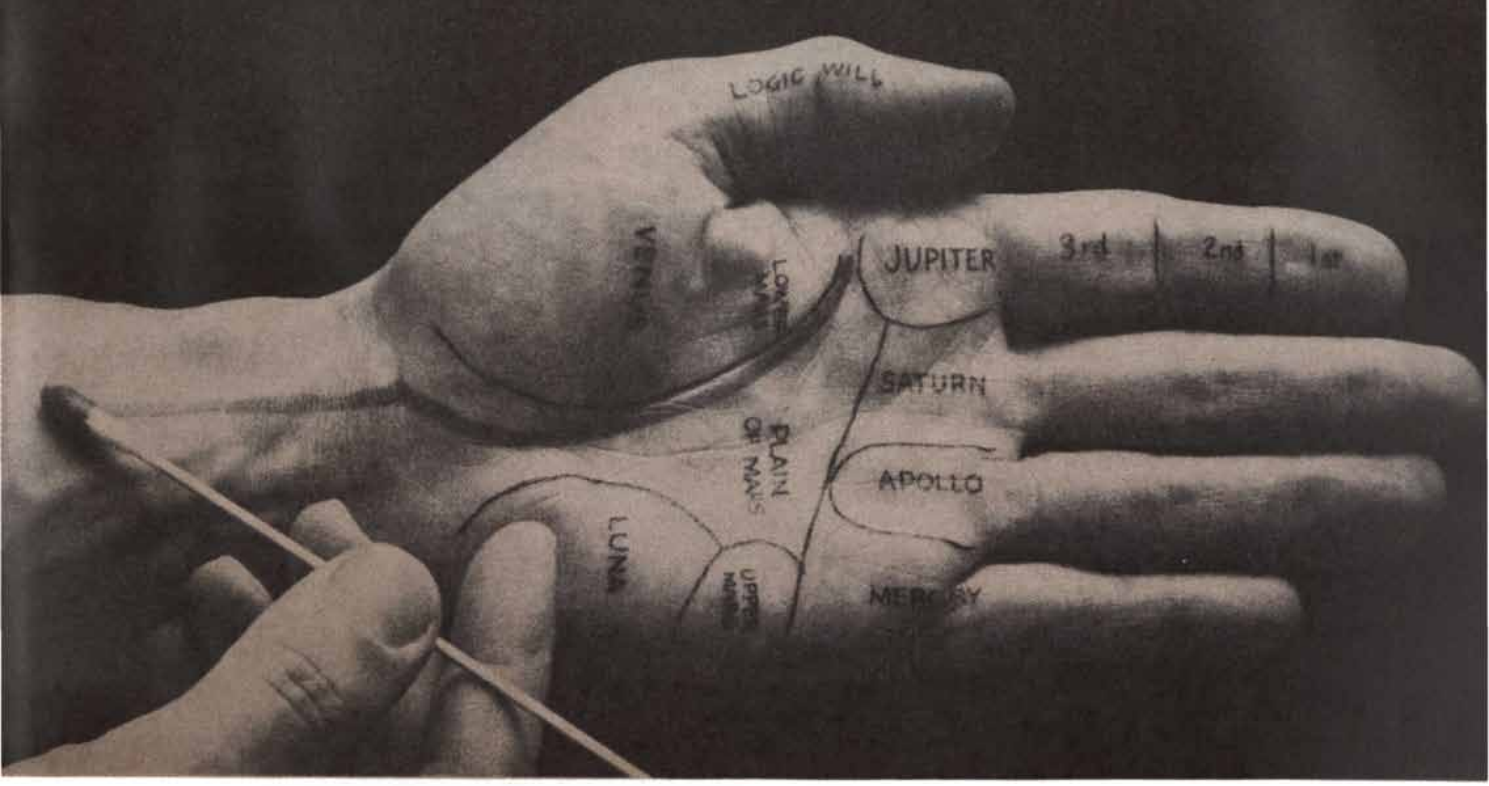
To use the Picturephone each party to a call sits about three feet away from a desktop unit that includes a camera and a screen 4¾ inches wide and 5¾ inches high. Ordinary illumination in the room is adequate for the camera. A user can cancel the transmission of his image at any time by pressing a button.

AT&T is establishing the service in the three cities as a test of public interest and reaction. The company says it cannot hope to provide the service to homes or offices at present, one reason being that the transmission of a picture requires a bandwidth of 500,000 cycles per second—a space that would accommodate 125 voice-only telephones.

Toolmaking Chimpanzees

The use of "tools" is uncommon but not unknown in the animal kingdom: solitary wasps tamp the soil over nest entrances with pebbles; short-billed finches probe for bark-concealed insects with thorns; sea otters have a hammer-and-anvil technique for opening shellfish. Toolmaking, however, appears to be confined to the primates and, except in the case of man, the behavior is known for the most part only among caged apes and monkeys. Jane Goodall of the University of Cambridge has now reported in *Nature* her observations of toolmaking and tool-using among wild chimpanzees over a three-year period in a Tanganyika reserve. The most frequently observed behavior (91 occasions) involved the chimpanzees' making probes out of twigs six inches to a foot long by stripping off leaves with their hands or lips. The probes were then pushed into holes in termite nests. When a probe was withdrawn, a few termites that had seized it were eaten.

Some chimpanzees prepared their "tools" before visiting termite nests, and immature animals frequently watched their elders at work and imitated their actions. Because the termites extend their passages to the surface of the nest only during three months of the year, this form of tool-using is unrewarding most of the time. Nonetheless, Miss Goodall saw one mature chimpanzee and one immature one make, and attempt to use, a tool out of season. She concludes that the chimpanzee population of the reserve is transmitting a series of primitive cultural traditions from one generation to the next.



WHAT'S HAPPENING TO MAN'S LIFELINE?

It's lengthening—figuratively—because of the cooperative probing by many different scientists into problems once faced exclusively by medical researchers.

Fever, the great warning symptom that may first have been measured by Galileo, is now being located exactly instead of generally, by infrared detection. Even soft tissue and fluids are being "photographed." Strep throat and certain other infections can be diagnosed in hours instead of days by utilizing a fluorescent antibody testing technique developed by optics and electronics engineers, physicians, and biochemists. The fluoroscopic light microscope used in this technique is also of value in research.

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THE EARLY RELATIVES OF MAN

New evidence from fossils of the period between 60 and 12 million years ago not only illuminates the main stages of primate evolution but also singles out the ape stock from which the human line arose

by Elwyn L. Simons

A major feature of biological evolution during the past 70 million years has been the rapid rise to a position of dominance among the earth's land-dwelling vertebrates of the placental mammals (mammals other than marsupials such as the kangaroo and primitive egg-laying species such as the platypus). A major feature, in turn, of the evolution of the placental mammals has been the emergence of the primates: the mammalian order that includes man, the apes and monkeys. And a major event in the evolution of the primates was the appearance 12 million to 14 million years ago of animals, distinct from their ape contemporaries, that apparently gave rise to man.

Much of the evidence of the origin of man is new, but by no means all of it. For many years students of human evolution have broadly agreed that man's earliest ancestor would be found among the apelike primates that flourished during Miocene and early Pliocene times, roughly from 24 million to 12 million years ago [*see illustration on page 55*]. As long ago as the 1920's William K. Gregory of the American Museum of Natural History, after studying the limited number of jaw fragments and teeth then available, flatly pronounced man to be "a late Tertiary offshoot of the *Dryopithecus-Sivapithecus* group, or at least of apes that closely resembled those genera in the construction of jaw and dentition."

Until recently students of primate evolution have had little more evidence to work with than Gregory and his contemporaries did. Within the past 15 years, however, a number of significant new finds have been made—some of them in existing fossil collections. The early primates are now represented by many complete or nearly complete skulls, some nearly complete skeletons, a number of limb bones and even the bones of hands and feet. In age these specimens extend across almost the entire Cenozoic era, from its beginning in the Paleocene epoch some 63 million years ago up to the Pliocene, which ended roughly two million years ago.

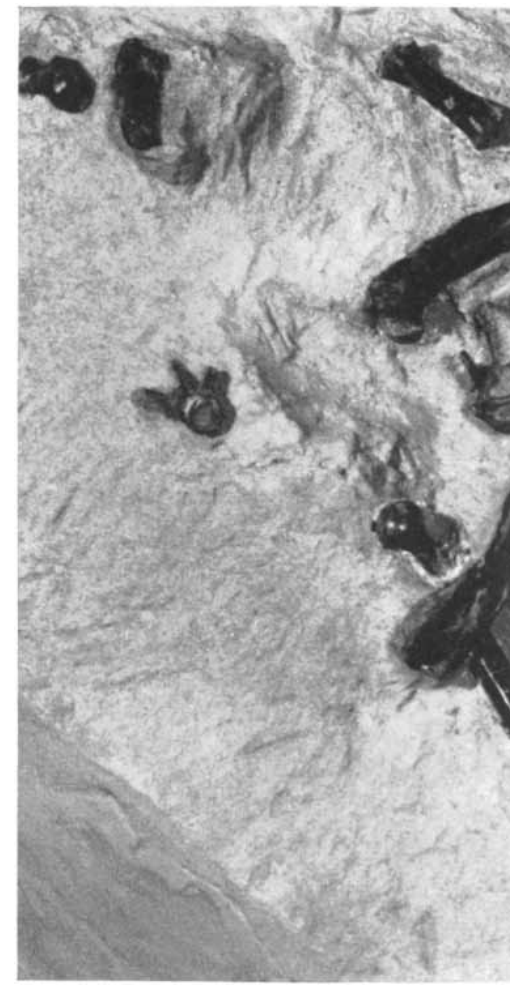
Sometimes a single jaw can tell a remarkably detailed evolutionary story, but there are no greater paleontological treasures than reasonably complete skulls and skeletons. Many such specimens have become available in recent years, but they do not lie in the exact line of man's ancestry. They are nonetheless important to the evolutionary history of all the primates. Both by their relative completeness and by their wide distribution in time they reveal new details concerning the main stages through which the primates probably passed during their evolutionary development.

To describe these stages is one of the two objectives of this article. The other objective is to summarize what is known about the relation of the early primates to the primate order's more advanced lineages, including man's own family: the Hominidae. The accomplishment of these objectives will show that the weight of today's knowledge fortifies Gregory's declaration of the 1920's.

Subdividing the Primates

Ideally zoological classification uses standard suffixes to guide the student through the maze of descending divisions: from class to order and thence —by way of suborders, infraorders, superfamilies, families, subfamilies and the like—to a particular genus and species. The grammar of primate taxonomy is not this simple. Two factors are responsible. First, there is no international agreement as to how the order of primates should be subdivided. Second, generations of literary usage preceding man's first awareness of evolution have made all nouns derived from the Greek *anthropos* or the Latin *homo* virtually synonymous.

Nonetheless, an ability to read these taxonomic signposts is vital to an under-



EARLY PRIMATE, about the size of a cat, was discovered in a Wyoming fossil deposit of middle Eocene age. One of the prosim-

standing not only of the relations among the 50-odd genera of living primates but also of the positions assigned to various extinct primates. This is because modern classification interrelates organisms in a pattern that reflects their evolutionary relations. In tracing the subdivisions that lead to man, for example, the first major branching divides the whole group of living primates into two suborders [*see illustration on the next two pages*]. The less advanced primates are assigned to the Prosimii; they are the various tree shrews, the many kinds of lemurs, the less abundant lorises and the solitary genus of tarsiers. The earliest known fossil primates belong exclusively to this suborder. The line to man, however, runs through successive divisions of the second primate suborder.

This suborder, consisting of the more advanced primates, is the Anthropoidea. It is divided into two infraorders. The less advanced anthropoids, including all the primates native to the New World, are the Platyrrhini. "Platyrrhine," which literally means "broad-nosed," refers to the wide spacing of the nostrils that is characteristic of the New World anthropoids.

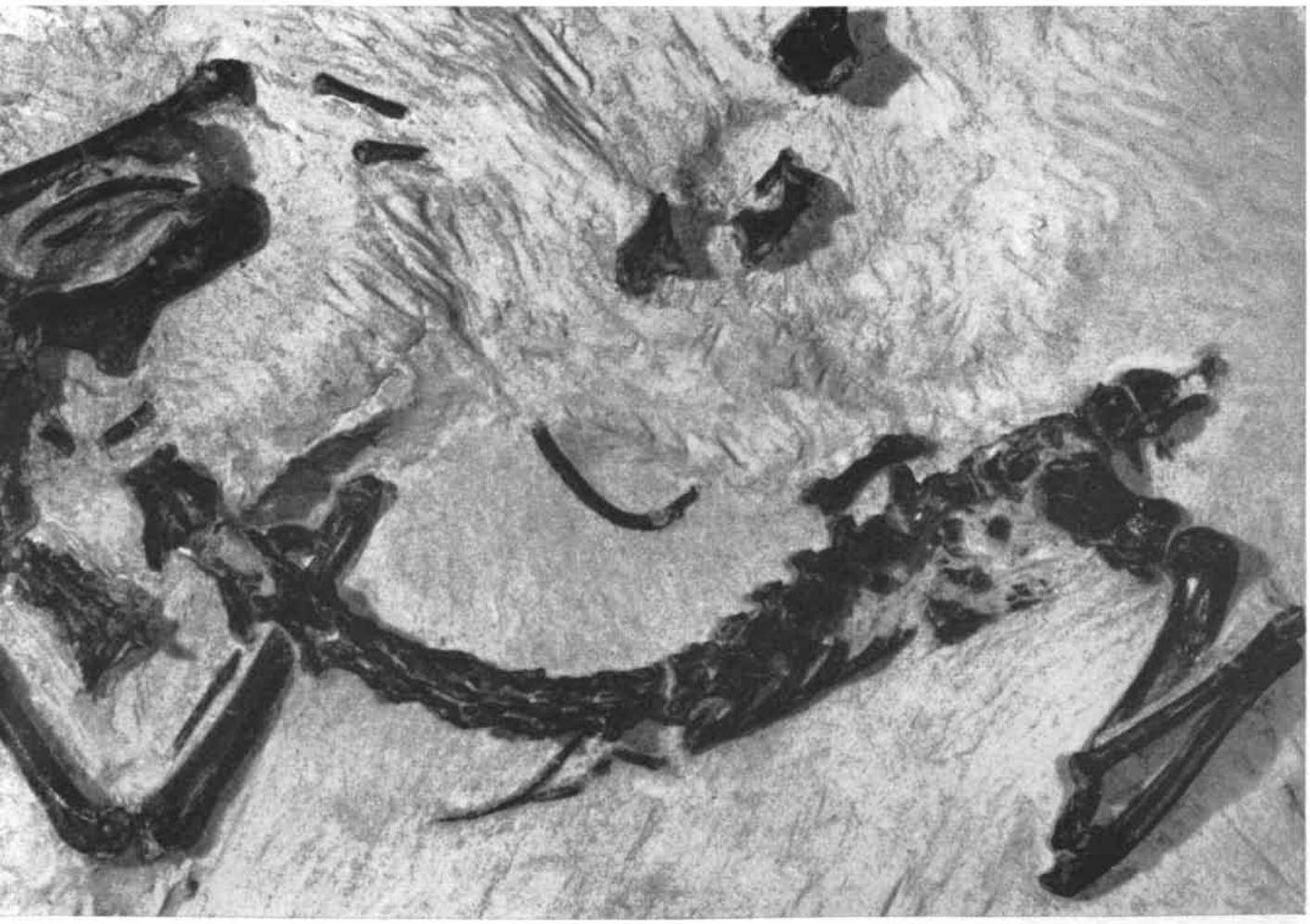
The more advanced anthropoids are the Catarrhini. They include all other living anthropoids: the Old World monkeys, the apes and man himself. "Catarrhine" is opposed to "platyrrhine"; it literally means "hooknosed" but refers to a close spacing of the nostrils. The catarrhine infraorder is in turn divided into two superfamilies: the Cercopithecoidea and the Hominoidea. The first of these means "apes with tails"; it embraces the two subfamilies and 13 genera of living Old World monkeys.

The second catarrhine superfamily, the Hominoidea, embraces the subdivisions that finally separate the genus *Homo* from the rest of the living primates. The hominoids are split three ways: the families Hylobatidae, Pongidae and Hominidae. The first of these takes its name from *Hylobates,* the gibbon of South Asia, and includes both this hominoid primate and the closely related siamang of Sumatra. The family Pongidae embraces the three genera of great apes: *Pongo,* the orangutan; *Pan,* the chimpanzee, and *Gorilla,* whose scientific name is the same as the common.

Of the family Hominidae, however complex its subfamilies and genera may or may not once have been, there survives today only the single genus *Homo* and its single species *Homo sapiens.* Man, then, is the sole living representative of the hominid family within the hominoid superfamily of the catarrhine infraorder of anthropoids. Or, to reverse the order of classification, among the 33 or so living genera of Anthropoidea whose names are accepted as valid there are only six genera of hominoids and a single hominid genus.

A Paleocene Tree-Dweller

The Age of Mammals was ushered in some 63 million years ago by a brief geological epoch: the Paleocene. Last-



ians, the less advanced of the two major divisions of the primate order, it is a member of the genus *Notharctus* and so belongs to a once abundant subfamily of tree-dwelling primates. Although primitive, the latter had many features in common with today's lemurs. They did not, however, give rise to any living prosimians and were extinct before the end of the Eocene, 36 million years ago.

ing perhaps five million years, the Paleocene was followed by the much longer Eocene epoch, which occupied roughly the next 22 million years. Both periods seem to have been characterized by warm temperatures that permitted tropical and subtropical forests to extend much farther north and south of the Equator than is the case today. These forests were inhabited by a diverse and abundant population of primates [*see illustration on page 55*]. The fossil record shows that species belonging to nearly 60 genera of prosimians, the bulk of them grouped in eight families, inhabited the Northern Hemisphere during Paleocene and Eocene times.

Three of these eight prosimian families are characterized by elongated front teeth, presumably adapted for chiseling and gnawing, as are the rather similar teeth of today's rodents and rabbits. It seems reasonable to suppose that these early primates started their evolutionary careers in competition for some kind of nibblers' and gnawers' niche in the warm forests. They were not successful; before the middle of the Eocene all three chisel-toothed prosimian families had become extinct. Perhaps they were put out of business by the rodents, which became abundant as these prosimians were dying out.

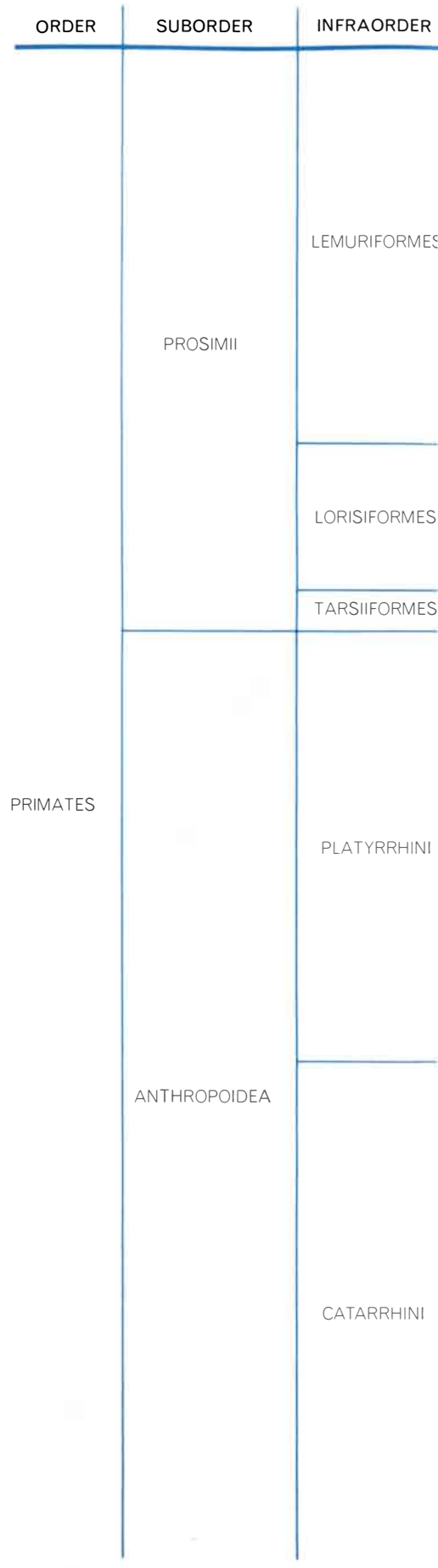
The skeletal remains of a member of one of these extinct families were recently found by D. E. Russell of the French national museum of natural history in late Paleocene strata near Cernay-lez-Reims in France. This early fossil primate belongs to the genus *Plesiadapis,* and the Cernay discovery includes a remarkably complete skull and a relatively complete series of limb and foot bones. An incomplete *Plesiadapis* skeleton is also known from Paleocene deposits in Colorado, and there are numerous jaws, jaw fragments and teeth from many other North American sites. These discoveries in opposite hemispheres, incidentally, make *Plesiadapis* the only genus of primate other than man's own that has inhabited both the Old and the New World.

Species of *Plesiadapis* varied in size from about the size of a squirrel to the size of a housecat. In life they probably looked as much like rodents as they did like primates [*see illustration on page 56*]. The patterns of the crowns of *Plesiadapis*' cheek teeth, however, resemble such patterns in lemur-like fossil primates of the Eocene epoch, and the structure of its limb bones links it with such living prosimians as the lemurs of the island of Madagascar (now the Malagasy Republic).

Plesiadapis is nonetheless distinctive. Its skull has a small braincase and a long snout. Its enlarged and forward-slanting incisors are widely separated from its cheek teeth. This arrangement is characteristic of the rodents, and although *Plesiadapis* appears too late to be an ancestor of the rodents, some workers have suggested that the order of rodents may be descended from animals not very different from it.

Plesiadapis exhibits two other traits that set the genus apart from almost all later primates. First, most if not all of its fingers and toes ended in long claws that were flattened at the sides. Among living primates only the tree shrews have a claw on each digit; all other species have either a combination of nails and claws or nails exclusively. Moreover, the claws of living primates are small compared with those of *Plesiadapis.* Regardless of their size, these claws probably served the same function as claws do among living tree shrews, helping this ancient arboreal primate to scramble up and down the trunks of trees.

The second peculiar trait, possibly one of lesser significance, is a resemblance between the structure of the middle ear of *Plesiadapis* and that of a nonprimate: the colugo, or "flying lemur," which still inhabits southeast Asia. The first thing to be said of the colugos, as George Gaylord Simpson has put it, is that they "are not lemurs and cannot fly." Colugos are so unusual that taxonomists have been obliged to place them in a mammalian order—the Dermoptera—all their own. The size of a squirrel or larger, with broad flaps of skin for gliding that run from its forelimbs to the tip of its tail, the colugo shows little outward resemblance to any other living mammal. It has been conjectured that the colugos are ultimately



TAXONOMY of the living primates ranks the order's 52 genera (*scientific and common names at far right*) according to divisions of higher grade. There is no universal agreement on how this should be done. For example, the two infraorders of anthropoids in this system are held by many investigators to be suborders and thus equal in rank with the Prosimii. It is generally agreed, however, that man belongs among the catarrhines and, within that group, is a member of the hominoid superfamily (as are all the apes) and the hominid family, in which he is the only living species of the genus *Homo*.

SUPERFAMILY	FAMILY	SUBFAMILY	*GENUS*	COMMON NAME
TUPAIOIDEA	TUPAIIDAE	TUPAIINAE	*TUPAIA* *DENDROGALE* *UROGALE*	COMMON TREE SHREW SMOOTH-TAILED TREE SHREW PHILIPPINE TREE SHREW
		PTILOCERCINAE	*PTILOCERCUS*	PEN-TAILED TREE SHREW
LEMUROIDEA	LEMURIDAE	LEMURINAE	*LEMUR* *HAPALEMUR* *LEPILEMUR*	COMMON LEMUR GENTLE LEMUR SPORTIVE LEMUR
		CHEIROGALEINAE	*CHEIROGALEUS* *MICROCEBUS*	MOUSE LEMUR DWARF LEMUR
	INDRIDAE		*INDRI* *LICHANOTUS* *PROPITHECUS*	INDRIS AVAHI SIFAKA
	DAUBENTONIIDAE		*DAUBENTONIA*	AYE-AYE
LORISOIDEA	LORISIDAE		*LORIS* *NYCTICEBUS* *ARCTOCEBUS* *PERODICTICUS*	SLENDER LORIS SLOW LORIS ANGWANTIBO POTTO
	GALAGIDAE		*GALAGO*	BUSH BABY
TARSIOIDEA	TARSIIDAE		*TARSIUS*	TARSIER
CEBOIDEA	CALLITHRICIDAE		*CALLITHRIX* *LEONTOCEBUS*	PLUMED AND PYGMY MARMOSETS TAMARIN
	CEBIDAE	CALLIMICONINAE	*CALLIMICO*	GOELDI'S MARMOSET
		AOTINAE	*AOTES* *CALLICEBUS*	DOUROUCOULI TITI
		PITHECINAE	*PITHECIA* *CHIROPOTES* *CACAJAO*	SAKI SAKI UAKARI
		ALOUATTINAE	*ALOUATTA*	HOWLER
		CEBINAE	*CEBUS* *SAIMIRI*	CAPUCHIN SQUIRREL MONKEY
		ATELINAE	*ATELES* *BRACHYTELES* *LAGOTHRIX*	SPIDER MONKEY WOOLLY SPIDER MONKEY WOOLLY MONKEY
CERCOPITHECOIDEA	CERCOPITHECIDAE	CERCOPITHECINAE	*MACACA* *CYNOPITHECUS* *CERCOCEBUS* *PAPIO* *THEROPITHECUS* *CERCOPITHECUS* *ERYTHROCEBUS*	MACAQUE BLACK APE MANGABEY BABOON, DRILL GELADA GUENON PATAS MONKEY
		COLOBINAE	*PRESBYTIS* *PYGATHRIX* *RHINOPITHECUS* *SIMIAS* *NASALIS* *COLOBUS*	COMMON LANGUR DOUC LANGUR SNUB-NOSED LANGUR PAGI ISLAND LANGUR PROBOSCIS MONKEY GUERAZA
HOMINOIDEA	HYLOBATIDAE		*HYLOBATES* *SYMPHALANGUS*	GIBBON SIAMANG
	PONGIDAE		*PONGO* *PAN* *GORILLA*	ORANGUTAN CHIMPANZEE GORILLA
	HOMINIDAE		*HOMO*	MAN

related to both the primates and the bats. The resemblance in ear structure is not the only similarity between the living colugos and the long-extinct *Plesiadapis:* the colugo's digits also bear sizable claws. Both of these similarities, however, could have been acquired independently rather than from a common ancestor.

Although early in time and cosmopolitan in range, *Plesiadapis* is clearly too specialized a primate to be the ancestor of later prosimians. This sterile offshoot of the family tree is significant to primate history on other grounds. First, the relative completeness of its remains makes *Plesiadapis* the most thoroughly known primate of the Paleocene. Second, many details of its skeletal form serve to link its order with that of the even earlier placental mammals—the Insectivora, from which the primates arose.

Eocene Evolutionary Advances

The next fossil primates of which there are nearly complete remains come from North American strata of the middle Eocene. The best-known examples are species of two related lemur-like genera: *Notharctus* and *Smilodectes.* The degree to which these prosimians have advanced beyond *Plesiadapis* demonstrates the rapid evolution of primates as much as 50 million years ago. Many incomplete specimens of *Notharctus* were exhaustively studied in the 1920's by Gregory. Since then an even more complete skeleton of one species —probably *Notharctus tenebrosus*—has come to light in the paleontological research collection of Yale University. Although the skull is missing, the rest of the skeleton represents one of the two most complete individual primates yet recovered from fossil beds of such early date. C. Lewis Gazin of the Smithsonian Institution has recently recovered several complete skulls and many other bones of *Smilodectes gracilis* in southwestern Wyoming. The abundance of this new material has permitted the assembly of a skeleton and a restoration of *Smilodectes*' probable appearance [*see illustration on page 57*].

These New World primates resemble living lemurs both in their proportions and in their general structure. In contrast to the small-brained, snouty, side-eyed *Plesiadapis,* the skull of *Smilodectes* shows an enlargement of the front portion of the brain and a shifting of eye positions forward so that individual fields of vision can overlap in front. These features of the head, taken together with the animal's rather long hind limbs, suggest that in life *Smilodectes* looked rather like one of today's Malagasy lemurs, the sifaka.

It is most unlikely, however, that either *Smilodectes* or *Notharctus* contributed to the ancestry of living lemurs. This honor can more probably be conferred on some member of a European genus, such as *Protoadapis* or *Adapis,* of equal Eocene age, if indeed the ancestors of modern lemurs were not already in Africa by this time. *Adapis* has the distinction of being the first fossil primate genus ever described. The French paleontologist Baron Cuvier did so in 1822, although he originally thought *Adapis* was a hoofed mammal or a small pachyderm and not a primate at all. Unfortunately none of these possible Old World precursors of living lemurs is sufficiently represented by fossils to provide the kind of detailed skeletal information we possess for their New World contemporaries.

This is also the case for a roughly contemporary European prosimian: *Necrolemur,* known from skulls and limb bones found in the Quercy deposits of France and by extrapolation from parts of a related species recovered in Germany. In *Necrolemur* the evolutionary advances represented by *Notharctus* and *Smilodectes* have been extended. Enlargement of the forebrain and a further facial foreshortening are apparent. A forward shift of the eye position —with the consequent overlapping of visual fields and potential for depth perception—should have equipped *Necrolemur* for an active arboreal life in the Eocene forests. Actually this early primate, although it is probably not ancestral to any living prosimian, shows a much closer affinity for the comparatively advanced tarsier of southeast Asia than for the more primitive Malagasy lemurs.

The evolutionary progress made by prosimians during the Eocene, both in North America and in Europe, is obvious. Yet not a single fossil primate of the Eocene epoch from either continent appears to be an acceptable ancestor for the great infraorder of the catarrhines, embracing all the living higher Old World primates, man included. One cannot help wondering what developments may have been taking place in Africa and Asia during the Eocene's span of more than 22 million years. In both regions the record is almost mute. In Asia the only known primate fossils dating to this epoch are a few equivocal bits and pieces from China and some fragments from a late Eocene formation in Burma. From the Eocene of Africa there are not only no primates but also no small mammals of any kind.

One of the Burmese fragments is a section of lower jaw containing three premolar teeth and one molar, described in 1938 by Edwin H. Colbert of the American Museum of Natural History, who named the new species *Amphipithecus mogaungensis.* A brief lesson in primate teeth is necessary to understand its significance. The lesson is painless; it merely involves counting. The facts are these: Regardless of tooth size or shape all adult catarrhines—Old World monkeys, apes and man—have the same "dental formula." In each half of a jaw—upper and lower alike—are found from front to back two incisors, a single canine, two premolars and three molars. In anatomical shorthand the fact is written:

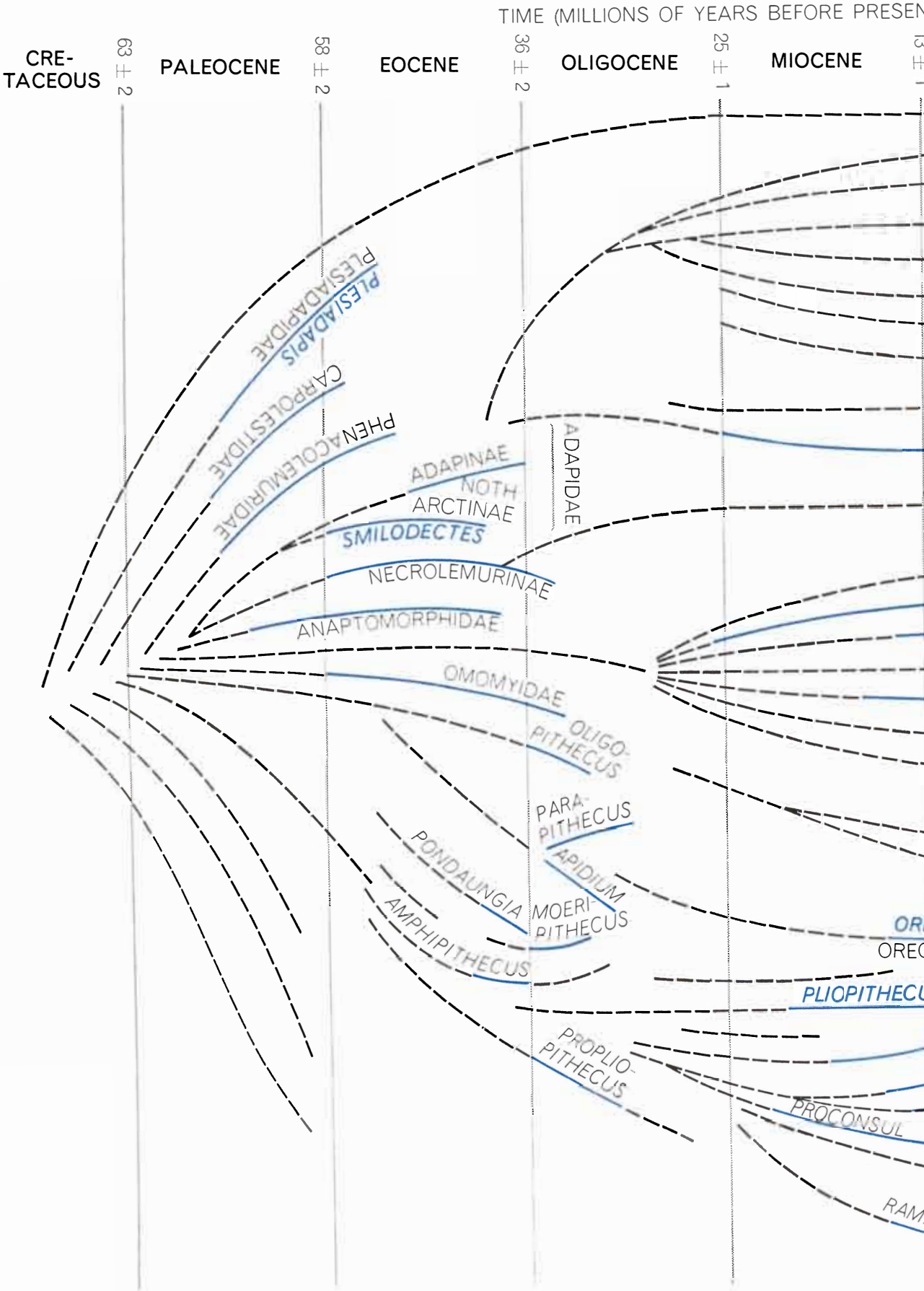
$$\frac{2:1:2:3}{2:1:2:3} \times 2 = 32.$$

Because of its three premolar teeth *Amphipithecus* is dentally more primitive than any catarrhine, fossil or living. It may have had such a dental formula as

$$\frac{2:1:3:3}{2:1:3:3} \times 2.$$

This is typical of some living lemurs and of many platyrrhines—the marmosets and monkeys of the New World. Yet in other characteristics the *Amphipithecus* jaw is advanced rather than primitive. The horizontal ramus—that portion of the jaw that holds the teeth—is deep and massive, as is also true in many fossil and living apes. The fossil premolars, and the molar as well, are

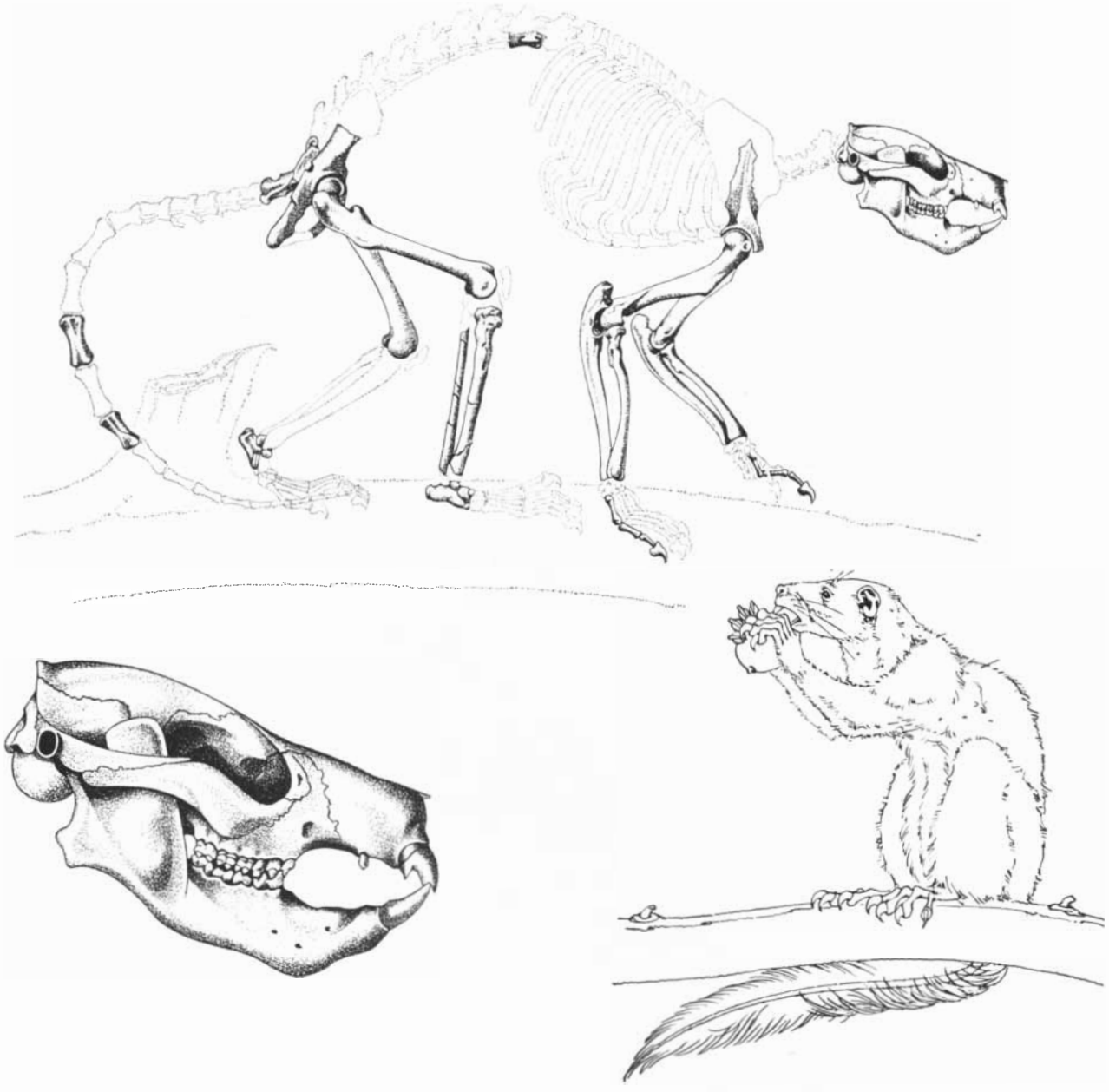
PHYLOGENY of all the primates traces the evolution of the order from its beginnings sometime before the middle of the Paleocene (*see time scale in illustration at right*). The first to appear were prosimian families that stemmed from a basic stock of small and sometimes arboreal mammals called Insectivora (whose living kin include the shrews and moles). The chart's broken lines show hypothetical evolutionary relations. In the interval between Eocene and Miocene times these relations are particularly uncertain. Solid lines (*color*) show the periods when species of the groups named (*black type*) are known to have flourished. The names of two prosimian and two anthropoid genera appear in color. Species of each are illustrated in detail on the four following pages.



similar to the corresponding teeth in *Oligopithecus,* a newly discovered catarrhine from the Oligocene of Egypt.

The other Burmese fossil consists of both rear portions of a lower jaw, discovered together with a segment of upper jaw containing two molar teeth. G. E. Pilgrim of the Indian Geological Survey gave this find the name *Pondaungia cotteri* in 1927. The two molars almost equally resemble those of prosimians on the one hand and of some Old World higher primates on the other. The material is so fragmentary, however, that some scholars have even questioned *Pondaungia*'s inclusion in the primate order. If neither *Amphipithecus* nor *Pondaungia* were known, it would seem almost certain that the Old World anthropoids had arisen in Africa. Further collecting in the Burmese Eocene formation that contained both Pilgrim's and Colbert's fossils is required before final judgment of their significance can be made.

By the end of the Eocene the primates had been differentiating for almost 30 million years. This is a long time. Yet only one result is known with certainty: A number of primates, lemur-like and tarsier-like, had evolved in the Old World, some of which must have contributed to the ancestry of today's lower primates, the Prosimii. Not until the close of the Eocene do some puzzling fossil fragments from Burma offer a hint of what must have been a major, even though still undocumented, evolutionary development in the Old World Tropics. This development can be postulated with confidence, in spite of a paucity of evidence, because early in the following epoch—the Oligocene—fossil Anthropoidea appear in substantial numbers and varieties. It is highly improbable that these Oligocene primates could have evolved, in terms of geologic time, almost overnight. So



PALEOCENE PROSIMIAN ***Plesiadapis*** **has been reconstructed (*skeleton at top*) on the basis of French and North American fossil finds and restored (*figure at bottom right*) by analogy with living tree shrews. Bones shown in outline are hypothetical. The characteristic wide gap between this rodent-like animal's cheek teeth and its slanting incisors is evident in the skull detail (*bottom left*). Species of *Plesiadapis* ranged from squirrel- to cat-size. They belong to an early primate family that died out 50 million years ago.**

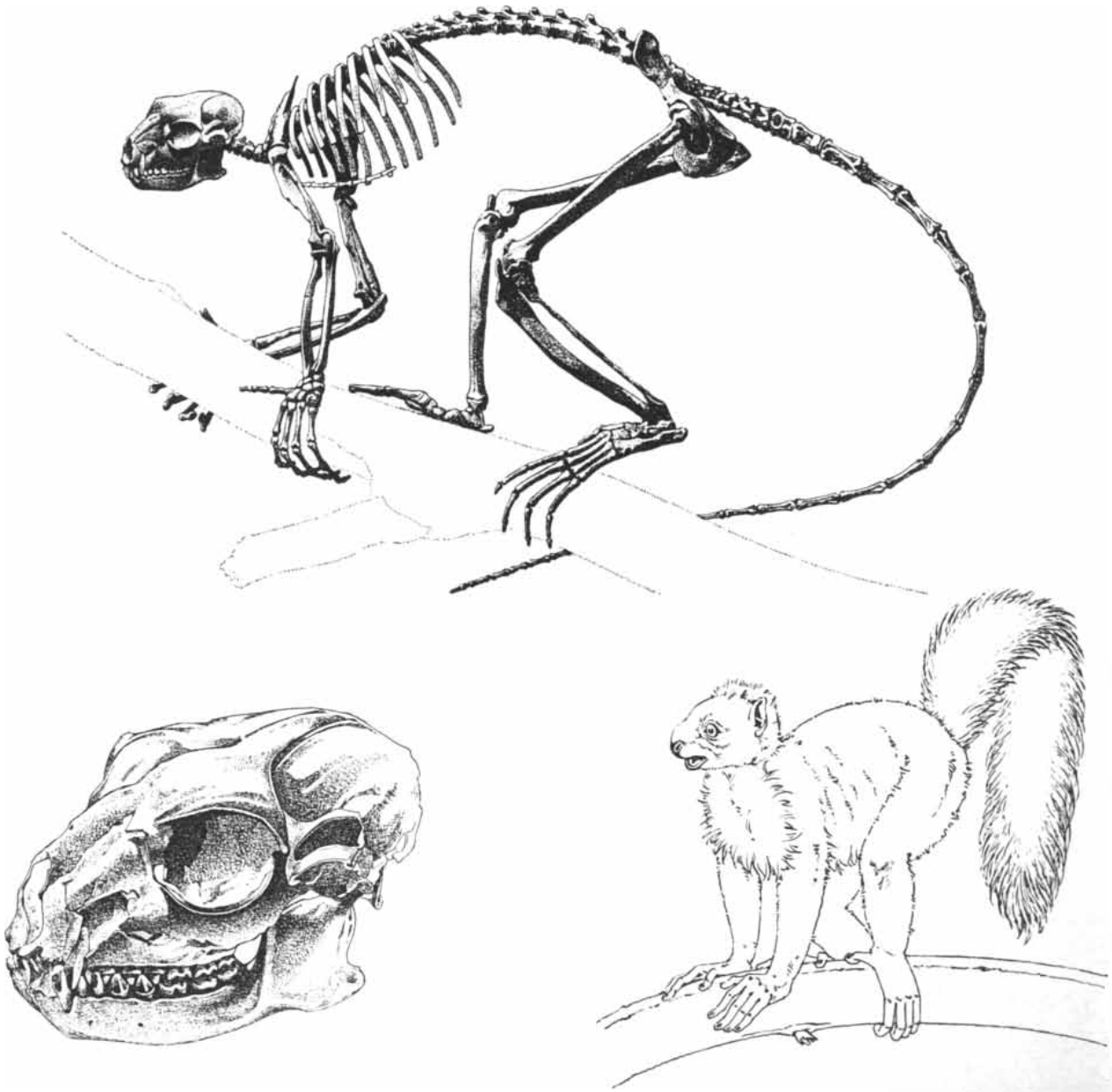
far our knowledge of their geographical distribution is exceedingly limited: all their remains discovered to date have come from a single formation in the desert badlands of the Egyptian province of the Fayum.

The Catarrhine Emergence

A hundred miles inland from the Mediterranean coast and some 60 miles southwest of Cairo a brackish lake stands at the edge of a series of escarpments and desert benches that are almost devoid of plant and animal life. At the end of the Eocene epoch the shore of the Mediterranean extended this far inland, and rivers flowed into the shallow sea through dense tropical forests. The rise and fall of sea and land is clearly revealed by alternating river-deposited strata and layers of marine limestone. In the middle of these escarpments, running from southwest to northeast between the lake and a lava-capped ridge called Gebel el Quatrani, is a fossil-rich stratum of sandy early Oligocene sediments that first yielded primate remains in the early 1900's.

Primates were not the only inhabitants of this forested Oligocene shoreline. Crocodiles and gavials swam in the sluggish streams. Tiny rodents and various relatives of today's hyrax lived in the underbrush, as did hog- and ox-sized cousins of the modern elephant. The largest animal of the fauna was a four-horned herbivore about the size and shape of today's white rhinoceros.

Until the recent Yale Paleontological Expedition the primate inventory from the Fayum totaled seven pieces of fossilized bone: one skull fragment (picked up by a professional collector in 1908 and sent to the American Museum of Natural History), one heel bone, three fragmentary portions of jawbone and two nearly complete lower jaws. This



EOCENE PROSIMIAN ***Smilodectes*** **is several million years junior to** ***Plesiadapis*** **and is a far more advanced animal. Its snout is shorter, the front portion of the brain is enlarged and its eyes are positioned on the skull in a manner that permits the visual fields to overlap. Although the notharctine subfamily to which this genus belongs was not ancestral to any of the living primates, its relatively long hind limbs give** ***Smilodectes*** **a remarkable resemblance to one modern prosimian, the sifaka, a Malagasy lemur.**

may not seem a particularly rich haul, but studies over the years have shown that these seven fossils represent at least four distinct genera and species of Oligocene primates.

By the end of the Yale Expedition's fourth season this past winter more than 100 individual primate specimens had been added to the Fayum inventory. Although many of these finds consist of single teeth, there are also more than two dozen lower jaws, a skull fragment and some limb bones. Thus far the Fayum beds have not yielded any skulls or other skeletal remains of the kind that provide so much detailed information on Paleocene and Eocene prosimians. What has been found, however, reveals a great deal. As one example, an incomplete lower jaw was discovered in 1961 by a member of the expedition, Donald E. Savage of the University of California at Berkeley. This fragment permits the establishment of a new primate genus, which I have named *Oligopithecus*. The molar teeth of the "type" species of the genus indicate that it may well be on or near the evolutionary line that gave rise to the superfamily of living Old World monkeys: the cercopithecoids.

The other Old World primate superfamily—the hominoids—also appears to be well represented among the Fayum fossils. Possible ancestors for one family of living hominoids—the gibbons and siamangs—are present: the well-preserved jaw of a gibbon-like animal, as yet undescribed, was turned up by the Yale Expedition in 1963. In this connection it should be noted that the study of all the Fayum fossils belonging to the genus *Propliopithecus*—for many years regarded as an ancestor of the gibbon—indicates that it probably represents a more generalized hominoid ancestor instead. This small Oligocene primate may well prove to be on or

MIOCENE ANTHROPOID *Pliopithecus* is reconstructed (*left*) on the basis of a fairly complete specimen discovered in 1957. Although it is as much as 20 million years old, its skull (*top right*) is very much like a modern gibbon's. These hominoids probably were ancestral to today's long-armed gibbons, but their anatomy is generalized and their fore- and hind limbs are of almost equal length.

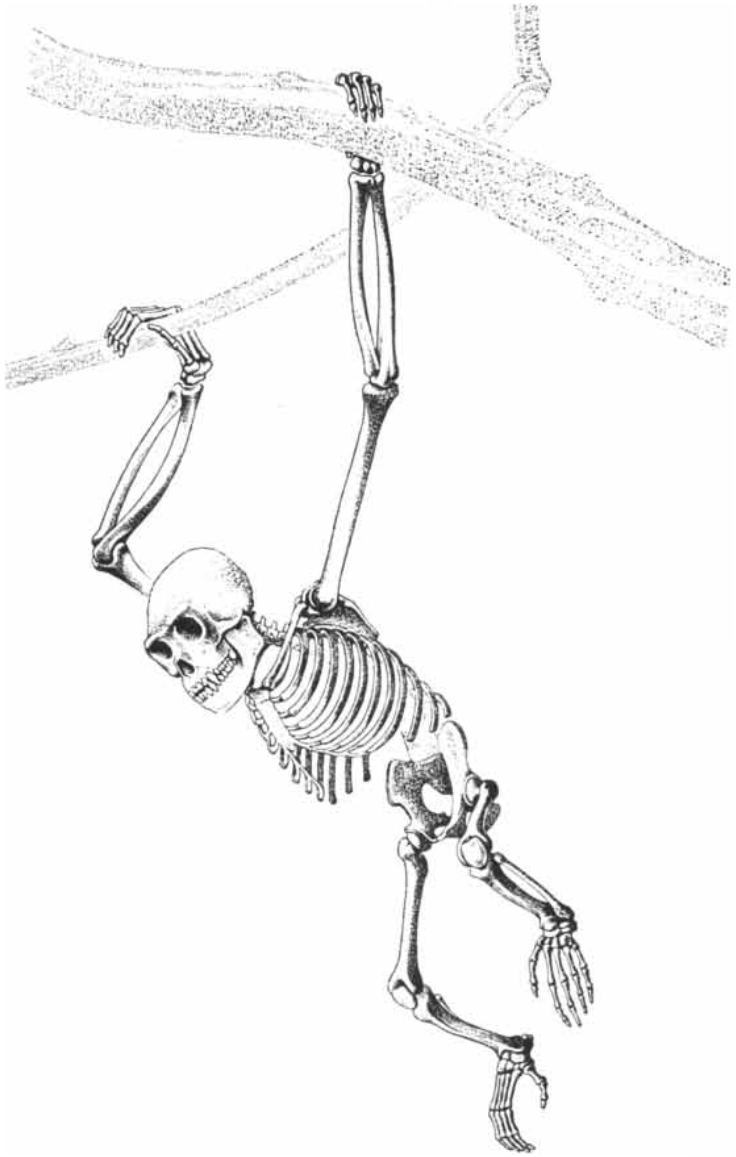
near the line of evolutionary development that led to the living pongids and to man.

The Miocene Hominoids

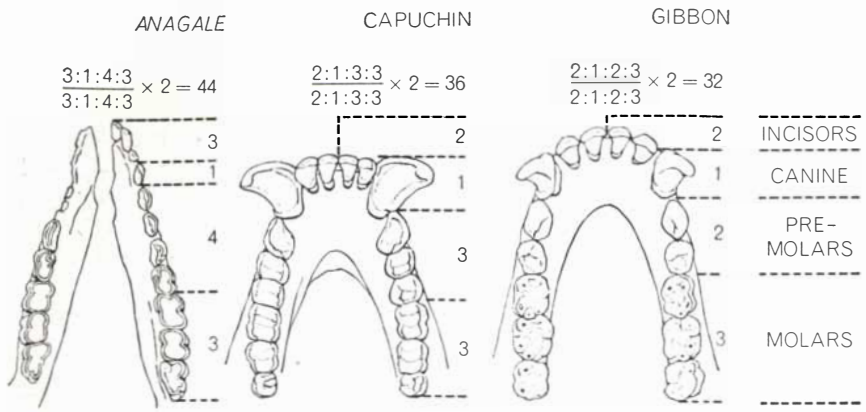
Throughout the entire 11-million-year span of the Oligocene the fossil fauna of Europe does not include a single primate. In the following epoch—the Miocene, which had its beginning some 24 to 26 million years ago—primates reappear in the European fossil record. A few years after Cuvier named *Adapis* the paleontologist-antiquarian Édouard Lartet reported a primate lower jaw from Miocene strata at Sansan in France. This fossil was the basis for establishing the genus *Pliopithecus*. Since then dozens of other *Pliopithecus* specimens have been uncovered in formations of Miocene and Pliocene age, in both Europe and Africa. The best of these *Pliopithecus* finds to date—a skull, including facial portions, and most of a skeleton—was made in a Miocene deposit near the Czechoslovakian town of Neudorf an der March in 1957. These remains provided the basis for the reconstruction shown on the opposite page.

Many millions of years younger than the gibbon-like hominoids of the Fayum, *Pliopithecus* presumably represents a further advance in the lineage that leads to the living gibbons. Yet this Miocene hominoid shows quite generalized characteristics. The arms of today's gibbons are considerably longer than their legs; *Pliopithecus,* in contrast, has hind limbs and forelimbs of nearly equal length. In fact, where comparisons are possible, *Pliopithecus* is not radically different from other roughly contemporary but not as fully preserved Miocene hominoids. Study of its skeleton tells us much about what the early hominoids were like.

A near contemporary of *Pliopithecus*



PLIOCENE ANTHROPOID *Oreopithecus* is not more than 14 million years old. Because most fossil anthropoids are small and their faces are snouty, the skeleton on which this reconstruction is based caused a sensation when first discovered. Its flat profile, four-foot height and also an apparent ability to walk erect brought *Oreopithecus* passing notoriety as a possible hominid "missing link."



HIGHER PRIMATES have fewer teeth than the original placental total of 44 (*see the lower jaw of* Anagale, *left*). The platyrrhine primates have lost an incisor and a premolar on each side of both jaws, and some have even lost molars. Thus the New World cebids have 36 teeth (*capuchin monkey, center*). All the catarrhines have lost one more premolar all around, so the Old World monkeys, apes and man have only 32 teeth (*gibbon, right*).

is *Dryopithecus,* the animal mentioned by Gregory as one candidate for a position ancestral to man. *Dryopithecus* was also named by Lartet; he described a lower jaw in 1856, almost 20 years after his discovery of *Pliopithecus.* Since that time many other fossil fragments of *Dryopithecus*—but no complete skulls or skeletons—have been found in strata of Miocene and even Pliocene age in Europe. In the late 1950's fossil teeth assignable to *Dryopithecus* were uncovered in brown coal deposits in southwestern China, indicating that the range of these hominoids extended across Europe to the Far East.

Because the fossil inventory for *Dryopithecus* consists mainly of individual teeth and teeth in incomplete jawbones, the reader will find useful some additional facts about primate dentition. These facts concern shape rather than number. First, although the crowns, or chewing surfaces, of any primate's molars may be ground flat by years of wear, each crown normally shows several bumps called cusps. Typically there are four cusps to a crown, one at each corner of the tooth. Second, all members of one of the two higher Old World primate superfamilies—the cercopithecoid monkeys—exhibit a unique cusp pattern. On the first and second upper and lower molars ridges of enamel project toward each other from the front pair of cusps; there are similar ridges between the back pair of cusps. Before the crown has been worn down there is often a gap in the middle of the ridge, but worn or unworn these molars are unmistakable.

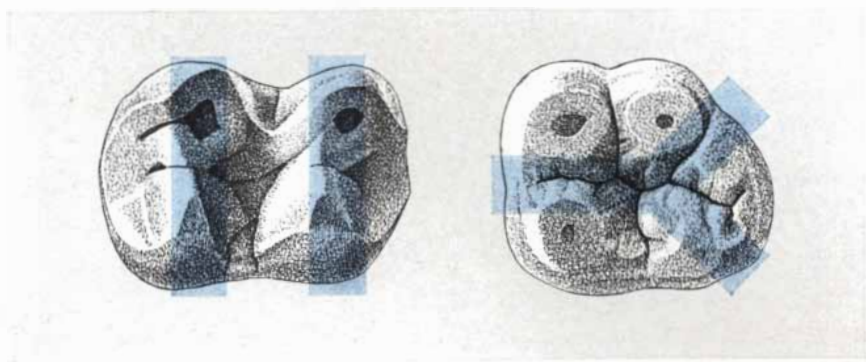
The hominoids, on the other hand, have their own distinctive cusp pattern. The lower molars normally have five cusps rather than four, and the pattern of valleys that separate these bumps of enamel somewhat resembles the letter Y, with the bottom of the Y facing forward. The pattern is called Y-5. The evolutionary significance of the pattern lies in the fact that the lower molars of *Dryopithecus* and of early men typically exhibit a Y-5 pattern. Thus Y-5 is a hereditary characteristic that has persisted among the hominoids for at least 24 million years.

Because the *Dryopithecus* fossil remains in Europe and the Far East are fragmentary, they reveal almost nothing about the skull and skeleton of this hominoid. Fortunately discoveries in Africa have altered the situation. There, thanks to the untiring efforts of L. S. B. Leakey and his colleagues, a substantial inventory of Miocene primate fossil remains has been accumulated, most of them from Rusinga Island in Lake Victoria and the nearby shores of the lake. As a result several species of African proto-ape, apparently ranging from the size of a gibbon to that of a gorilla, have been described.

In spite of this variety in size, all these species are assigned to the single genus *Proconsul.* The name *Proconsul* is an "inside" British joke: the "pro" is simply "before" but "Consul" was the pet name of a chimpanzee that had long been a beloved resident of the London Zoo. All jokes apart, the name implies an evolutionary position for these African hominoids close to the ancestry of living chimpanzees and quite possibly to the ancestry of gorillas as well.

Among the *Proconsul* species the fossil remains that are most nearly complete belong to the gibbon-sized *Proconsul africanus.* They include parts of two skulls—almost complete in the facial portions—and some limb bones, including parts of a foot and a forelimb with a hand. The picture that emerges from the study of this material is that of an advanced catarrhine, showing some monkey-like traits of hand, skull and brain but hominoid and even partially hominid characteristics of face, jaws and dentition. The foot and forelimb are also more suggestive of some ape-like adaptations—including an incipient ability to swing by the arms from tree branch to tree branch—than they are of either arboreal or ground-dwelling Old World monkeys.

Recent taxonomic investigations show that species of the genus *Proconsul,* with their relative abundance of skeletal remains, should almost certainly be lumped together with the genus *Dryopithecus.* What such an assignment would mean, in effect, is that all these Miocene-Pliocene hominoids—not only Eurasian but African as well—belong to



SHAPE OF MOLAR TEETH serves to split the catarrhines into two groups. The crowns of Old World monkeys' molars have a cusp at each corner (*baboon, left*): both front and rear pairs of cusps are connected by ridges (*color*). The crowns of apes' and man's lower molars normally have five cusps (*chimpanzee, right*), and the "valleys" between the cusps resemble the letter Y (*color*). This Y-5 pattern first appeared some 24 million years ago.

a single cosmopolitan genus. This might have been recognized 30 years ago except for a series of mischances. A. T. Hopwood of the British Museum (Natural History), who named *Proconsul* in 1933, stated that the lower jaws and teeth of *Proconsul* and *Dryopithecus* could not be distinguished as belonging to separate genera. He found the opposite to be true of the upper teeth, but it happens that the particular specimen of *Dryopithecus* upper teeth he chose for comparison was not of that genus at all: it belonged to another primate, *Ramapithecus*. When W. E. Le Gros Clark of the University of Oxford and Leakey later enlarged the definition of *Proconsul*, they still drew the primary upper-dental distinctions from the same specimen, which was not recognized as *Ramapithecus* until 1963. *Proconsul* and *Ramapithecus* are not the same genus. *Proconsul* and *Dryopithecus*, in all probability, are.

The Puzzle of the Coal Man

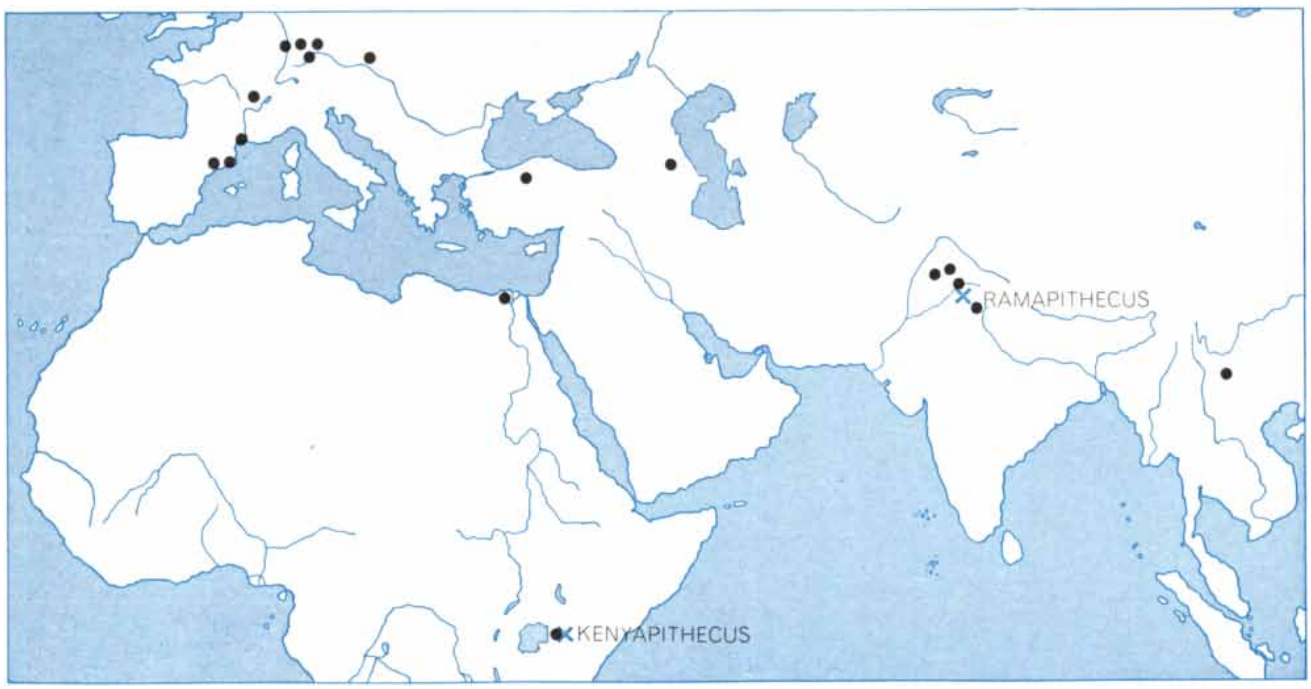
In any listing of the more complete early primates the Italian species *Oreopithecus bambolii*, sometimes irreverently known as the Abominable Coal Man, cannot be omitted. Its first bits and pieces were discovered almost 100 years ago. Since then *Oreopithecus* remains have been found in abundance in the brown-coal beds of central Italy, a formation that is variously assigned to late Miocene or early Pliocene times. In 1956 Johannes Hürzeler of the natural history museum in Basel assembled a number of new *Oreopithecus* specimens, and in 1958 Hürzeler was instrumental in the recovery of a nearly complete skeleton from a coal mine at Grosseto in Italy. This superb fossil is still being examined by specialists from various nations.

Evidently these Miocene-Pliocene primates were of substantial size—some four feet tall and probably weighing more than 80 pounds. Among the living primates the closest in size would be a female chimpanzee. Because its face is short and flat instead of showing an elongated snout, and because studies of its pelvis and limb bones suggest the possibility of an erect walking posture, *Oreopithecus* has received some notoriety as a possible direct precursor of the hominid family. Intensive study of the 1958 specimen, however, has led a number of workers to rather different conclusions.

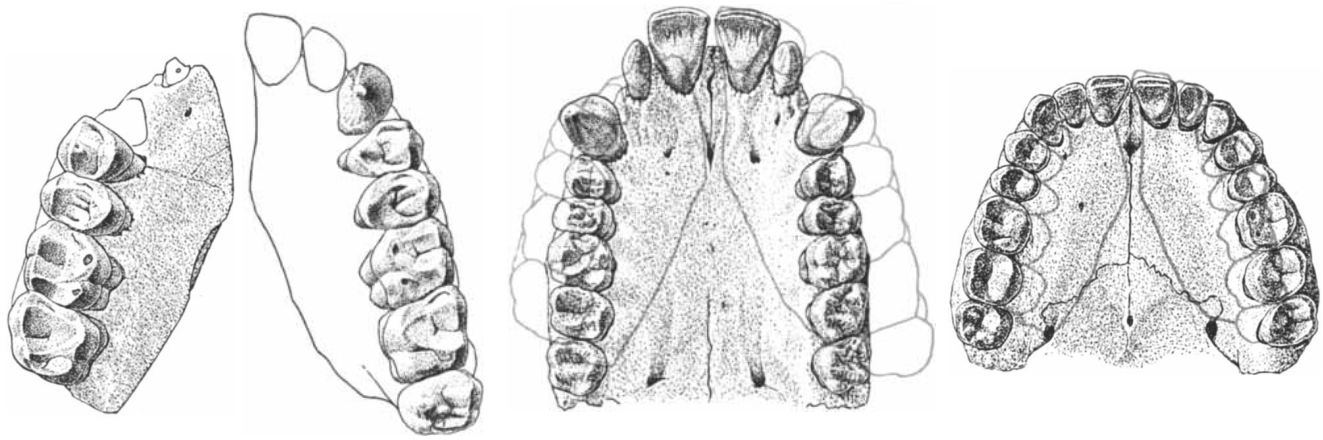
One of the surprising things about *Oreopithecus* was first noted by Gregory in the 1920's: the cheek teeth of its lower jaw strongly resemble the corresponding teeth of *Apidium*, one of the four primates named from the original Fayum finds of the early 1900's. The surprise is that *Apidium* dates to the Oligocene, some 20 to 25 million years earlier than *Oreopithecus*. This remarkable dental coincidence might easily have remained no more than a curiosity if the Yale Expedition had not recovered a number of additional *Apidium* teeth—this time the cheek teeth from upper jaws. The study of these teeth is not yet complete, but it is already evident that the newfound *Apidium* uppers correspond as well to the equivalent *Oreopithecus* uppers as the lowers do to the lowers. Such a similarity strongly suggests that, in spite of their separation in time, the ancient *Apidium* and the comparatively modern *Oreopithecus* are representatives of a single group of now extinct Old World higher primates. *Apidium* cannot be directly ancestral to *Oreopithecus*, however, because it lacks one pair of incisors that are still present in *Oreopithecus*. Although in the evolutionary sense this group is not far removed from the pongid-hominid stem, it seems to have developed its own distinctive characteristics by early Oligocene times.

A Dryopithecine from India

Having come to the end of Miocene times, with a scant 12 million to 14 million years remaining in which to discover a human forebear, we must reexamine Gregory's declaration. One of his candidates, *Dryopithecus*, has now been shown to be a long-lived and cosmopolitan genus, one of an abundant dryopithecine group to which in all probability the African species of *Pro-*



RANGE OF THE DRYOPITHECINES during Miocene and early Pliocene times extended across Eurasia from France to western China and also included East Africa and northwest India. No other hominoid primates of that time were so widespread. Crosses (*color*) show where the advanced hominoid genus, *Ramapithecus*, and the apparently identical *Kenyapithecus* have been found.



UPPER JAW OF RAMAPITHECUS, in a life-sized reconstruction at left, is compared with that of an orangutan (*center*) and a man (*right*). In each comparison the jaws have been made the same size. The U-shaped arc formed by the ape's teeth contrasts sharply with the curved arc in *Ramapithecus*, which is closer to the human curve. This, as well as the manlike ratio in comparative size of front and cheek teeth and the modest canine, are grounds for considering *Ramapithecus* man's earliest known hominid ancestor.

consul belong. What about *Sivapithecus*, Gregory's other nominee for a position as a hominid ancestor?

The Siwalik Hills of northwestern India and adjacent Pakistan have been known to paleontologists since the first half of the 19th century for their fossil-rich deposits of Miocene and Pliocene age. It was from these strata that Pilgrim, who described the Burmese borderline primate *Pondaungia*, uncovered and named *Sivapithecus* in 1910. Later, in the 1930's, G. Edward Lewis collected fossils for the Yale-Cambridge North India Expedition from these same beds and discovered a number of primate jaw fragments and teeth. In due course they were assigned to several separate primate genera, including some additional examples of Pilgrim's *Sivapithecus*.

Recent reexamination of *Sivapithecus* species suggests that they are not markedly different from *Dryopithecus*. Like *Proconsul*, they may well deserve nothing more than subgeneric status among the cosmopolitan dryopithecines. This would mean that not only Africa and Eurasia but also India supported separate populations of a single hominoid genus during Miocene and the earliest of Pliocene times—a span of at least 15 million years. However confused and confusing dryopithecine taxonomy and evolutionary relations are at present, the inescapable fact remains that throughout this entire span of time this is the only group of primates known in any Old World continent that can be considered close to the source of the hominid family line.

Because of the dryopithecines' very broad distribution throughout the Old World, the precise time and location of the primates' evolutionary advance from hominoid animals to specifically hominid ones may always remain uncertain. Yet a tentative guess is possible.

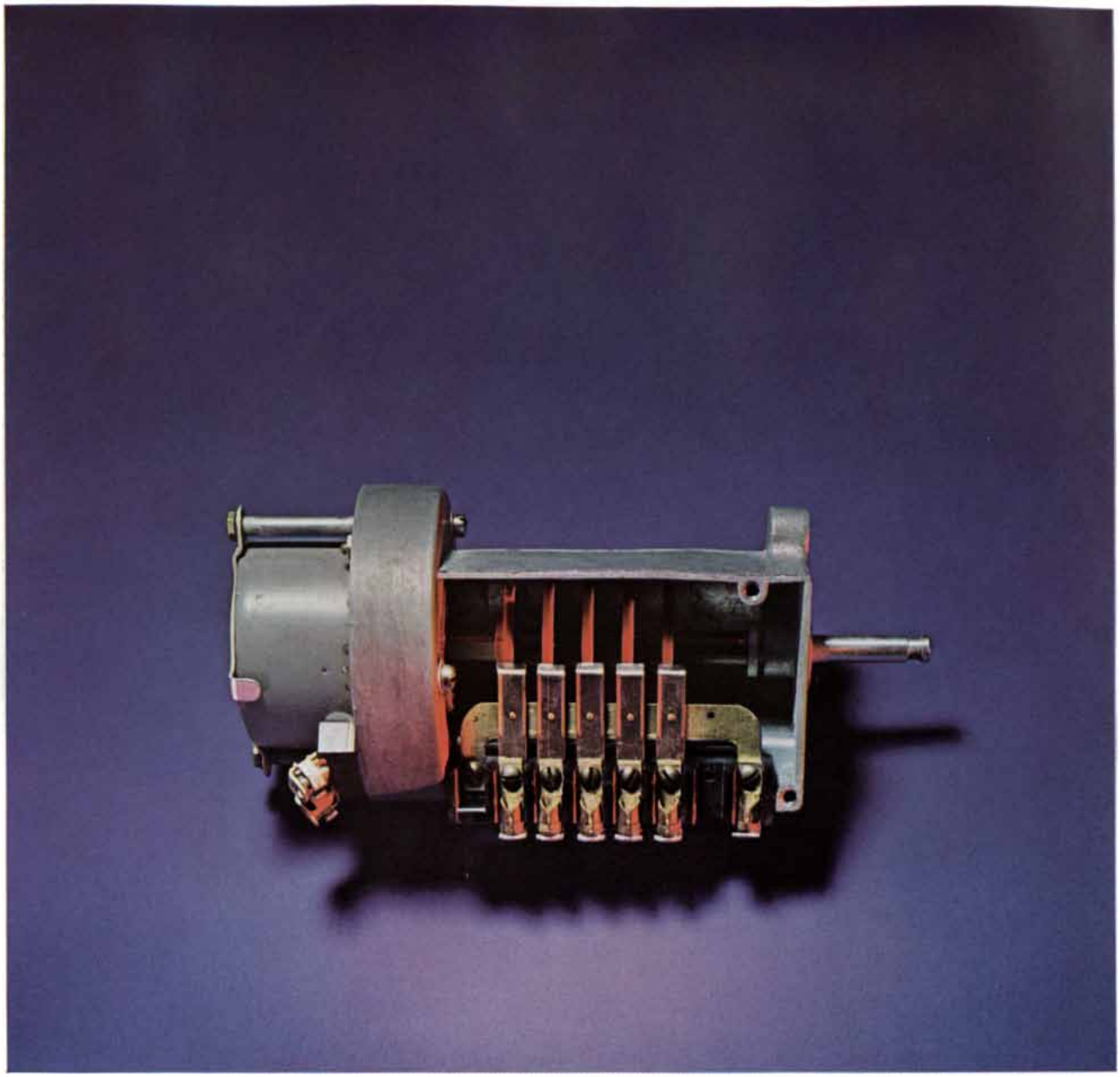
Another of the fossil primates Lewis collected in the Siwalik Hills was *Ramapithecus*. The type species of *Ramapithecus* is founded on a portion of a right upper jaw and is named *Ramapithecus brevirostris*. The fossil includes the first two molars, both premolars, the socket of the canine tooth, the root of the lateral incisor and the socket of the central incisor. When it and other fossils of *Ramapithecus* are used to reconstruct an entire upper jaw, complete with palate, the result is surprisingly human in appearance [*see illustration above*]. The proportions of the jaw indicate a foreshortened face. The size ratio between front teeth and cheek teeth is about the same as it is in man. (The front teeth of living apes are relatively large.) Estimating from the size of its socket, the canine tooth was not much larger than the first premolar—another hominid characteristic, opposed to the enlarged canines of the pongids. The arc formed by the teeth is curved as in man, rather than being parabolic, or U-shaped, as in the apes.

From Relative to Ancestor

Just such traits as these, intermediate between the dryopithecines and hominids, had led Lewis in 1934 to suggest that *Ramapithecus* might well belong to the Hominidae. This suggestion was challenged in the years immediately following. In my opinion, however, both the reexamination of the type species and the identification of new material reinforce Lewis' original conclusion. Taxonomic decisions of this sort are not made lightly, and to draw a large conclusion from limited fossil evidence is always uncomfortable. Thus it was particularly gratifying to learn of Leakey's recovery, in 1962, of the jaws of a similar hominid near Fort Ternan in southwestern Kenya.

Leakey has assigned this fossil to the species *Kenyapithecus wickeri*. Like the remains of Lewis' *Ramapithecus brevirostris*, it preserves much of the upper dentition. Included are the first two molars on both sides, an intact second premolar and the stub of a first premolar. The socket for one canine is intact; a canine tooth and a central incisor were found separately. Potassium-argon dating of the specimen yields an absolute age of about 14 million years, a time near the boundary between the Miocene and the Pliocene.

The significance of the Fort Ternan find lies in the fact that *Kenyapithecus* not only has an abundance of close anatomical links with *Ramapithecus* but also exhibits no pertinent differences. In this new specimen, a continent removed in space from *Ramapithecus*, are found the same foreshortened face, dental curve and small canine tooth—each a hominid trait. The conclusion is now almost inescapable: in late Miocene to early Pliocene times both in Africa and India an advanced hominoid species was differentiating from more conservative pongid stock and developing important hominid characteristics in the process. Pending additional discoveries it may be wiser not to insist that the transition from ape to man is now being documented from the fossil record, but this certainly seems to be a strong possibility.



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The Thymus Hormone

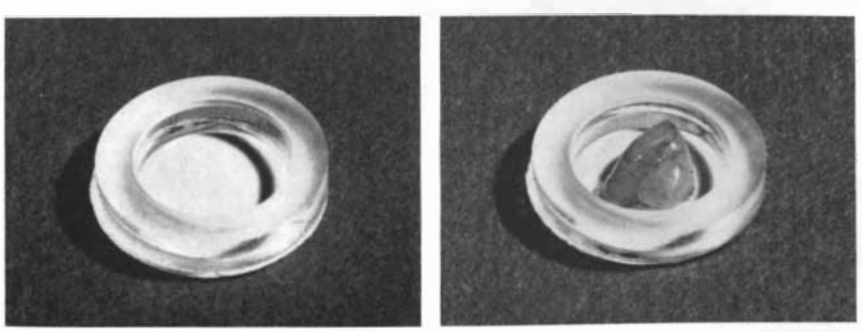
The blood cells that manufacture antibodies trace their origin back to the thymus gland. It has recently been discovered that the gland also secretes a substance that enables the cells to make antibodies

by Raphael H. Levey

Until a few years ago the function of the thymus gland, a two-lobed structure that lies in the upper chest in front of the aorta, was an enigma to investigators. Removal of the organ from experimental animals or in the course of surgical operations on human patients caused no noticeably harmful effects. In fact, in all animals including man the thymus, although it is prominent at birth, begins to atrophy of its own accord long before the animal reaches maturity. Certain crucial experiments performed only three years ago, however, indicated that the thymus does, after all, play a most important role: it appears to be a principal actor in the body's defenses against infection and similar immunological challenges [see "The Thymus Gland," by Sir Macfarlane Burnet; SCIENTIFIC AMERICAN, November, 1962]. Since then the gland has been the subject of intensive and fruitful investigation in many laboratories. Among other things it has been discovered that the thymus produces a previously unsuspected hormone.

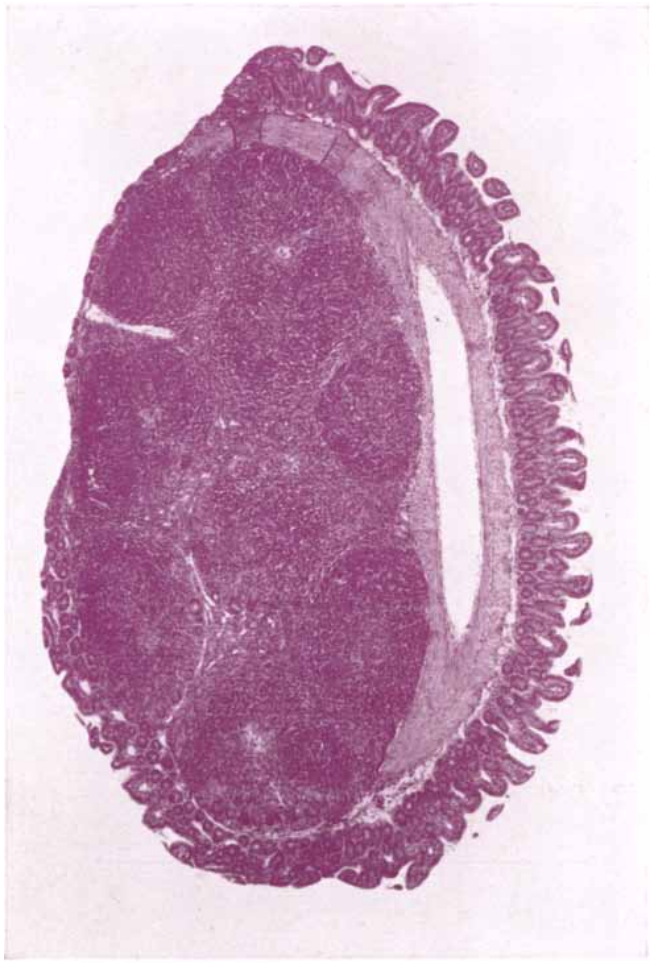
A central figure in this story is the mouse, which has provided most of the information about the activities of the thymus by its responses to various surgical experiments. In a newborn mouse the thymus is about three millimeters long and two millimeters wide. The organ continues to grow until the age of weaning; then it begins to decrease in size in the process known as age involution. If the thymus is surgically removed at that time, the mouse will show no ill effects. A turning point in the investigation of the thymus came in 1961, when Jacques F. A. P. Miller of the Chester Beatty Research Institute in Britain undertook the experiment of thymectomizing mice immediately after birth. These mice grew normally for several weeks or months, but then they became ill and soon died of a wasting disease whose main features were loss of weight, weakness, lethargy and diarrhea. Detailed internal examination showed that the mice had suffered a severe depletion of the white blood corpuscles called lymphocytes.

In the mouse the lymphocytes constitute some 70 percent of all the white blood cells (in the human body they represent only 20 to 25 percent). It has now been established that the thymus is by far the most important source of lymphocytes in the newborn mouse. It serves as the seedbed for these vital cells and sends them forth to the other lymphoid organs: the spleen, the lymph nodes and areas in the small intestine known as Peyer's patches. In these locations the lymphocytes continue to divide. As the primary factory for lymphocytes, the thymus produces them as much as 10 times faster than the other organs do. The cortex, or outer layer, of the thymus is densely packed with these cells in their small, fully developed form. In the other lymphoid organs the production of lymphocytes takes place in nodules that have a "germinal center" where medium-sized lymphocytes can be seen actively dividing. This division becomes particularly active, and the germinal center enlarges, in the nodules of lymph nodes that are responding to an infection or a graft of foreign tissue.

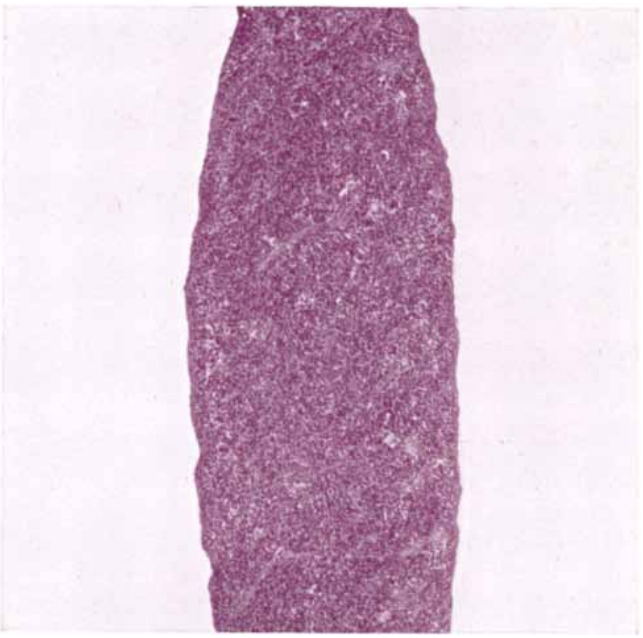


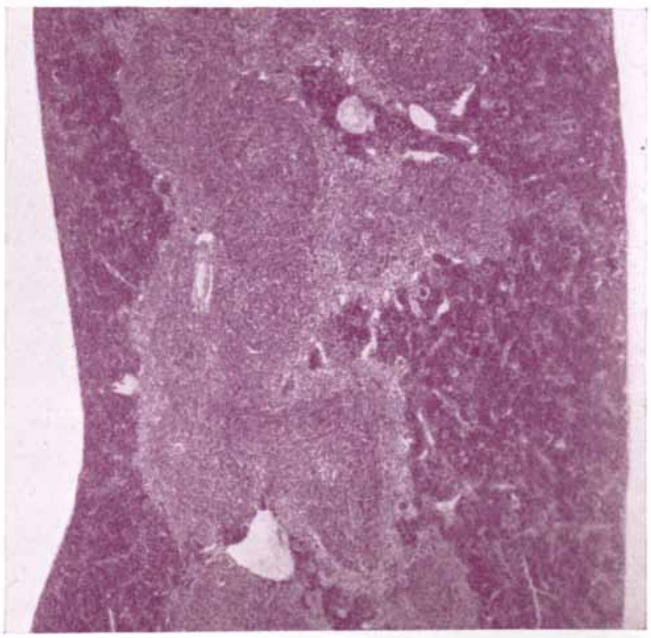
DIFFUSION CHAMBER ensures that no cells from an implanted thymus reach the host animal's bloodstream; any effects of an implant can be ascribed to a humoral factor. The chamber is made by gluing a fine filter to a plastic washer 1/4 inch in inside diameter (*left*). With a newborn-mouse thymus inside (*right*), the capsule is closed with a second filter.

Various experiments have demonstrated clearly that the thymus is essential for the normal development of immunological competence, at least in the mouse. A mouse whose thymus has been removed at birth fails to produce circulating antibodies against foreign substances. In fact, such a mouse will accept a skin graft from an unrelated animal, whereas normal mice invariably reject such foreign grafts. Without much doubt these effects can be attributed to the depletion of small lymphocytes in the mouse that has been thymectomized at birth. Lacking these cells, the animal loses most of its immunological potential. There is considerable evidence that the small lymphocytes from the thymus not only seed the lymph nodes for further lymphocyte pro-

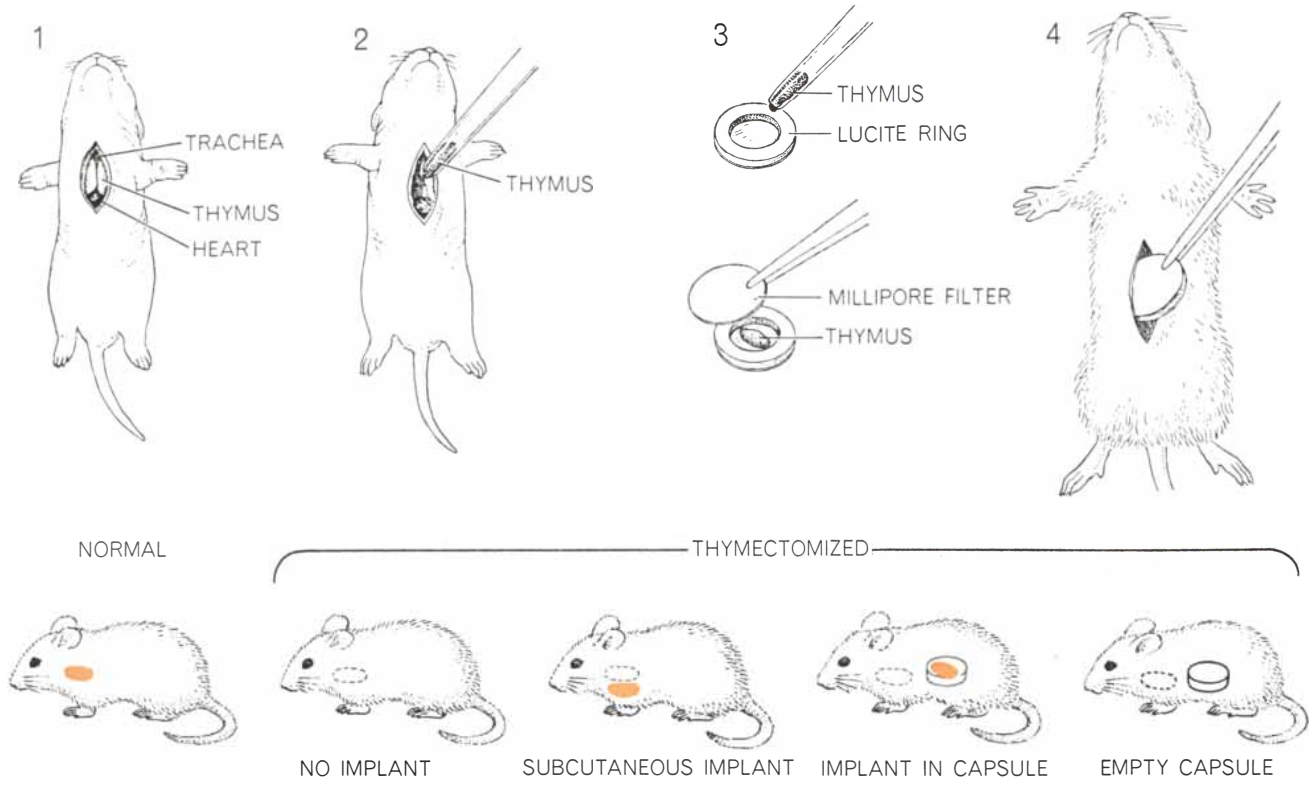


PEYER'S PATCH, an area of lymphoid tissue in the wall of the intestine, atrophies in mice thymectomized at birth (*left*) but remains large and active in thymectomized mice that receive a capsule implant (*right*). In the control animal the patch has been reduced to the small, rounded granular area at the top center; it is here enlarged 55 diameters. In the implanted animal the patch, enlarged 30 diameters, is the oval area at left, occupying most of the photograph. It is filled with "germinal centers" rich in lymphocytes.





SPLEEN is another lymphoid organ that demonstrates the effect of implantation of a capsule-enclosed thymus. The section of spleen at left, enlarged 50 diameters, came from a mouse thymectomized at birth and is atrophied. The section at right, enlarged 40 diameters, came from a thymectomized mouse that received an implant; it is large and well developed and is filled with lymphocytes.



EXPERIMENTS BEGIN with a thymectomy performed on a newborn mouse (*1*). The thymus is removed by suction (*2*) and placed in a Millipore diffusion chamber (*3*). The capsule is implanted in a two- or three-week-old mouse (*4*). The bottom row shows the conditions of the animals involved in these experiments: normal mouse with its own thymus intact and thymectomized mice without any implant, with thymus implanted under the skin rather than in a capsule, with thymus inside a capsule and with an empty capsule.

duction but also are precursors of the plasma cells, which synthesize antibodies. (Plasma cells are found in the lymph nodes but not in the thymus.)

The immunological importance of the small lymphocytes shows itself in another and more direct way. Consider a normal newborn mouse. Apart from the lymphocytes in its thymus gland, it has not yet developed any significant immunological defenses of its own. If this mouse is inoculated with foreign lymphoid cells that are capable of growing in its tissues, we should expect the graft to take over and grow at the expense of the mouse's own tissues, a process that is known as the graft-against-host reaction. That is precisely what happens. The mouse's growth slows down; the animal becomes anemic and in general exhibits a stunted development that is called "runt disease." Most important, the mouse is drastically depleted of lymphocytes, which have been sacrificed in an immunological battle against the foreign cells. As the body's sole defense against the graft, the lymphocytes of the thymus, spleen and lymph nodes have been overwhelmed and used up. It is significant that runt disease is similar to the wasting disease that overtakes mice deprived of the thymus gland, and therefore of lymphocytes, at birth.

All these experimental findings gave a strong indication of the function of the thymus gland, but they were still not direct proof. The classic method of determining the role of a gland is to remove it from an experimental animal, observe the effects closely, then reimplant the same tissue and investigate how and to what extent this restoration counteracts the effects of removal. Until recently this approach had not produced much enlightenment about the thymus, because there was very little effect to investigate when the organ was removed from grown or growing animals. But after Miller's demonstration that striking effects emerged when the thymus was extracted at birth, experimenters promptly began to test the results of reimplanting the thymus in such animals.

The results were both dramatic and in the classic tradition. When mice that had been thymectomized at birth received, within three or four weeks, subcutaneous grafts of thymic tissue from donor mice of the same strain, they did not fall victim to the wasting disease. Their lymphoid organs produced lymphocytes at about the normal rate, and the animals proved capable of evincing all the normal immunological reactions.

Two of the outcomes of this kind of operation were, however, rather puzzling. In the first place, most of the lymphocytes produced in the thymic graft turned out to be related genetically to the cells of the host mouse, not to the cells of the donor that had supplied the grafted tissue! (The cells could be distinguished because the donor cells were marked by an unusual chromosome.) The same was true of the lymphocytes multiplying in the target lymphoid organs (the spleen and lymph nodes); they too were of the host type rather than the donor type.

This fact suggested that the thymus gland does something more than merely supply lymphocytes as seeds, or parents, to produce new lymphocytes by division. The thymic grafts in these mice were somehow stimulating the hosts to make lymphocytes out of their own cells.

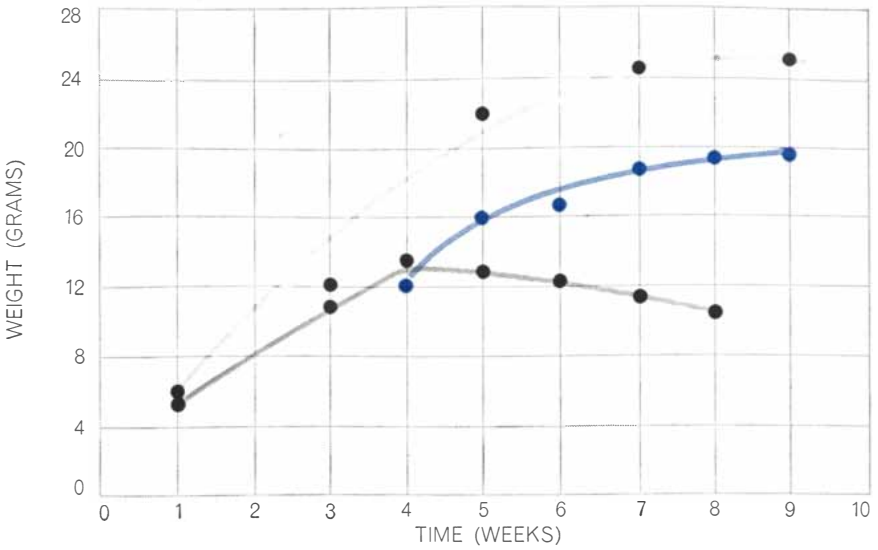
The second curious outcome of the thymus-grafting experiments pointed in the same direction. It was found that when thymic tissue from a newborn mouse was placed under the skin of an older mouse whose thymus was deteri-

orating, the grafted thymus continued to show its own characteristic rapid rate of production of lymphocytes. This again suggested that the young thymic tissue contained an intrinsic stimulating factor.

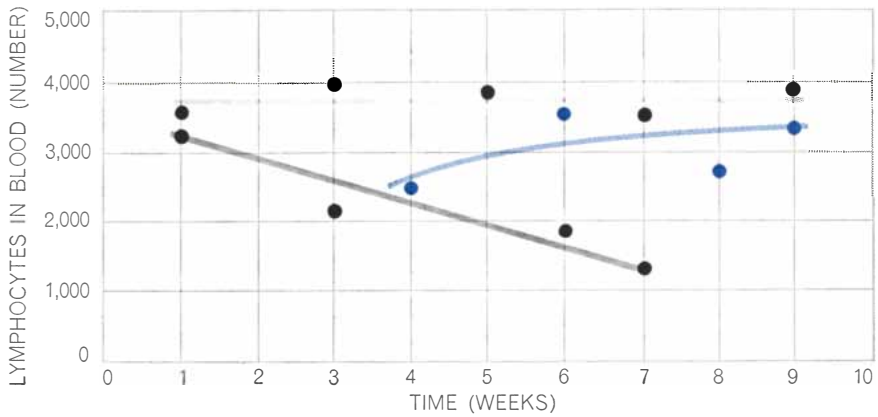
I was intrigued by these observations, and my interest was shared by two colleagues in the Laboratory of Biology of the National Cancer Institute: Nathan Trainin and Lloyd W. Law. The thymus has been much on the minds of investigators of leukemia, a cancerous disease marked by the uncontrolled increase of lymphocytes and other white blood cells [see "Leukemia," by Emil Frei III and Emil J. Freireich; SCIENTIFIC AMERICAN, May]. Trainin, Law and I undertook to investigate the stimulating influence of the thymus gland.

One way to explore the problem would be to expose the target organs—the spleen and the lymph nodes—to the substances produced by the thymus but not to the thymic cells themselves. Fortunately a technique for accomplishing this was available. It was based on the use of a plastic capsule with pores so fine that it holds in cells but lets out all the chemical products of the cells. We constructed and tested a suitable capsule for our experiments. It consisted of a Lucite washer, or ring, 6.4 millimeters (about a quarter of an inch) in internal diameter, with Millipore filters of cellulose glued over the top and bottom. This formed a circular diffusion chamber 6.4 millimeters across and 1.6 millimeters deep. The pore size of our filters was less than half a micron —about a fifteenth of the average diameter of the small lymphocytes of a mouse. We evaluated the ability of the capsule to contain cells by filling it with highly malignant lymphoid tumor cells and then implanting it in mice. None of the mice developed tumors; since as few as four viable cells of the tumor are usually capable of producing tumors in a susceptible mouse, this was conclusive verification that the filter was an effective barrier against cells. On the other hand, the pores allowed free passage to fluids and colloids, thus admitting nutrients for the cells into the capsule and letting molecular products pass out.

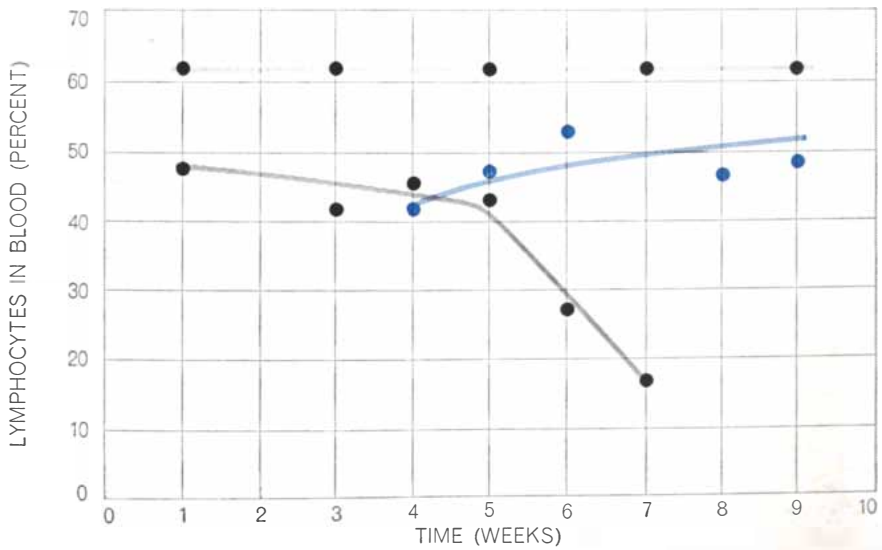
The standard procedure in the experiments we carried out was as follows. The thymus was removed from the experimental mouse within 12 hours after birth. Three to four weeks later we implanted in the mouse's abdominal cavity a Millipore diffusion chamber



EFFECT OF IMPLANT on body weight is shown. A normal animal gains steadily (*light gray curve*). A thymectomized animal loses weight and dies in about eight weeks (*dark gray*). The implantation of a thymus in a chamber maintains the growth curve (*color*).



NUMBER OF LYMPHOCYTES in the peripheral blood remains satisfactory in the case of implanted animals (*colored curve*), whereas it falls off sharply in thymectomized mice.



PERCENTAGE OF LYMPHOCYTES among white cells is level in normal mice (*light gray curve*) but drops suddenly in animals without a thymus (*dark gray*). The implantation of another thymus inside a chamber tends to restore the normal proportion (*color*).

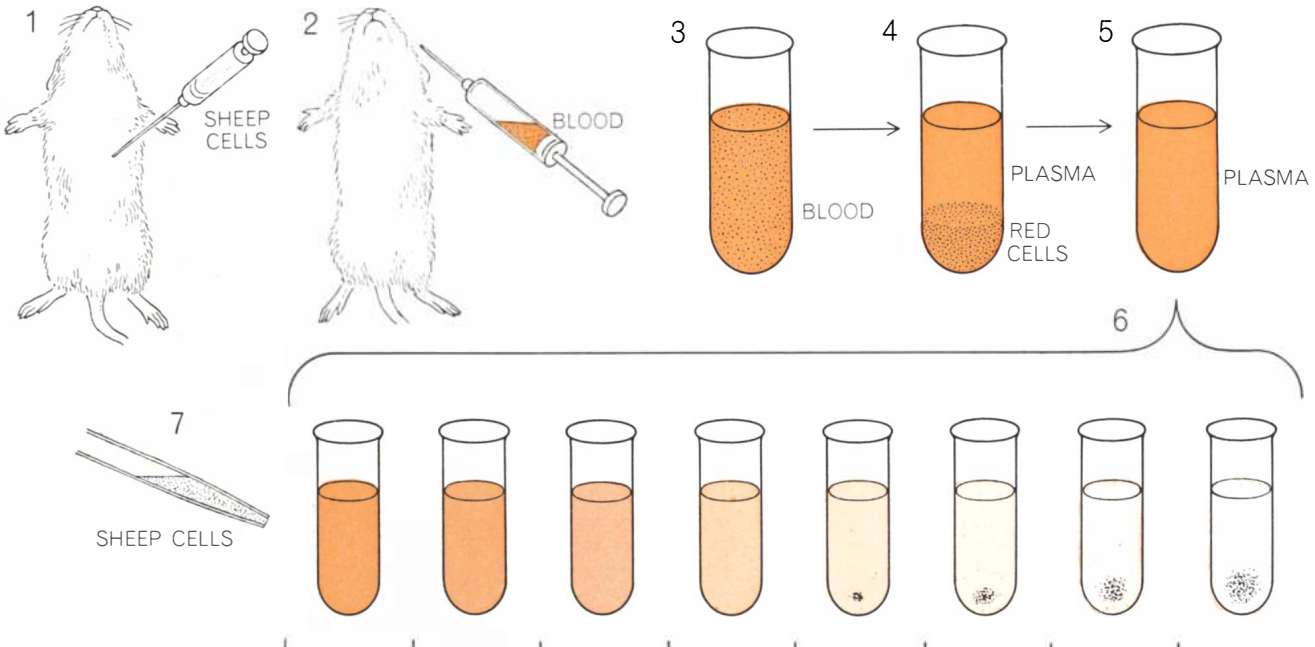
containing a whole thymus taken from a newborn donor mouse of the same strain. Then we watched for the results, comparing them with the simultaneous histories of control groups of mice (some not operated on at all, some thymectomized but not provided with a thymus-containing capsule, some implanted with an empty capsule and some grafted subcutaneously with an unenclosed thymus).

The thymectomized control mice that received no substitute thymus (including those implanted with an empty capsule) all fell victim to the wasting disease. They grew more slowly than normal mice, began to deteriorate at about five weeks of age and died by the seventh or eighth week. All showed a severe loss of small lymphocytes, and their lymphoid organs were stunted and contained no germinal centers.

In contrast, the mice implanted with a substitute thymus, even though it was enclosed in a capsule, grew and survived almost like normal animals. Their body weight increased steadily; they showed no signs of the wasting disease or of any depletion of small lymphocytes in the blood. Their lymphoid organs were normal or even better developed than in nonthymectomized animals. The spleen was sometimes oversized and was filled with many lymphatic nodules containing active germinal centers; the lymph nodes were large and abundant; the walls of the small intestines showed an extraordinary number of large and active Peyer's patches. In short, the lymphoid organs were stimulated to intensely active production of lymphocytes.

When we tested these mice for their immunological potential, they showed the same remarkably normal reactions. We inoculated the mice with red blood cells from sheep. Normal mice usually produce within one week powerful antibodies, called hemolysins, that destroy these cells. Mice thymectomized at birth, on the other hand, fail to produce any substantial amount of these antibodies. It turned out that an experimental mouse with a capsule-enclosed thymus planted in the peritoneal cavity did produce the antibodies, in an amount approaching that produced in normal animals [*see illustration below*].

Next we subjected such mice to a more elaborate and sensitive test of their immunological behavior. For this experiment we used certain strains of mice that are unusually resistant to the effects of neonatal thymectomy: they do not show symptoms of the wasting disease or any depletion of lymphocytes until they are several months old. They are, however, immunologically defective, as we found in experiments performed in collaboration with Wallace P. Rowe and Paul Black of the National Institute of Allergy and Infectious Diseases. These experiments involved infection of the mice with a highly viru-



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NORMAL	2	0	0	10	5	16	10	5
SUBCUTANEOUS IMPLANT	0	0	2	4	1	1	1	1
IMPLANT IN CAPSULE	11	3	5	3	6	5	6	0
THYMECTOMIZED	17	0	4	3	0	0	0	0

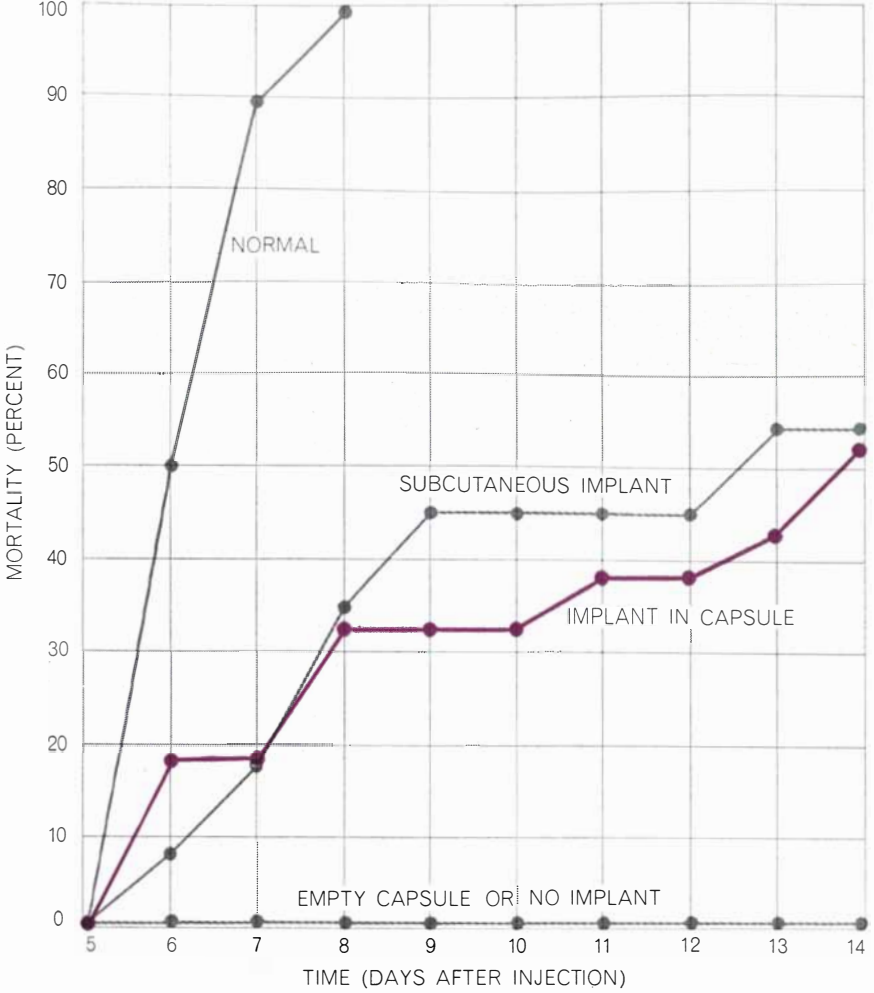
IMMUNOLOGICAL TEST measures the ability of mice to form an antibody that destroys foreign red blood cells. Sheep cells are injected into mice (*1*). Seven days later a sample of the mouse's blood is drawn (*2*) and centrifuged (*3, 4*) to remove cells. The remaining plasma (*5*) is serially diluted (*6*) and a measured number of sheep cells are added to each test tube (*7*). The dilution at which most of the sheep cells are destroyed, leaving only a small clump, is the antibody titer of the animal involved; the titer is 80 in the illustration. The table shows that the antibody titer of animals with implants inside capsules compares well with that of normal mice.

lent disease of the central nervous system called lymphocytic choriomeningitis.

When the virus responsible for this disease is injected into the brain of a normal susceptible mouse, the animal invariably dies within eight days. The direct cause of death is presumed to be a dense infiltration of the meninges by small lymphocytes. This produces a hypersensitive reaction similar to the reaction of a tuberculous patient to tuberculin, which also is associated with a rush of lymphocytes to the site of the injection. In both cases the reaction is delayed: for 48 to 72 hours in the case of the tuberculin injection and for seven days in the case of the injection of the meningitic virus into the mouse's brain.

Now we found that mice thymectomized at birth did not succumb to the infection, even when injected with a normally 100 percent fatal dose of the virus. The virus multiplied normally in the mice's tissues, but there was no flood of lymphocytes into the meninges. In other words, thymectomy had prevented the hypersensitive reaction by suppressing the immunological response involving lymphocytes. Would thymectomized mice with a capsule-enclosed thymus show the normal immunological response? We made the test. After implanting the capsule in the mouse at the age of three weeks, we injected into its brain a week later a large amount of the virus: about 200 times the usually lethal dose. Whereas all thymectomized mice not supplied with a substitute thymus survived this dose, 54 percent of our experimental mice with the capsule-enclosed thymus were killed by it. And their meninges showed the characteristic influx of lymphocytes that marked the reaction of normal mice.

This accumulation of diverse kinds of evidence made quite clear that the thymus in the diffusion chamber, even though it released no cells, nevertheless provided the body of the mouse with agents or services the thymus normally provides. Most impressive was the fact that the thymus implanted in a cell-tight capsule was just about as effective as a subcutaneous graft of a thymus that freely transmitted lymphocytes to the lymphoid organs. The thymectomized mouse's protection against the wasting disease and its immunological powers were about the same in both cases.

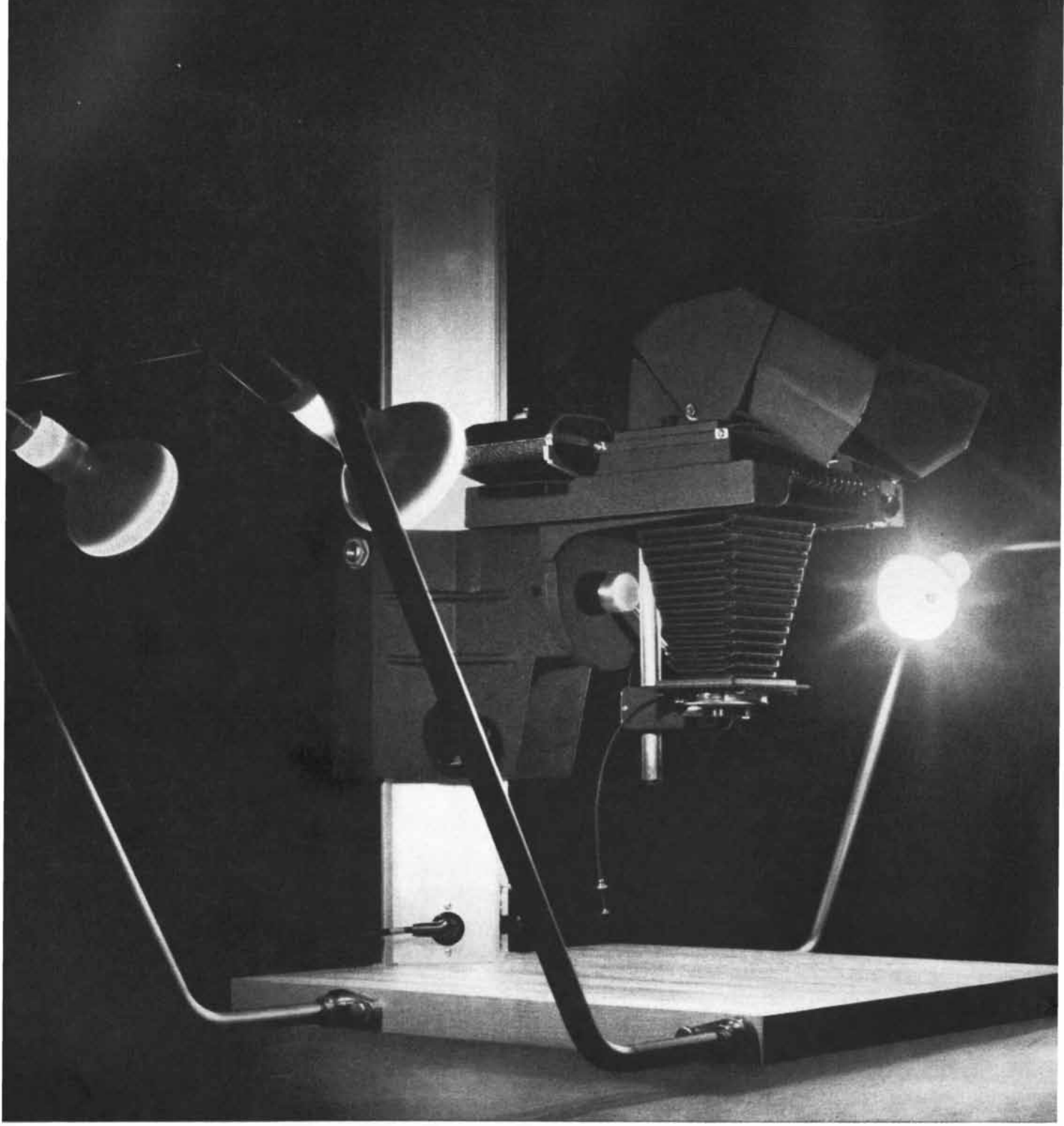


HYPERSENSITIVITY REACTION to LCM virus kills mice of a certain strain in eight days. Thymectomized mice do not succumb to this reaction. The implantation of a thymus under the skin, however, restores the sensitivity, and more than half of such grafted mice die. The implantation of a thymus inside a chamber has just about the same effect.

We must conclude that in normal circumstances the thymus sends something besides lymphocytes to the target organs—the spleen and lymph nodes. It sends a messenger or factor that prompts those organs to produce lymphocytes themselves from their own cells. It seems safe to surmise that this factor is a hormone; it admirably answers the definition of a hormone, namely a substance that is secreted by a gland, travels to other organs by way of the bloodstream and produces a specific effect on their activities. This thymic hormone has not yet been given a name, but there is no longer much doubt of its existence.

A capsule-enclosed thymus gland implanted in the body of a mouse apparently serves the animal's lifelong needs although the lifetime of the gland in the capsule is not much more than about 60 days. In this respect it mimics the normal situation: the thymus with which an animal is born also has a limited career of activity. The gland tides the animal over a critical period in its early development and then ceases to be indispensable. Once it has activated the other lymphoid organs to produce lymphocytes it subsides to a minor role. Its brief heyday of activity in the first weeks or months of the animal's life has been all-important, however, for the future survival of the animal. The hormone the thymus provides at that time, in an amazingly small amount, directs the development of the system of immunity that will protect the animal for the rest of its life.

Our findings tend to support a modified version of the "selective" theory of immunity that Sir Macfarlane Burnet has described in an article called "The Mechanism of Immunity" [SCIENTIFIC AMERICAN, January, 1961]. He suggested that the body contains a variety of lymphocytes, each of which has a built-in capacity to produce a specific antibody, or at least to give rise to cells that will produce it. When the right antigen comes along, the particular clone, or group, of cells that is capable of generating production of the



This MP-3 does the work of a view camera, micro/macro camera, copy camera, slide maker, enlarger and darkroom. And does the job in 2 minutes or less.

It's virtually an industrial studio in itself.

If you need a picture of an assembly, for instance, you can put it on the lighted base, click the shutter and peel out a finished picture 10 seconds later. If you need a macrophotograph of a small part you can make a 4 x 5 print in 10 seconds. If you need a photomicrograph put a microscope under the camera. If you need any of these in *color,* you can get them in a minute. If you want to make a black and white slide of a wall chart, you can swing the camera head 90°, and with transparency film, get one in 90 seconds. If you want a negative you can make one in 20 seconds. If you need multiple records, make multiple originals. And finally, if you aren't in a hurry, use any conventional roll or sheet film.

The MP-3 does all this with interchangeable camera backs. With them, you can use any of thirteen different Polaroid Land films plus conventional films.

For all its flexibility, the MP-3 is extremely simple to use. Controls are almost self-explanatory. You set up your shot and focus at eye level on a bright ground glass screen. And if you don't get exactly the picture you want the first time, you can take another on the spot.

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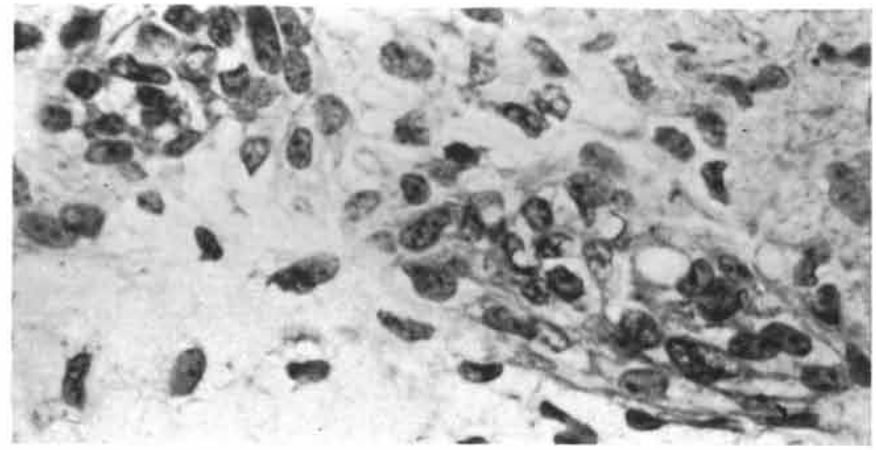


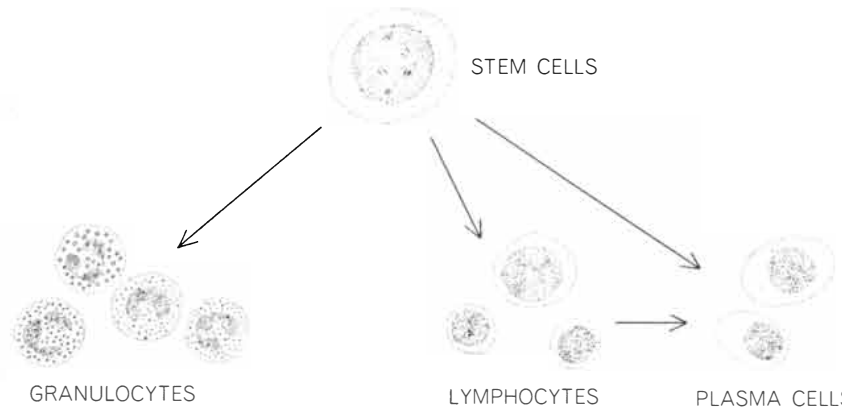
THYMIC TISSUE recovered from chambers is usually found to be still viable, as in the case of this specimen, which had been implanted 40 days. The enlargement is 650 diameters.

specific antibody is stimulated to multiply. Recently James L. Gowans of the University of Oxford presented evidence that there may be two classes of lymphocytes: (1) "committed" ones, which have already reacted with a specific antigen, and (2) "uncommitted" ones, which are free to react to new antigenic stimuli. In the light of these hypotheses and the available experimental evidence, one can outline a general picture of the immunity system in mammals and the role of the thymus in it, as follows:

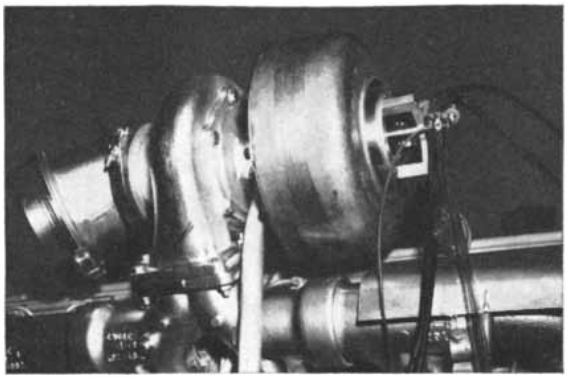
When an animal is born, the thymus is actively producing lymphocytes. The thymic hormone renders these cells capable of reacting with antigens. They are still uncommitted, but, as Burnet suggests, each has only a restricted range of response to specific antigens. Shortly after birth the lymphocytes produced by the thymus begin to migrate to the other lymphoid organs. As soon as each competent lymphocyte encounters and reacts with an appropriate antigen, it becomes committed and begins to multiply, giving rise to plasma cells that synthesize antibodies to the antigen.

The spleen, lymph nodes and other lymphoid organs contain a small supply of lymphocytes and multipurpose cells called stem cells when the animal is born, but these cells are not able to react with antigens or to multiply until they are activated by the hormone from the thymus. Soon after birth hormonal messengers from the thymus begin arriving and render the lymphocytes in these organs capable of proliferating and of becoming "committed." Once a sufficient self-replenishing reservoir of such cells has been established in the spleen and lymph nodes, the main job of the thymus is done and it can retire.

This kind of scheme can explain the results of our experiments on the immunity reactions of the mouse. Removal of the thymus at birth deprives mice of their source of immunologically competent lymphocytes. In the case of the resistant strains of mice that maintained a high level of lymphocytes in the



LYMPHOCYTES originate primarily in the thymus. Plasma cells, which probably are the actual makers of antibody, may be derived from lymphocytes. They may also come, like lymphocytes themselves and the other white cells (granulocytes), from precursors: stem cells.



What happens when a turbocharger hits 115,000 RPM?

Trouble. When a turbine wheel spins at 115,000 revolutions per minute—at ambient temperatures up to 1400° F.—almost anything can happen. We had to find out exactly what.

The energy output of modern diesel power packages—widely used in tactical vehicles and at missile sites—has been increased significantly by turbocharging and aftercooling.

Five years ago these turbochargers loafed along at 30,000 RPM—a leisurely pace by today's 50,000 to 70,000 RPM standard. Tomorrow operating speeds of 115,000 will be routine.

To provide metallurgical and design knowledge essential to turbo development, we had to determine what happens when speeds mount to the 115,000 RPM range.

First we had to produce a signal which would indicate both amplitude and frequency of turbine blade vibrations. Long experience with strain gauges came in handy here.

Hold fast at 1400° F.

Then, of course, we had to develop techniques to hold gauges and lead wires securely in position—withstanding terrific heat and large centrifugal forces.

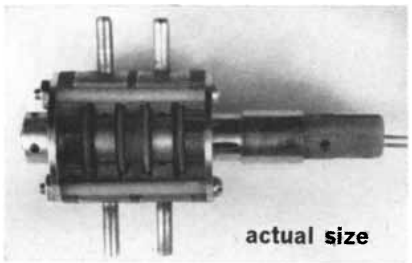
Ceramic-type cements were used to hold the gauges fast. The "armadillo" method was used to shield lead wires.

The toughest problem was transmitting strain signals from the rotating turbocharger assembly to the stationary recording equipment without loss of signal fidelity. Brush-type slip rings were quickly eliminated because of their high noise level.

Fortunately, Caterpillar engineers had pioneered in the development of slip rings using mercury as a conductor between a moving rotor and stationary collecting rings.

The mercury rings had a low noise level. And, because they required only two slip ring channels for each information channel, we were able to reduce the overall size while increasing speed capabilities.

This is what Caterpillar's high-speed mercury slip ring looks like.



Signals from the strain gauges are recorded simultaneously with turbine shaft speeds on a special magnetic tape recorder-reproducer.

This permits us to analyze the frequency and modes of blade vibration—as well as the nature of the vibration, simple or complex. Vibration frequencies of 25,000 cycles a second are not unusual.

Since the time base of the recorded signal can be expanded, high frequency signals can be reduced to a range suitable for recording on light beam galvanometer-type equipment. This method can be used for detailed waveform study when complex vibration modes are experienced.

When the duration of the resonance is long, the recorded signal may be analyzed by obtaining Lissajous patterns on an oscilloscope.

So far, the slip ring and recording equipment have permitted us to measure blade vibrations at speeds up to 86,000 RPM. Test stand data indicates that speeds over 100,000 are possible in the near future.

How about 115,000 RPM?

Our engineers say that it's just a matter of time. Time and patient, thorough research. The kind of research which has become a standard among the engineers, chemists and metallurgists who are exploring tomorrow's unknowns at Caterpillar.

If you need more detailed information about Caterpillar's broad research and development capabilities in the areas of vehicles or diesel engines, write us.

If you have a specific problem in vehicle or power design, or if you'd like to know more about the mercury slip ring, call us.

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THE LASE

The amazing laser makes light beams which weld, measure, balance, heat, survey, detect, communicate, time, sterilize, map, machine, heal, analyse, search, melt. The world's first working laser was built by Hughes.

Even science fiction writers were unprepared for the laser when it burst on the scientific world in 1960. Few would have predicted that man could indeed create light that was coherent — whose waves all "marched in lockstep." Light so coherent that a beam sent from a laser is only a few feet wide ten miles away. Whose energy could be controlled to generate instant heat millions of times hotter than the sun.

Today the laser has caught the imagination of researchers in hundreds of fields. Dentists are "welding" fillings into teeth. Watchmakers are drilling tiny holes in ruby jewels in microseconds instead of hours. The human voice as well as pictures have been transmitted on a laser beam. Experts calculate one beam could carry all the telephone conversations being made at this moment.

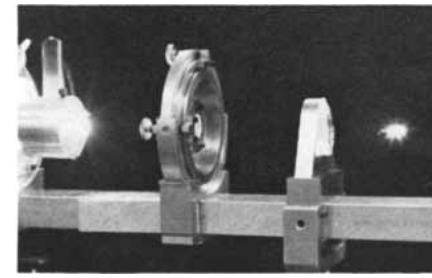
One of the first practical uses of the laser is the Hughes Colidar (Coherent Light Detection and Ranging). The first laser rangefinder, it can measure distances with accuracy and speed never before obtainable. Several versions, for use by troops, in tanks and helicopters, pinpoint targets several miles distant.

In the new field of microminiaturization, Hughes laser welders offer clear advantages. Joining the tiny bits of metal for interconnections between thin film elements, for example, is virtually impossible with other methods. But the laser can fuse wires just 0.0005″ in diameter, join dissimilar metals, and even go through the glass envelope of a display tube to weld otherwise inaccessible connections.

The world's first working laser, built by Hughes, used a ruby which "lased" in one color — red. Latest example of Hughes research is the achievement of the first "variable" laser which produces 60 new colors. Using a "noble" gas — such as argon, xenon, krypton and neon,

LASER RANGER IN GUN CONFIGURATION FIRES A LIGHT BEAM TO GIVE PRECISE RANGE OF OBJECTS UP TO TEN MILES AWAY — RANGE IS INSTANTLY READOUT BY OPERATOR.

NEWEST HUGHES LASER DEVELOPMENT HAS JUST ADDED 60 COLORS TO THE GAS LASER'S CAPABILITY — FILLING THE PREVIOUS GAP IN LIGHT SPECTRUM. THIS OPENS GREAT NUMBERS OF NEW LASER APPLICATIONS.



AIR SPARK, PRODUCED BY 100,000,000 WATTS FROM HUGHES LASER, WHEN AIR MOLECULES ARE IONIZED FOR SPLIT SECOND

THIN FILM CIRCUIT (RIGHT) OF ALUMINUM IS JOINED BY MICROSCOPIC WELDS IN NICKEL RIBBON. THE ABILITY TO WELD DISSIMILAR METALS IS JUST ONE OF THE LASER'S ADVANTAGES IN METALWORKING. (CIRCUIT SHOWN IS TWICE ACTUAL SIZE.)

Creating a new world with electronics

HUGHES

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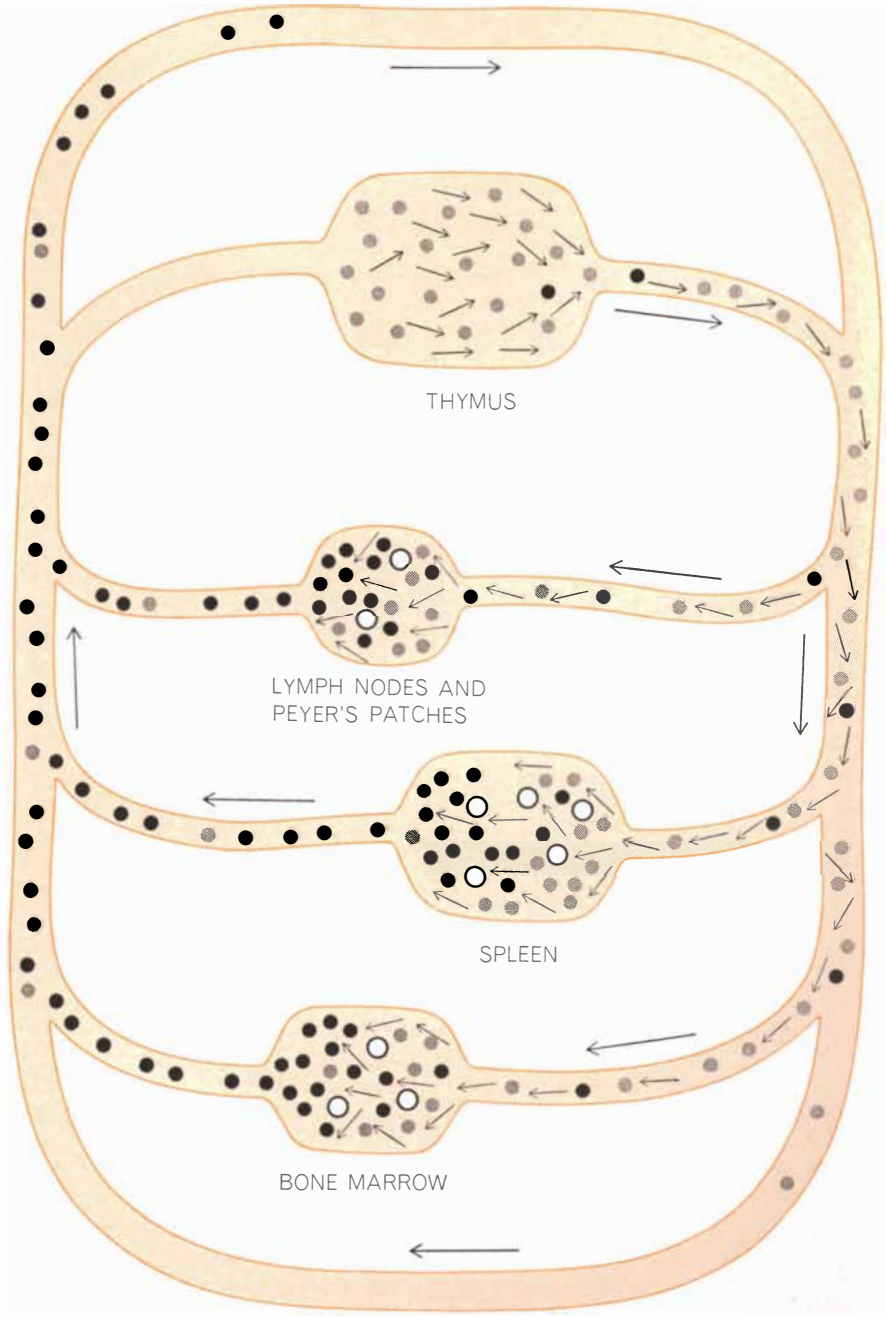
blood in spite of thymectomy at birth, the explanation of their failure to show an immune response to the virus injection is that their lymphocytes, in the absence of the thymus hormone, were incapable of generating a line of replicating cells that would react against this new antigen.

The next step in the investigation is clear, because the path has been well marked by the classic studies of endocrine glands and their hormones. Now that the specific effects of removing the organ and reimplanting it have been intensively tested, the third step, according to the traditional strategy, is to isolate the hormone—if indeed it is a hormone—and proceed to study its chemical action. When this is accomplished, the chemical basis of resistance to infection and to grafts of foreign tissues may be much clearer.



ROLE OF THYMUS in immunity may be as suggested in this diagram. At birth most lymphocytes are in the thymus; a few are in other lymphoid organs, along with precursor stem cells (*circles*). The lymphocytes are incompetent (*gray dots*), unable to react to antigens, until they are exposed to a humoral factor that originates in the thymus (*black arrows*). The humoral factor travels through the bloodstream to other lymphoid tissues and there produces competent lymphocytes (*black dots*) that can become antibody-producing cells. The factor may also stimulate the stem cells to proliferate and differentiate into lymphocytes.

GERM-FREE ISOLATORS

They are widely used to raise laboratory animals in an environment that is entirely free of microorganisms. Other potential applications are in surgery on human patients and in the manufacture of spacecraft

by P. C. Trexler

What would the lives of men and other animals be like in the total absence of germs? This question occurred to biologists and medical men soon after Louis Pasteur demonstrated that microorganisms play a profoundly important role in many normal and pathological processes in nature. Today the matter is investigated simply by raising an animal in an "isolator" that is entirely free of germs. The successful development of the isolator not only has made it possible to answer such biological questions but also has opened up a new range of possibilities in medicine and even technology. These include performing surgical operations in an environment unusually free of germs and manufacturing germ-free components for spacecraft without having to subject them to possible damage by heating.

Pasteur himself believed that, since animals had evolved in such close association with microorganisms, microorganisms were essential to animal life. It was primarily in response to this contention that the first attempts to isolate living animals in a germ-free environment were made. In 1895 two workers in Germany, George H. F. Nuttall and H. Thierfelder, built a chamber that could be sterilized with steam and placed inside it newborn guinea pigs that had been delivered under sterile conditions by Caesarean section. They managed to keep several of the guinea pigs alive in the chamber for 10 days, and at the end of that time they were able to demonstrate that there were no microorganisms present in the animals. The time limit was imposed by the amount of sterile food they could store in the chamber at the beginning of the experiment; as soon as the food ran out the animals were removed to conventional quarters and the experiment was over.

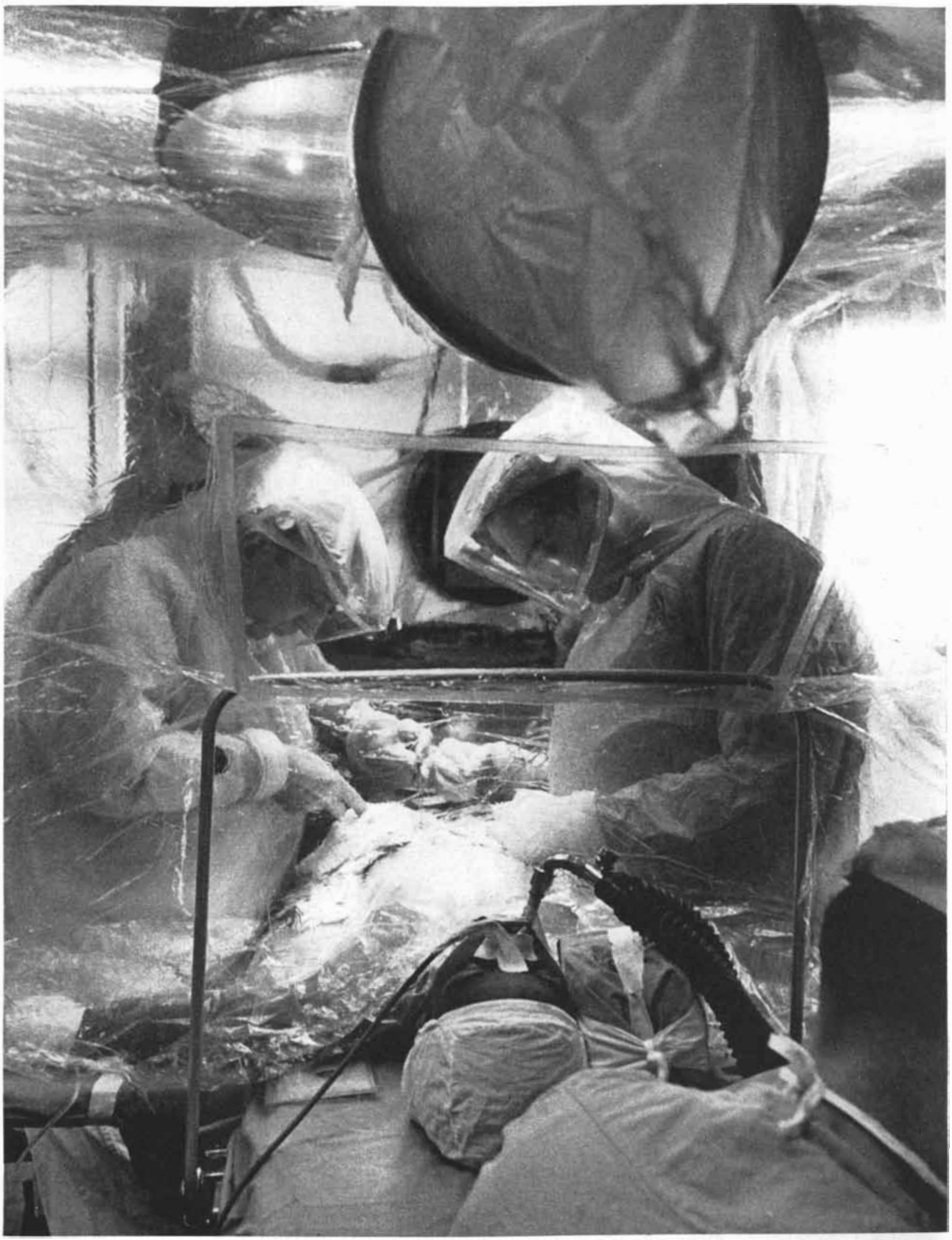
In 1915 another German experimenter, Ernst Küster, devised an isolator with a sterile lock, that is, a double-doored antechamber into which materials could be introduced, sterilized with steam and then passed into the main chamber. In this apparatus Küster reared a goat free of microorganisms for 34 days. Other workers undertook to perform such experiments, but without notable success. They were frustrated not only by frequent microbial contamination of their chambers but also by the lack of knowledge of how to prepare adequate sterile rations for their animals. The chicken, however, was added to the list of animals that had been briefly reared under germ-free conditions.

Then, in 1932, a new effort to produce germ-free animals was launched at the University of Notre Dame—paradoxically as a means of culturing microorganisms. At the time microbiologists were particularly interested in the changes they observed in the microorganisms they were growing in glassware. It was known that some disease organisms changed from virulent to nonvirulent forms and vice versa, and that they changed in appearance; it was also thought that bacteria, like many higher microorganisms, might change form in the course of their life cycle. Such changes, a fuller knowledge of which seemed of considerable importance for the control of infectious disease, could not be studied in the normal animal environment of the microorganism; the inevitable presence of other microorganisms would confuse the observations. The goal of the Notre Dame program was to provide germ-free animals into which a single species of microorganism could be introduced for investigation in the absence of other species.

James A. Reyniers, then an instructor of bacteriology at Notre Dame, rediscovered the work of Nuttall and Thierfelder. Subsequently the Notre Dame group developed an isolator of the kind built by Küster. The apparatus was basically a stainless-steel drum with a lock, glass viewing ports and ports fitted with long rubber gloves for handling animals and materials. It was sterilized by steam and could be joined to a similar isolator at the lock. With such an arrangement germ-free animals and materials can be passed into a freshly sterilized chamber while another part of the system is flooded with steam; in this way contamination by microorganisms can be prevented over long periods.

Germ-free monkeys and rats now joined the guinea pig, the goat and the chicken. The rat, which is the most widely used laboratory animal, was unusually difficult to rear under germ-free conditions. Rats are born in a comparatively undeveloped state and ordinarily suckle for about three weeks. If they are removed from their mothers by Caesarean section and nursed with an eyedropper, the milk often gets into their lungs and drowns them. The only solution, after hundreds of efforts, was to feed them tiny amounts of milk around the clock.

Most of this work was interrupted by World War II, but a few isolators containing germ-free rats were left in the charge of a graduate student. During this time a pair of the rats mated and the female gave birth; they were the first animals to reproduce in an environment without microorganisms. The event indicated that it was possible to raise whole colonies of germ-free ani-



GERM-FREE SURGERY is performed inside a transparent vinyl isolator at the Albert Einstein College of Medicine. The surgeon and his assistants work in flexible pullover jackets that are continuous with the walls of the chamber; they are therefore topologically outside the chamber but can work inside. The vinyl film has been cemented to the lower abdomen of the patient, thereby immobilizing any germs on the surface of the skin. An incision is then made through the film and skin directly into the body of the patient. A constricted part of the lower intestine was removed in this operation. Circular object at top is an air-exhaust valve.

mals. It also demonstrated that the germ-free animal is normal in that it can reproduce, even though a contaminated animal will reproduce more readily.

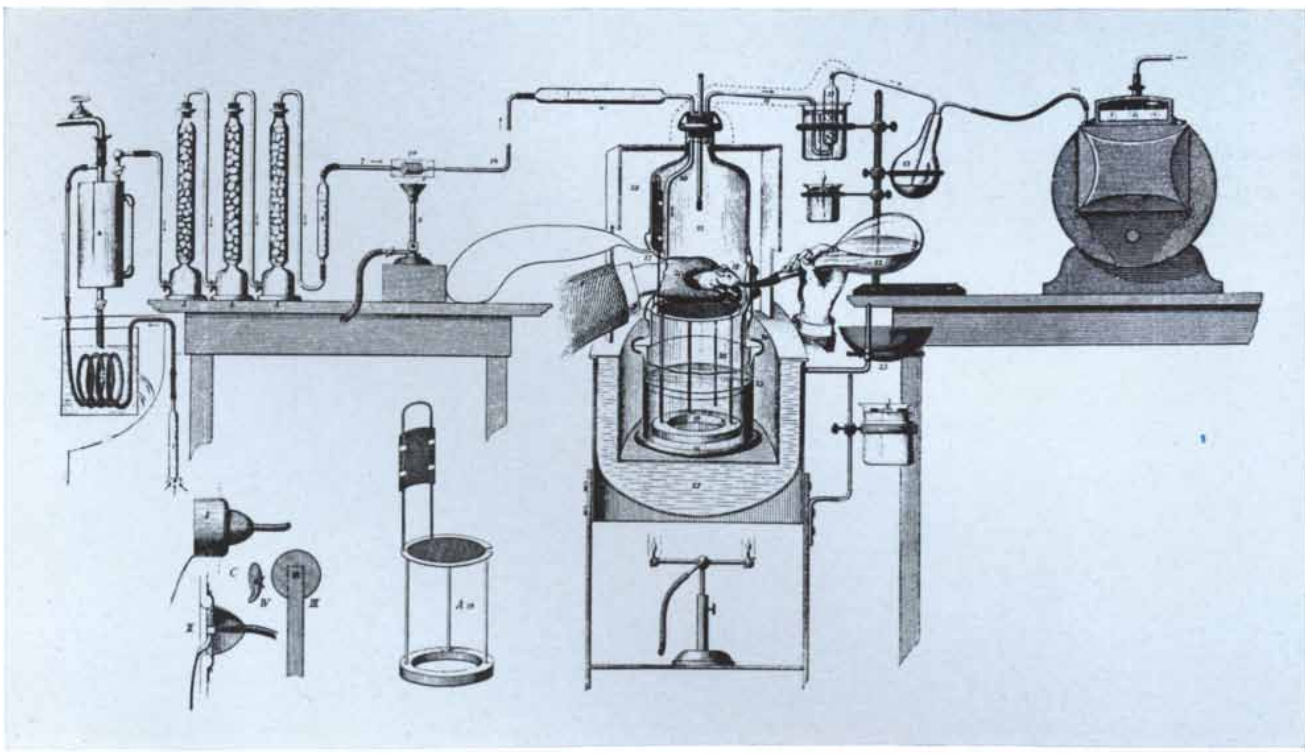
After the war isolators of the steam-sterilized stainless-steel type were built in Sweden and Japan, and similar devices were installed at the Walter Reed Army Institute of Research and the National Institutes of Health. These isolators, together with those at Notre Dame, did yeoman service; indeed, most of what is now known about animals in the germ-free state was learned with them. It became apparent, however, that the steel isolator constituted something of a barrier to further progress in the field. Its installation was expensive and its operation required a considerable force of skilled workers. This barrier was removed when, in 1957, our group at Notre Dame developed an isolator whose walls were not steel but transparent, flexible vinyl film.

There are several advantages to the use of this material. It is not only cheaper than steel; it is also lighter and can be readily altered or repaired in the laboratory. Food, bedding, surgical instruments and other supplies can be introduced into the isolator through a sterile lock, but they can also be introduced in a much more convenient way. The supplies are first sealed in a package of film and sterilized in a steam autoclave; the package is then cemented or heat-sealed to the wall of the sterile chamber. The supplies are passed into the isolator by cutting into the package with a hot wire from within the chamber. The opening can be closed from the inside with a strip of adhesive tape, or the package can be left in place as a sterile appendage. The entire operation can be performed in a minute or two—much less time than it takes to pass supplies through a steam-sterilized lock.

Flexible-film isolators can be sterilized with steam, but most of them now in use are sterilized cold by being soaked or sprayed with peracetic acid. A 2 percent solution of peracetic acid will inactivate the most resistant spores of bacteria and molds within a minute as a liquid and within 15 minutes as a saturated vapor; the solution also effectively inactivates virus particles. Peracetic acid leaves no toxic residue because it breaks down into acetic acid, water and oxygen. In convenience of establishing and maintaining germ-free animals in a germ-free environment the flexible-film isolator is a major advance.

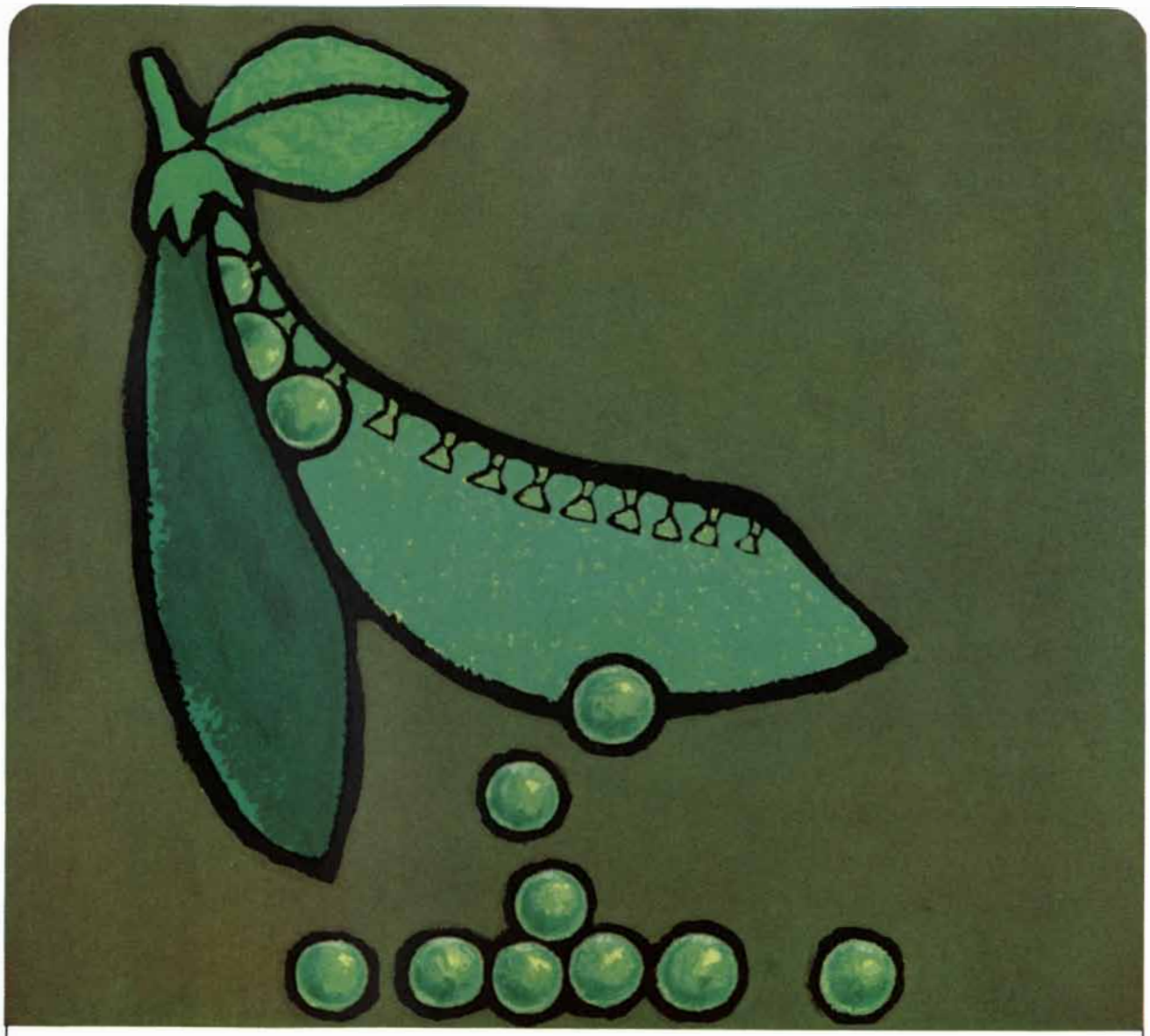
An even greater advance lies in the freedom of observation and manipulation the flexible-film isolator gives the investigator. He can literally design his experiment and place the isolator around it rather than design the experiment to fit the isolator. He is not limited to working through shoulder-length rubber gloves; the floor or wall of the chamber can be adapted to serve as a transparent pullover jacket that enables him to operate inside the chamber while he remains topologically outside it [*see illustration on page 84*]. This innovation has been extended to entirely enclosing the experimenter in a suit of transparent film; he can then enter a germ-free room, several of which have now been constructed.

Today the inventory of animals that have been reared under germ-free conditions has been enlarged from guinea pigs, goats, chickens, monkeys and rats to include mice, rabbits, cats, dogs, sheep, pigs, cattle and turkeys. What do studies of these animals reveal of the way in which germ-free animals differ from normally contaminated animals? As an example, rats are susceptible to tooth decay; in the absence of microorganisms, as one might expect, they develop no cavities. The intestinal tract of a normally contaminated animal has the appearance of an inflamed tissue



FIRST GERM-FREE ISOLATOR was built in 1895 by George H. F. Nuttall and H. Thierfelder. The main components of their apparatus are depicted in this contemporary engraving. Newborn guinea pigs were placed inside a glass chamber soon after it had been sterilized with steam. Several of the animals were kept alive in the chamber for 10 days, and at the end of that time they were shown to be entirely germ-free. The animals could be manipulated with the aid of a rubber glove attached to the wall of the chamber.

INNOVATION!



A NEW TECHNIQUE FOR PROTECTING COMPONENTS

(It's based on the principle of individual pea protection, rather than a pod)

Semiconductors, the wonder midgets of electronics, have to be kept safe from moisture, dust and air to perform reliably. Usually the vulnerable slice of semiconductor material, with several electrical junctions etched on it, is put into a single sealed, metal package—like peas in a big pod. Good protection, but it takes up needed space.

Now, in devices called multiple diodes, GT&E scientists can seal each junction in a glass coating, like the skin on a pea. This glassivation process takes away the need for a big overall moisture-sealed enclosure. Instead, a smaller, flat, molded package can be used. More junctions fit into less space, with no loss in protection and reliability.

As part of an extensive research program, exciting advances are being made at the laboratories of GT&E. Scientists and engineers work in a climate of invention that fosters progress in our many fields—communications, electronics, lighting, chemistry, metallurgy and atomic energy. Research is our solid base for future growth.

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Replica of a 16th Century English Nocturnal—Courtesy The Mariners Museum, Newport News, Virginia

from nocturnal to avionic systems

A few hundred years ago—when navigation was still in its infancy—an Englishman, Humphrey Cole, constructed the "nocturnal," an instrument for determining time at night through observation of the polestar relative to its guards or the pointers in Ursa Major.

In its time the nocturnal was a definite advancement in celestial navigation. However, adverse weather conditions such as fog or snow made it useless. Today supersonic aircraft demand guidance and navigation systems with all-weather capability—a capability inherent in every AC avionics system. As proof of this, AC produces the bombing-navigation systems for the SAC B-52C&D. And AC Airborne Inertial Reference Units are used in the Air Force ALRI program.

In other fields, AC is responsible for the inertial guidance systems in Titan II and III; through a team effort, the development of the Apollo Command Module guidance-navigational system; and other major projects where advanced inertial sensing systems are required.

Perhaps AC's proven past experience, present programming and advanced planning can play an integral part in your aerospace projects. For further information, contact Director of Sales-Engineering, AC Spark Plug Division, General Motors, Milwaukee, Wisconsin.

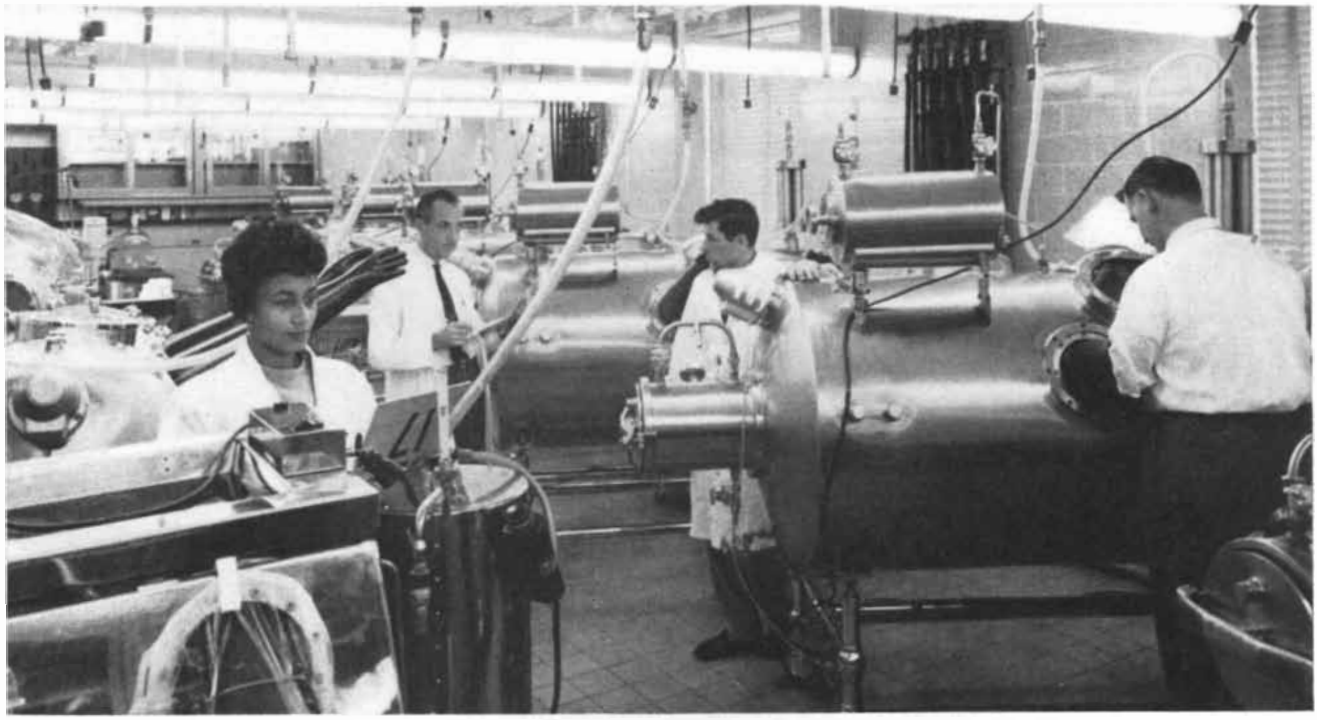
MASTER NAVIGATORS THROUGH TIME AND SPACE

GUIDANCE AND NAVIGATION FOR SPACECRAFT • BALLISTIC MISSILES • AVIONICS • SPACE BOOSTERS • DELIVERED ON TIME AT LOW COST WITH OUTSTANDING ACCURACY AND RELIABILITY

because of the microorganisms that live in it; the intestinal tract of a germ-free animal is pale and flaccid.

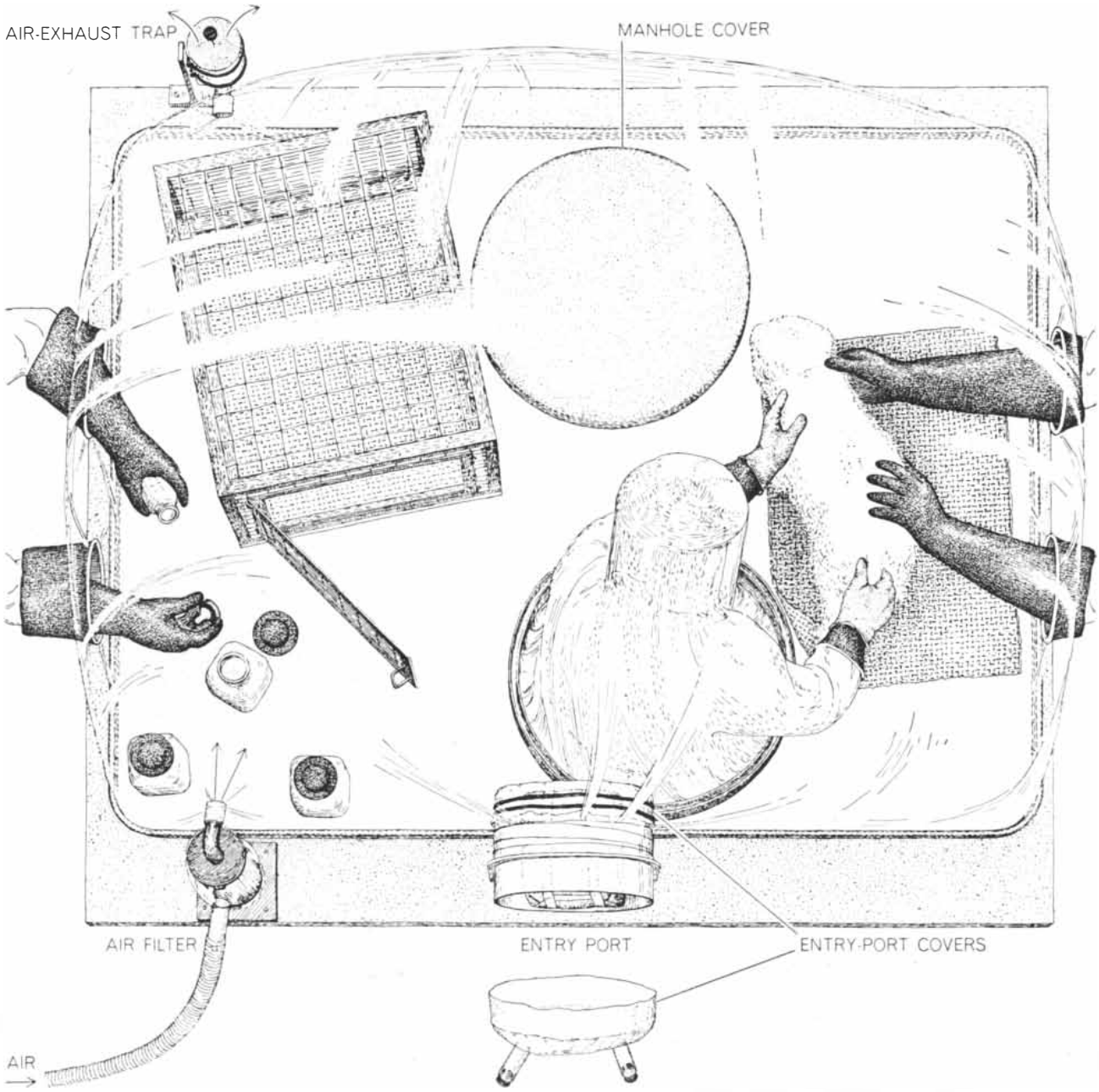
Perhaps the most striking anatomical difference in a germ-free animal involves its cecum, a blind pouch that opens into the upper part of the large intestine. In a normal mouse the cecum accounts for 1 to 3 percent of the body weight; in a germ-free mouse it may constitute as much as 30 percent. This large mass within the abdominal cavity can interfere with the reproduction of the animal and can kill it by rupturing or twisting. What causes the enlargement is not known.

The blood of a germ-free animal contains very little gamma globulin: the blood fraction containing the antibodies that neutralize bacterial toxins and other foreign substances. In the lymphatic



STAINLESS-STEEL ISOLATORS house hundreds of germ-free rats at the National Institute of Dental Research in Bethesda, Md. The protuberance at the end of the isolator at right is a sterile lock used in transferring animals from one isolator to another.

VINYL ISOLATORS in the department of veterinary medicine at Ohio State University are used to maintain several species of animals in a germ-free condition. Besides being cheaper than stainless-steel isolators, vinyl isolators are much more adaptable.



SEVERAL OPERATIONS are being performed simultaneously in this drawing of a typical vinyl isolator. One worker has entered the transparent pullover from under the table and is examining the lamb with another worker, whose arms are in the rubber gloves (*right*). Meanwhile a third worker fills bottles with sterile formula (*left*). A package of sterile supplies has been placed in the entry port from the outside; it will be removed from the inside after the outer cover has been replaced and the port has been sterilized.

system of the germ-free animal's intestinal and respiratory tracts the lymph nodes, which play an important role in the body's defenses against infection, are greatly reduced in size. When the germ-free animal is removed to a normally contaminated environment, however, its defenses against infection are quickly activated and its differences disappear.

It is in this respect that germ-free animals have their greatest usefulness. As the Notre Dame workers hoped in the 1930's, a germ-free animal infected with a single species of microorganism responds normally, so that the organism and its effects can be studied in isolation. It has turned out to be even more enlightening to infect a germ-free animal with two or more known microorganisms, so that the behavior of microorganisms in communities can be examined. Germ-free animals that have been infected for such purposes cannot very well be called germ-free; these animals are usually termed gnotobiotes, from the Greek for "known biota."

An example of a study employing gnotobiotes has to do with the organism *Shigella,* which causes bacillary dysentery. Although man is quite susceptible to infection by *Shigella,* it is difficult to produce the disease in normally contaminated laboratory animals. A contaminated guinea pig can be infected, but only if it has been treated with opiates and toxic drugs. A germ-free guinea pig, on the other hand, can be infected without prior treatment and

What If They Took Away Your Signature?

What if everything you did went unsigned, unnamed, unidentified?

It might be bad. Or it might be good. It depends on what kind of person you are.

If you don't believe your product or service is any better than the next man's, there's no point in identifying it. It could even be dangerous!

But if you're genuinely proud of your work, chances are that you want the world to know you did it. You and no one else.

That's how brand names began. Proud artisans painted, stamped or engraved their work with an identifying mark. Later, to insure an acceptable standard of quality, the craft guilds required each member to affix the guild mark to each item produced.

But really good craftsmen still wanted individual recognition. So each combined his mark with that of the guild. The resultant "hallmarks" were of value to both buyer and seller. The buyer, in his quest for quality, needed only to look for wares with the mark of a trusted craftsman. The seller, if his wares represented an exceptional value, was assured of repeat business.

Today, brand names serve somewhat the same purpose hallmarks once did. One of the products in the Cyanamid family of companies serves as an example:

A number of years ago, a man by the name of John H. Breck had a hair problem. Unable to find any satisfactory preparations to help his condition, he formulated some himself. They were so effective that they became quite popular. And to make sure that customers got the right products, John Breck simply named them after himself. Today, because of their consistently high quality, Breck® hair preparations are more popular than ever.

(Identifying the maker of a product gives the consumer this advantage, too: if you don't like the product, you know where to complain. And if you've ever written a letter of complaint to a responsible company, you know how seriously these are taken.)

An interesting extension of the way in which brand names serve consumers can be seen in Melmac® quality melamine dinnerware and in apparel, carpets and draperies made of Creslan® acrylic fiber. The finished products are actually made by other companies. Cyanamid authorizes them to use the Melmac® and Creslan® labels only if the end-products meet or exceed quality standards set up and supervised by Cyanamid. It's simply one more way of insuring the quality of the consumer's purchase...and our own reputation.

At Cyanamid and its subsidiaries, we're convinced that brand names are useful in helping people get the products with the features they want. The number of people who buy and come back for Breck®, Creslan®, Melmac®—and other important products such as Formica® laminated plastic—indicates that the consumer has a definite opinion of what suits him best.

But perhaps the best argument for brand names is your own experience. How willing would you be to accept a substitute for your favorite automobile? Or brand of coffee? Or author, for that matter?

And when it comes to an area like medicine—where life is often at stake—we depend even more on a trusted brand name. This is one reason our Lederle Laboratories division believes: "There is no generic substitute for a Lederle drug." It is part of Cyanamid's philosophy: There is no generic substitute for individual pride. Or for individual responsibility. Or for the quality and value they generate.

That's what we build into our products. That's why we sign them.

CYANAMID

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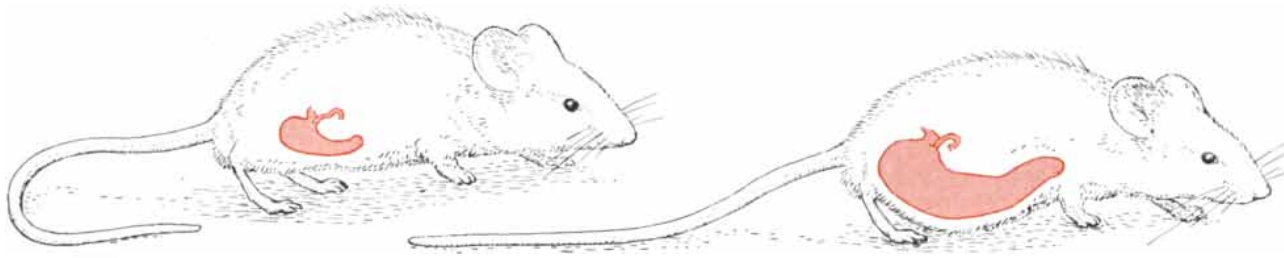

SIZE OF CECUM, a blind pouch that opens into the upper part of the large intestine, is one of the most striking anatomical differences between a normal mouse (*left*) and a germ-free mouse (*right*). The cecum normally accounts for 1 to 3 percent of the body weight; in a germ-free mouse, on the other hand, it may constitute as much as 30 percent. What causes the enlargement is not known.

develops a typical case of bacillary dysentery.

Now, if the germ-free animal is first infected with the colon bacillus, which is always present in the intestine of a normally contaminated guinea pig, it is resistant to infection by *Shigella*. If, however, it is first infected with lactobacilli, which are also present in the intestine of the normal animal, it is susceptible to *Shigella*. By the same token, a germ-free guinea pig cannot contract amebic dysentery unless it is first infected with some of the normal intestinal microorganisms. Gnotobiotes obviously provide a means for investigating the ecology of the microorganisms that live inside animals.

Microorganisms were of course cultivated on a large scale in animals long before the arrival of gnotobiotes: horses and other farm animals have been routinely inoculated with microorganisms to produce antiserums that can be used against the same infection in a human patient. When small germ-free animals are similarly inoculated, the antiserum they manufacture is highly specific because it is not contaminated with antiserums produced in response to earlier infections. Now that sheep and pigs are routinely reared under sterile conditions, it would seem feasible to make ultrapure antiserums for diagnostic and therapeutic purposes.

Joshua Lederberg of Stanford University has suggested that large animals be bred in pure strains to provide organs for transplantation to human patients; the known antigenic composition of the organs might make it easier to circumvent the antigen-antibody reaction that normally causes the body to reject the foreign graft. If such animals were reared under germ-free conditions, the organs would contain neither microorganisms and their products nor tissues and antibodies produced in response to infection. The absence of these elements might further reduce the reaction to the transplanted organ.

Germ-free animals offer great advantages for such experimental purposes, but it should be observed that the vast majority of laboratory animals are used not for experiments but for biological testing and screening. Here too, however, gnotobiotes can be most useful. The essence of biological testing is uniformity among the test animals; often every member of a test population is a member of a specially bred pure strain. Yet laboratory animals are notably susceptible to infection. To make matters worse, many of the infections are "silent" and hence cannot be perceived. Obviously the infections confuse the results of the test program, particularly when it involves the study of another infection. Such problems would obviously not arise with gnotobiotes.

The production of gnotobiotic animals is already a substantial enterprise. During the past year 15,000 such animals were reared in the U.S. alone. It is no longer necessary for the user to secure his animals by Caesarean section under sterile conditions; he can obtain them by express. They are shipped either in the isolators in which they are to be studied or in smaller containers. Air is supplied to the animal through sterilizing filters by a battery-operated blower.

The success of the isolator immediately suggested that it might be used in hospitals with human patients. Here, of course, the object is not to make the patient entirely germ-free but to shield him, or those around him, from as many microorganisms as possible. In recent years resistant strains of bacteria have appeared in many hospitals, and in spite of the great array of modern drugs and germicides hospital-acquired infections remain a serious problem. Even before our group at Notre Dame announced its first flexible-film isolator in 1957 we had made several design studies of isolators for human patients with R. T. McIlvenny of Northwestern University. In 1959, while I was still at Notre Dame, I joined with Stanley M. Levenson of the Walter Reed Army Institute of Research to develop such isolators; this joint effort has been continued at the Albert Einstein College of Medicine in New York.

The Walter Reed–Notre Dame collaboration led to a flexible-film isolator suitable for surgical operations. The system was fundamentally the same as the one devised for animals: the surgeon wore a pullover jacket that gave him freedom to move from the waist up within the sterile chamber. The security of the apparatus against contamination by microorganisms was demonstrated by a long series of operations on dogs. Four uncomplicated operations were then performed on human patients; at each of these operations one member of the surgical team had had no experience with isolators. The surgeons encountered no difficulties in these experimental operations.

The object here is to protect the patient from infection, but in some hospital situations an infected patient must be isolated from other patients. This usually involves a depressing "solitary confinement" in an isolation ward. For the past year I have been working with the staff of Union Hospital in Dover, Ohio, and a neighboring plastics manufacturer to develop a flexible-film isolator primarily for such patients. This system, which is now being tested, makes it possible to move the patient to a smaller plastic chamber on a stretcher and take him to another room for treatment or X-ray examination without danger of spreading microorganisms. At present it is customary to

on target with LEM tanks . . . the Lunar Excursion Module now being built by Grumman Aircraft for NASA's Apollo project. Because of our extensive knowledge of titanium — gained in making Minuteman rocket cases — and our experience in building other low-weight/high-strength pressure vessels for Apollo and Titan III, Grumman called on us to design LEM's descent-stage propellant tanks to stringent specifications. Result: Lightweight tank design with better than a million-to-one strength-to-density ratio, able to withstand severe vibrations. Another example of the kind of performance that is keeping our aerospace and nuclear programs on target.

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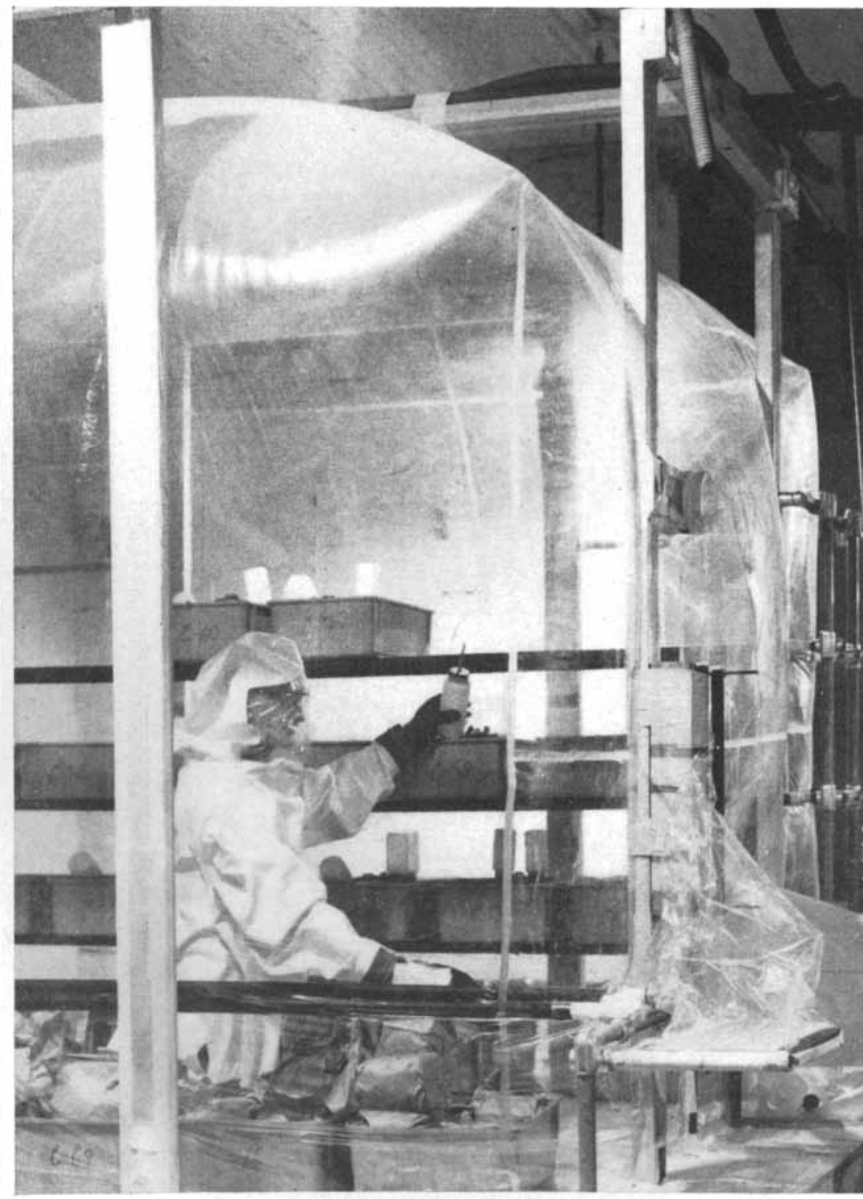
move such patients at the end of the day so that the treatment or examination room can be decontaminated during the night.

When plans were first being laid for the exploration of the solar system, biologists were quick to point out some new hazards of microbial contamination. If a contaminated vehicle from the earth were to land in an environment not unfavorable to microorganisms, they might change the environment before men had had a genuine opportunity to study it. Even more important, if there should be microorganisms on other bodies in the solar system, they cannot be allowed to enter the terrestrial environment. The microbiologist has no difficulty in imagining catastrophic consequences from such an invasion.

Up to now components of the U.S. spacecraft that have been aimed at the moon and Venus have been sterilized; some components have been given "waivers" so that they could be completed on schedule. The sterilization has been accomplished with dry heat, which according to some reports may have damaged the parts and caused them to fail in space. It is perhaps needless to add that the technology for manufacturing the components, and perhaps the entire vehicle, in a cool sterile environment is at hand.



LARGE ISOLATORS can be built of vinyl film to accommodate entire colonies of animals, in this case rats. The experimenter works freely in his pullover jacket, which he enters through a manhole in the table. The apparatus is at the University of Notre Dame.

THE CHINAMPAS OF MEXICO

They are highly productive farm plots surrounded on at least three sides by canals. Created in an ancient drainage project, they were the economic foundation of the Aztec empire

by Michael D. Coe

When the Spanish conquistadores entered Mexico in 1519, they found most of the peoples in the region unwillingly paying tribute to the emperor of the Aztecs, who ruled from a shimmering island capital in a lake on the site of modern Mexico City. Less than 200 years earlier the Aztecs had been a small, poor, semibarbaric tribe that had just settled in the area after centuries of wandering in search of a home. Shortly after their arrival they fought with their neighbors and were obliged to retreat to two small islands in the lake. There they adopted a unique form of land reclamation and agriculture known as the chinampa system. This system, which had long been practiced on the margins of the lake, was one of the most intensive and productive methods of farming that has ever been devised. It provided the Aztecs with land to live on and with the first surplus of food they had ever known. Their new wealth enabled them to create a standing army that soon subjugated nearby peoples. Driven by the demands of their sun-god for sacrificial captives, and supported by chinampa agriculture (which was also practiced by some of their vassals), the Aztecs quickly expanded their empire throughout Mexico.

The Spaniards toppled the Aztecs within two years and razed their magnificent pyramid temples, but the chinampa system has persisted to the present. Now, after enduring for perhaps 2,000 years, it too appears to be facing extinction.

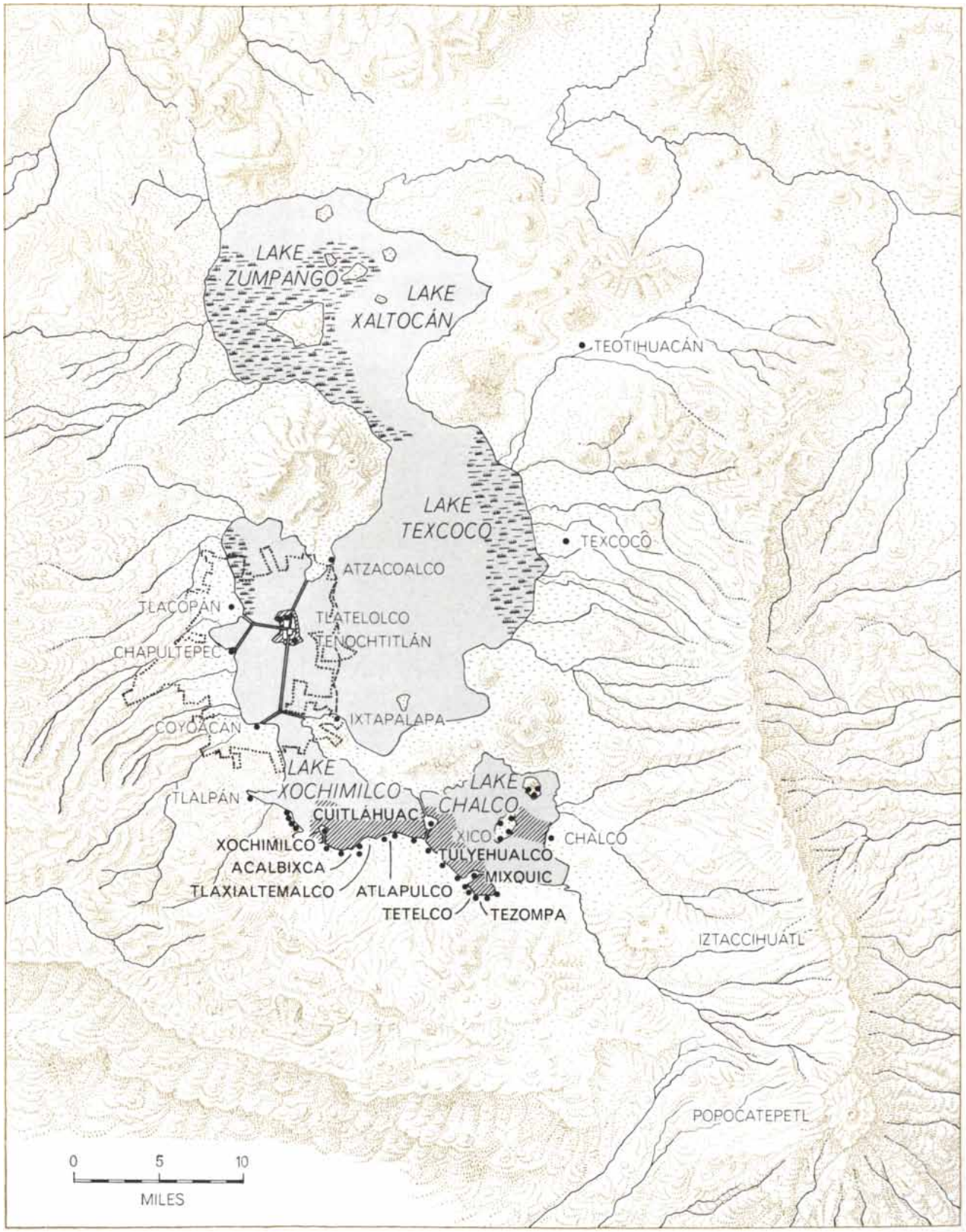
Chinampas are long, narrow strips of land surrounded on at least three sides by water. Properly maintained, they can produce several crops a year and will remain fertile for centuries without having to lie fallow. The important role they have played in the long history of Mexico is probably unknown to the *chinamperos* who tend them and to the many tourists who visit the most famous chinampa center: the town of Xochimilco south of Mexico City.

In Xochimilco the guides relate the charming story that chinampas are, or once were, "floating gardens." This is a tall tale that goes back at least to 1590, when a Father Acosta included it in his *Natural and Moral History of the Indies:* "Those who have not seen the seed gardens that are constructed on the lake of Mexico, in the midst of the waters, will take what is described here as a fabulous story, or at best will believe it to be an enchantment of the devil, to whom these people paid worship. But in reality the matter is entirely feasible. Gardens that move on the water have been built by piling earth on sedges and reeds in such a manner that the water does not destroy them, and on these gardens they plant and cultivate, and plants grow and ripen, and they tow these gardens from one place to another."

Acosta may have been deceived by the rafts of water vegetation that even today are towed to the chinampas and dragged onto them as compost. The real interest of a chinampa town such as Xochimilco lies not in its fables and its tourist attractions—flower-garlanded boats plying canals, waterborne mariachi bands and floating soft-drink purveyors—but in the problem of the nature and origin of the chinampas and the relation of this form of agriculture to the rise of the pre-Columbian civilizations of central Mexico.

The chinampa zone is located in the Valley of Mexico, a landlocked basin entirely surrounded by mountains of volcanic origin. The valley, which is a mile and a half above sea level, has an extent of some 3,000 square miles. In pre-Spanish times a sheet of water, called by the Aztecs the Lake of the Moon, covered a fourth of the valley during the rainy summer season. In the dry winter season evaporation reduced this shallow body of water to five separate lakes: Zumpango on the north, Xaltocán and Texcoco in the center and Xochimilco and Chalco on the south [*see illustration on opposite page*]. The last two were really a single lake divided by an artificial causeway. Villages were established in the valley sometime late in the second millennium B.C.; since then the valley has supported dense populations of farmers. During the first or second century A.D. the populous city of Teotihuacán, which covered at least eight square miles at the northeastern edge of the valley, came to dominate the region. Although Teotihuacán was overthrown as long ago as A.D. 600, its enormous pyramid temples still stand. The last, most powerful and best known of the civilized states of the valley before the arrival of the Spanish was the empire of the Aztecs, centered on the island of Tenochtitlán-Tlatelolco in the western part of Lake Texcoco.

Since the Spanish conquest in 1521 man has drastically changed the valley. In the colonial era the water was partly drained in the course of reclaiming land for agriculture. Far more, however, was removed by a great tunnel bored through the mountains to the north in 1900, during the rule of Porfirio Díaz. The valley has been further dried out by the tapping of springs and digging of wells to provide water for the rapid growth of Mexico City. Of the estimated six billion cubic meters of water avail-



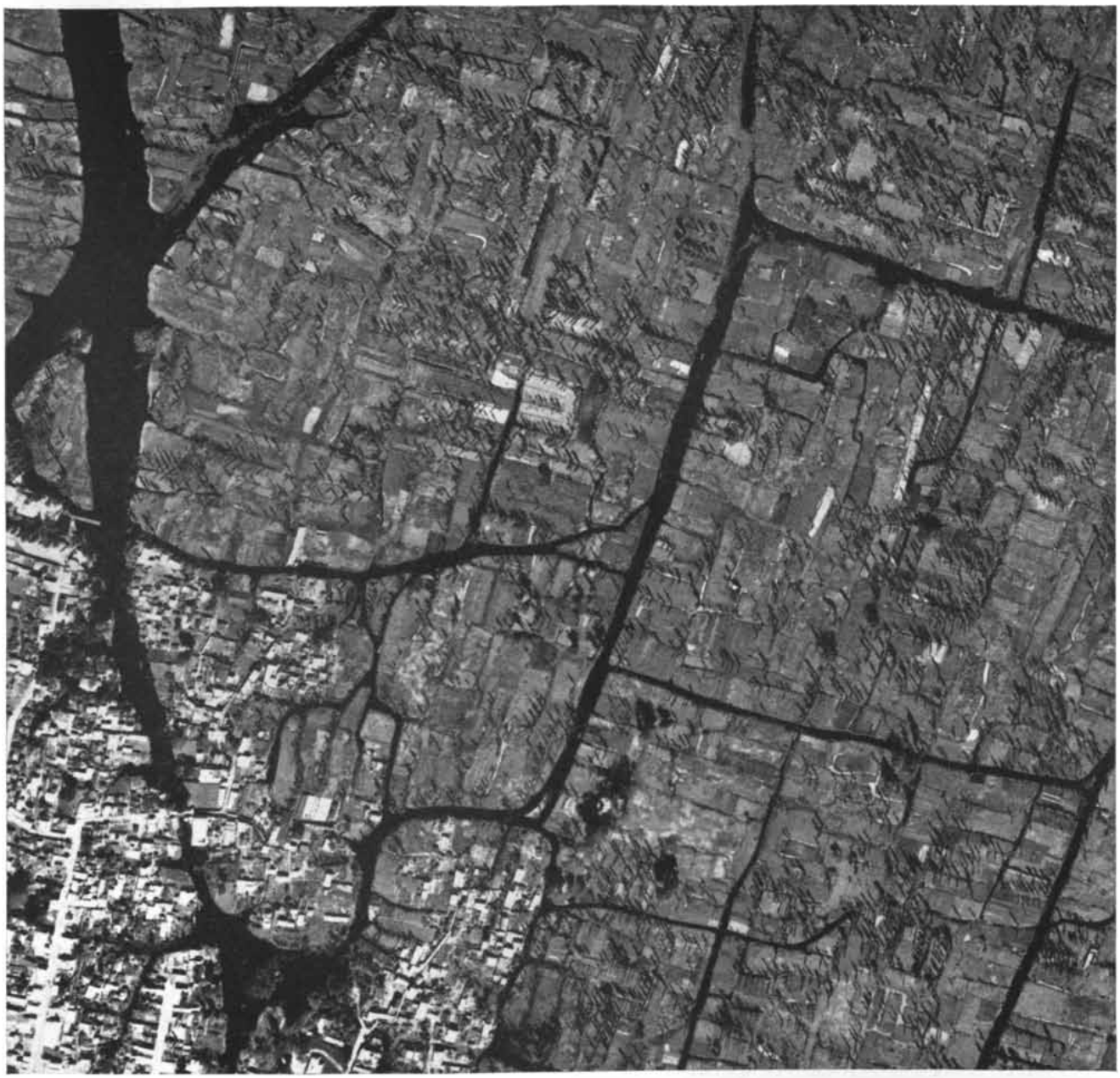
CHINAMPA AREAS (*hatched*) **and the Valley of Mexico are shown as they appeared in summer at the time of the Spanish conquest in 1521. In the rainy summer season the five lakes coalesced into one large lake: the Lake of the Moon. Tenochtitlán-Tlatelolco was the Aztec capital. The dotted line marks the limits of modern Mexico City. The broken line between Atzacoalco and Ixtapalapa shows the location of the great Aztec dike that sealed off and protected the chinampas from the salty water of Lake Texcoco. Causeways and aqueducts leading to the Aztec capital are also shown. The names of the nine chinampa towns that remain today are given in heavy type. The large black dots without names are the sites of the freshwater springs that fed the chinampa zones.**

able in the valley each year, 744 million cubic meters is consumed by the urban population. Most of the rest evaporates. As a result only isolated puddles of the Lake of the Moon remain, including parts of Lake Texcoco and Lake Xochimilco. Dehydration has so weakened the underlying sediments that the larger buildings of Mexico City are sinking at the rate of about a foot a year.

The removal of the water has also had a disastrous effect on the chinampas. From ancient times down to the past century or so many chinampa towns—small urban centers surrounded by the lovely canals and cultivated strips—existed on the western and southern margins of the old Lake of the Moon. Today only nine remain, and eight of them are probably doomed. Xochimilco alone may endure because of its importance as a tourist center.

In a masterly study of Xochimilco published in 1939 the German geographer Elizabeth Schilling established to the satisfaction of most interested scholars that the chinampa zone is an example of large-scale land reclamation through drainage. Recently detailed aerial photographs have confirmed her judgment. These show Xochimilco to be a network of canals of various widths laid out generally at right angles to one another to form a close approximation of a grid. This could not have been achieved by a random anchoring of "floating gardens." Departures from the pattern have probably come about through destruction and rebuilding of the chinampas, which are easily ruined by flooding and neglect.

To the trained observer the photographs reveal carefully planned canals that drained the swampy southern shore

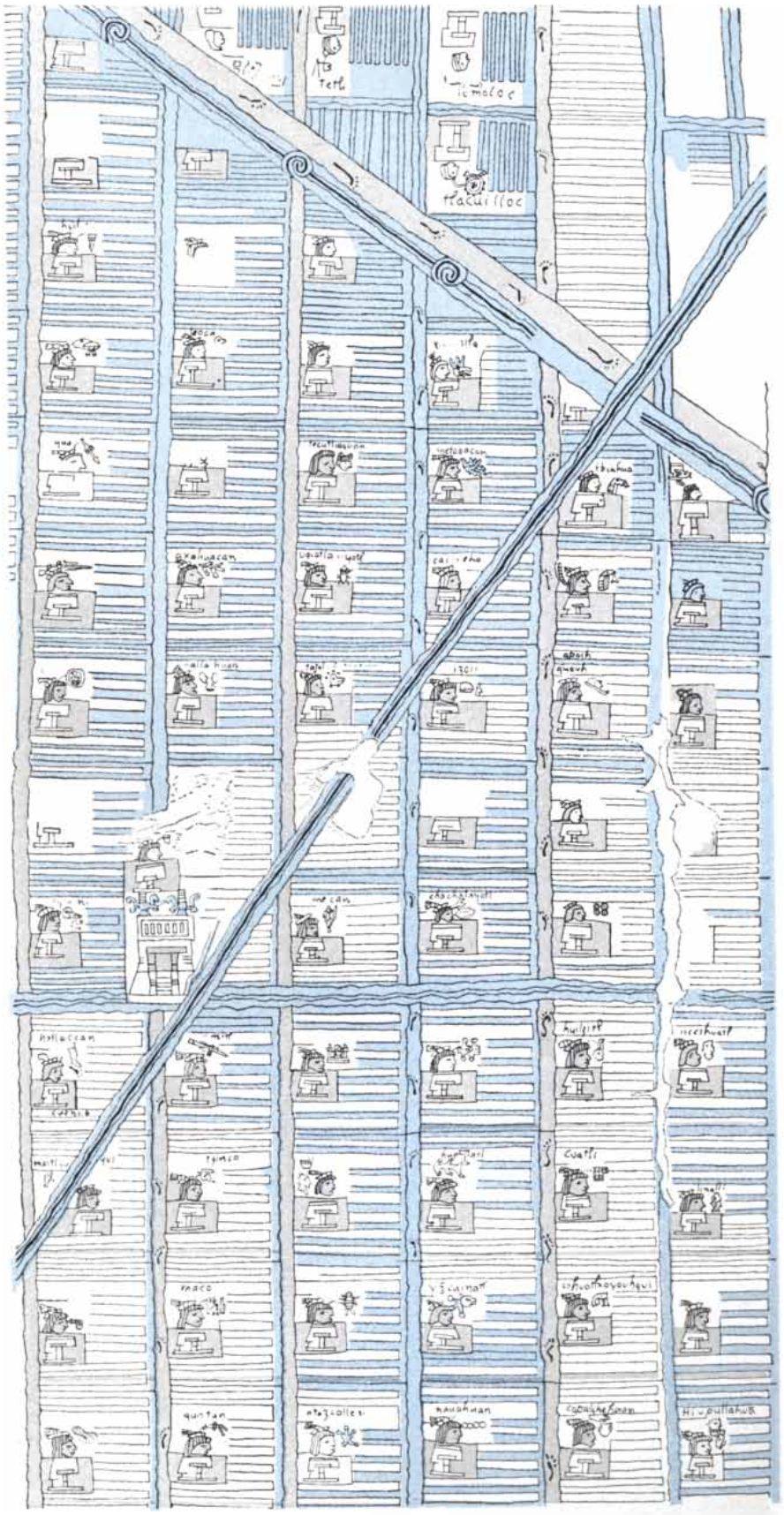


CHINAMPA GARDENS and canals that surround each of them on at least three sides form a grid pattern in this vertical air view. The grid "tilts" about 16 degrees east of north. Many of the canals that appear to be silted up are simply covered with waterweeds. Part of the town of Xochimilco, south of Mexico City, is at lower left. First canals were dug 2,000 years ago to drain swampy areas.

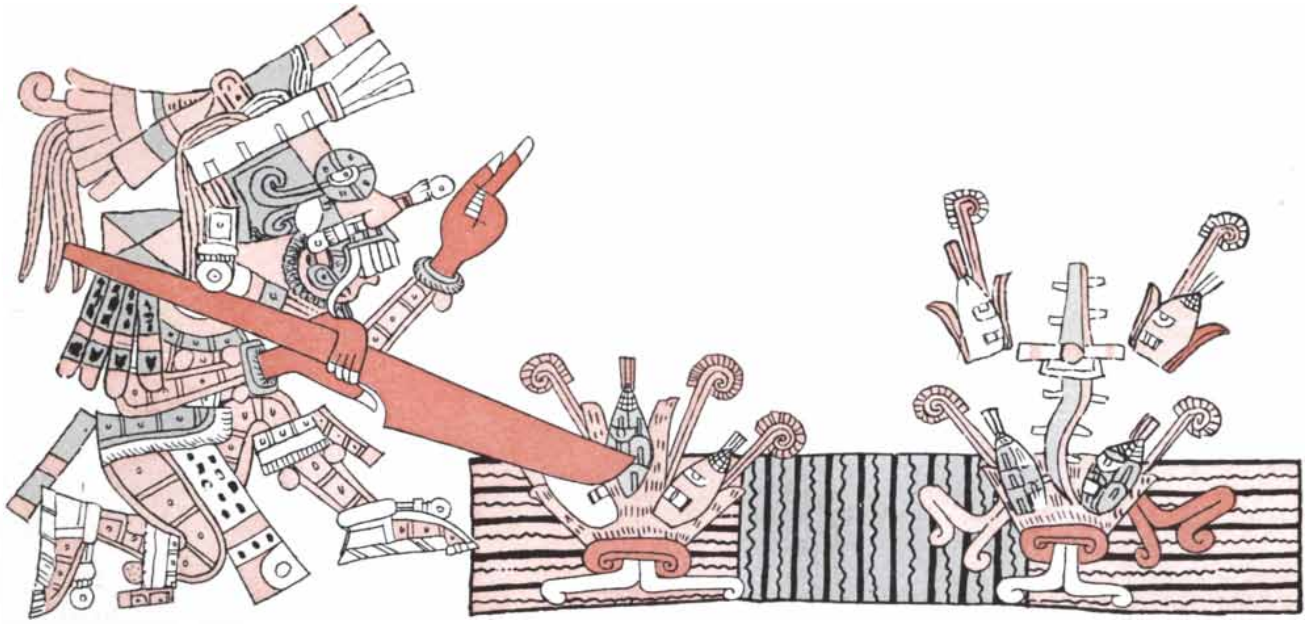
of Lake Xochimilco, where water flowing in from numerous springs had been held in the spongy soil. Here the water table was higher than the surface of the open lake to the north. The canals permitted the spring water to flow freely into Lake Xochimilco and thence into Lake Texcoco, which was deeper. The peaty sediments then released much of the trapped water. Mud dug out in making the canals was piled between them, adding height to the narrow islands and peninsulas that constitute the chinampas. The sides of the garden plots were held in place by posts and by vines and branches woven between them. Later living willow trees replaced many of these wattle walls. Until a few decades ago the water flowed out of Lake Xochimilco into Lake Texcoco through the willow-bordered Canal de la Viga, which carried native women to the market of Mexico City in canoes laden with the rich produce of Xochimilco. Now abandoned, the canal is largely silted up.

In many ways this remarkable drainage project resembled land-reclamation schemes elsewhere, such as those in the fens of eastern England or the polders of the Netherlands. It was unique, however, in the kind of farm plots that resulted, in the technique of their cultivation and in their enormous productivity. Each chinampa is about 300 feet long and between 15 and 30 feet wide. The surrounding canals serve as thoroughfares for the flat-bottomed canoes of the farmers. Ideally the surface of the garden plot is no more than a few feet above the water. Before each planting the *chinamperos,* using a canvas bag on the end of a long pole, scoop rich mud from the bottom and load it into their canoes. The mud is then spread on the surface of the chinampas. In the wet season (June through October) water held in the chinampa provides enough moisture for the crops; toward the end of the dry season, when the canals are lower, the plots must be watered. After a number of years the surface of a chinampa is raised too high by the repeated application of mud and must be lowered by excavation. The surplus soil is often removed to a new or rebuilt chinampa.

New chinampas are made, naturally enough, by cutting new canals, which today is accomplished with power dredges. Older plots that have fallen into disrepair are often reconditioned. In both operations rafts of water vegetation are cut from the surface of the canals, towed to the plot and dragged



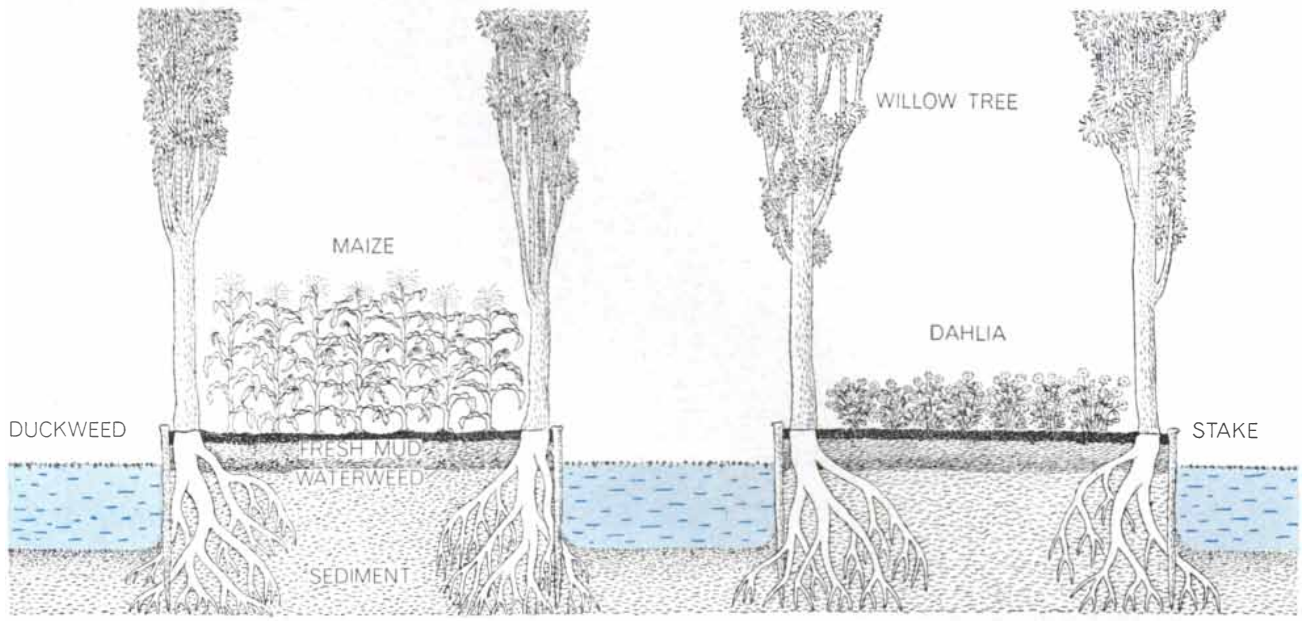
ANCIENT AZTEC MAP of a portion of Tenochtitlán-Tlatelolco shows that it was a chinampa city. Six to eight plots are associated with each house. Profile of the householder and his name in hieroglyphs and in Spanish script appear above each house. Footprints indicate a path between plots or beside a canal. This is a copy of a small part of the damaged map, which is in the National Museum of Anthropology in Mexico City.



DIGGING WITH A "COA," the cultivating stick of the ancient Mexicans, the rain-god tills magic maize. The drawing is copied from a late preconquest Mexican religious work. The *coa* is considerably broader near the digging end than it is toward the handle.

into place one on top of another until they reach the desired height. After that they are covered with the usual mud. Thus each plot has its own built-in compost heap.

An essential element in chinampa farming is the technique of the seed nursery, which has been thoroughly investigated by the anthropologist Pedro Armillas of Southern Illinois University and the geographer Robert West of Louisiana State University. The nursery, at one end of the chinampa near a canal, is made by spreading a thick layer of mud over a bed of waterweeds. After several days, when the mud is hard enough, it is cut into little rectangular blocks called *chapines*. The *chinampero* makes a hole in each *chapín* with a finger, a stick or a small ball of rag, drops in the seed and covers it with manure, which now comes from cattle but in Aztec days came from humans. For protection against the occasional winter frosts the seedbed is covered with reeds or old newspapers. During dry weather the sprouting plants are watered by hand. Finally each seedling is transplanted in its own *chapín* to a place on the chinampa, which has been cultivated and leveled with a spade or hoe (the Aztecs employed a



CROSS-SECTION DIAGRAM of chinampas and canals gives an idea of their construction. Fresh mud from bottom of canals and weeds for compost beneath the mud keep the chinampas fertile. Trees and stakes hold the sides of the chinampas firmly in place.

digging stick called a *coa*) and then covered with canal mud. The only crop for which the seedbed stage is not necessary is maize, which is planted directly in the chinampa.

The *chinamperos* report that they usually harvest seven different kinds of crop a year from each plot, of which two are maize. Crops raised today at Xochimilco include five varieties of maize, beans, chili peppers, tomatoes and two kinds of grain amaranth—all of which were cultivated before the Spanish arrived. Also grown are vegetables introduced from Europe, such as carrots, lettuce, cabbages, radishes, beets and onions. Xochimilco means "place of the flower gardens" in the Nahuatl language spoken by the Aztecs and still used today by the older people of the chinampa towns. The growing of flowers for sale goes back to the preconquest era, when flowers were offered on the altars of the pagan gods. Native species have imaginative Nahuatl names: *cempoaxóchitl* ("twenty flower," a marigold), *oceloxóchitl* ("jaguar flower"), *cacaloxóchitl* ("crow flower"). The gardens produce dozens of varieties of dahlia, the national flower of Mexico. European flowers include carnations, roses and lilies.

Carp and other fishes abound in the canals and are netted or speared by the *chinamperos*. Another inhabitant of the canals is the axolotl, a large salamander valued by zoologists as a laboratory animal and prized by the people of Xochimilco for its tender meat and lack of hard bones. Water birds were once caught in nets but are now scarce due to the indiscriminate use of firearms.

A basic question for the archaeologist and the historian is: How old are the chinampas? The traditional histories of the peoples of central Mexico list the Xochimilcas as one of eight tribes (the Aztecs were another) that came into the valley after a migration from a legendary home in the west. They were settled at Xochimilco by A.D. 1300 and were ruled by a succession of 17 lords. In 1352 and again in 1375 they were defeated by the Aztecs; finally, in the 15th century, they were incorporated into the Aztec state, which had absorbed the rest of the chinampa zone as well.

Some recent archaeological evidence makes it appear certain that Xochimilco, and by extension the other chinampa towns, existed long before the Xochimilcas arrived. A local newspaperman and booster of Xochimilco, José Farias

SEED NURSERY, made from small squares of rich mud, is an essential element of chinampa farming. Each square, or *chapín*, holds one seed and manure for it. When seedlings sprout, they will be transplanted in the *chapines* to places on the chinampa.

SCOOPING UP MUD from the bottom of the canal, the *chinamperos* load it into their canoe. They will spread the mud on the chinampa plot before setting out the new crop.

Galindo, has been collecting fragments of ancient pottery and clay figurines found by the *chinamperos* in the mud of the canals and in the garden plots. It is evident that such signs of human residence must postdate the initial digging of the canal system; until that had been done no one could have lived in the tangled marshes. Aztec bowls, dishes and figurines of gods and goddesses abound in Farias Galindo's collection, as might be expected from the many references to Xochimilco in Aztec documents. Of particular interest is the much older material that has been found. This includes a bowl of Coyotlatelco ware made between A.D. 600 and 900, heads broken from figurines of the Teotihuacán III culture, which flourished between A.D. 200 and 600, and Teotihuacán II figurine heads, which are as old as the beginnings of the great city of Teotihuacán in the first and second centuries A.D. Therefore it is likely that the chinampas of Xochimilco were planned and built almost 2,000 years ago.

Who was responsible? The only power in central Mexico at that time capable of such an undertaking was the growing Teotihuacán state, so that whoever built Teotihuacán also created the chinampas. Another piece of information points to the same conclusion. The grid of the Xochimilco canals is not oriented to the cardinal directions but to a point 15 to 17 degrees east of true north. So are the streets of the ruined city of Teotihuacán, and so are the grids of most of the other chinampa towns. We do not know why this is, but there were probably astrological reasons. It has been said that an urban civilization as advanced and as large as Teotihuacán must have been based on irrigation agriculture, but field archaeologists can find no trace of large-scale irrigation works. It seems far more likely that the growth of Teotihuacán was directly related to the establishment and perfection of the chinampas on the southern shore of the lake. Successive peoples and powers entered the valley and took advantage of the same system.

On the eve of the Spanish conquest Xochimilco was a flourishing island town under Aztec control, with at least 25,000 inhabitants—craftsmen as well as farmers. Cortes wrote of its "many towers of their idols, built of stone and mortar." The town, which was and still is on higher and drier ground than the chinampas, was approached from the south by a causeway crossing many canals. Its numerous wooden bridges could be raised to delay the approach of enemies. At the mainland end of the causeway was a large market; this is now the center of town. Xochimilco was divided into 18 *calpullis,* each with its own name. The Aztec institution of the *calpulli* is not well understood, but it seems to have been a local ward based on kinship. Their names survive today, and every *chinampero* knows to which ward he belongs. The *calpullis* were grouped into three larger units; the town as a whole was ruled by a native lord closely related to the Aztec emperor.

Wills, petitions and other documents filed early in the colonial period show that in Xochimilco land tenure, as well as the social system, was basically the same as that in the Aztec capital of Tenochtitlán-Tlatelolco. There were three categories of chinampa lands: (1) chinampas belonging to the *calpullis,* which could be used by a *calpulli* member to support himself and his family as long as he did not leave the land uncultivated for two years in succession; (2) office land, which belonged to the position filled by a noble official but not to him personally; (3) private land, which could be disposed of as the individual saw fit.

POTTERY FIGURINES of the types found in the chinampas and canals of Xochimilco were made in Aztec times, A.D. 1367 to 1521 (*top three*), during the Teotihuacán III period, A.D. 200 to 600 (*middle four*), and in the Teotihuacán II era, A.D. 1 to 200 (*bottom*). This ancient evidence of human occupation indicates that the chinampas are 2,000 years old.

The island capital of the Aztecs was also surrounded by chinampas. The National Museum of Anthropology in Mexico City possesses a remarkable Aztec map on a large sheet of native paper made from the inner bark of a fig tree. This document, studied in recent years by Donald Robertson of Tulane University, shows a portion of the Aztec capital generally covering the section that is now buried under the railroad yards of Mexico City. In all likelihood it was drawn up as a tax record by Aztec scribes and used by bureaucrats into the period of Spanish domination. The similarity of the plan to that of modern Xochimilco is obvious. It shows a network of canals laid out in a grid, with the larger canals crossing the pattern diagonally. Roads

and footpaths parallel the major canals, which the Spaniards said were crossed by wooden bridges.

The plan depicts some 400 houses, each with the owner's head in profile and his name in hieroglyphs. The Spanish later added Spanish transliterations of the names and also drawings of churches and other colonial structures. The property surrounding each house consists of six to eight chinampas. It was the cutting of canals and the construction of chinampas by the poor and hungry Aztecs who first came here in the 14th century A.D. that filled in the swampy land between the low rocky islands on which they had camped. The work eventually resulted in the coalescence and enlargement of the islands into the marvelous capital city that so impressed the conquistadores.

The more substantial houses of stone and mortar occupied the central sections of the capital, where the land was higher and firmer. In the very center were such large public buildings as the pyramid temples and the palaces of the emperor and his chief nobles. The bulk of the population was nonagricultural, consisting of priests, politicians, craftsmen, traders and soldiers. Nevertheless, Tenochtitlán-Tlatelolco was a chinampa city; the Spanish described it as another Venice. Thousands of canoes laden with people and produce daily plied the hundreds of canals, which were bright green with water vegetation. An Aztec poet has described the beauty of his native home:

The city is spread out in circles of jade,
Radiating flashes of light like quetzal plumes.
Beside it the lords are borne in boats:
Over them spreads a flowery mist.

The real basis of the native economy in the Valley of Mexico was the chinampa zone, which extended all the way from Tenochtitlán-Tlatelolco south to the shore of Lake Xochimilco and then east into Lake Chalco. The rest of the land in the valley, although it produced crops, was far less favorable to farming because of the arid climate. The chinampas, however, presented two difficult problems apart from those involved in their cultivation and day-to-day maintenance. One problem was to keep the water level high, the other was the prevention of floods.

The valley had no external outlet. Year after year over the millenniums nitrous salts had been swept down into

RUINS OF TEOTIHUACÁN, the large city that dominated much of Mexico from about A.D. 100 to 600, are still among the most impressive in Mexico. The rise of this great urban center may have been made possible by the development of the chinampas to the south.

the Lake of the Moon by the summer rains and had been concentrated by evaporation in the eastern part of Lake Texcoco. It was essential to keep the deadly salts away from the chinampas. For this reason the chinampas could only function properly if they were fed constantly by freshwater springs, which maintained the water level and held back the salt water. Such springs are found today in greatest abundance south of Lake Xochimilco, where chinampa towns still exist. Long ago there were adequate springs on the island of Tenochtitlán-Tlatelolco, but the rapid growth of the Aztec capital and its associated chinampas made the springs inadequate. The problem was solved by the construction of aqueducts to bring fresh water from mainland springs. It has sometimes been assumed that the sole purpose of the aqueducts was to carry drinking water to the inhabitants of the capital, but, as the ethnohistorian Angel Palerm of the Pan American Union has noted, their thirst must have been incredible.

These covered masonry watercourses were no mean structures. The first was completed in the reign of Montezuma I (1440–1468); it brought water over a causeway from the west into the city from a large spring at the foot of Chapultepec hill. Cortes wrote that the flow was "as thick as a man's body." A second aqueduct was built by the emperor Ahuítzotl (1486–1502). For this aqueduct a spring at Coyoacán, on a point of land separating Lakes Texcoco and Xochimilco, was enlarged; the aqueduct ran along the causeway that led north to Tenochtitlán-Tlatelolco. Ahuítzotl's effort was initially crowned with disaster: the volume of water was so great that violent floods resulted. The flow of the spring diminished, it was recorded by pious Aztec chroniclers, only when the emperor sacrificed some high officials and had their hearts thrown into it, along with various valuable objects.

The second major problem of the chinampas—periodic flooding by salty water—was also finally solved by construction works. The nitrous salts, which had already made the waters of the eastern part of Lake Texcoco unsuitable for chinampas, rose and moved into the chinampa zone during the summer rains, in spite of the flow from the springs. The problem apparently became acute only in the Aztec period, when, according to the pollen chronology worked out by Paul B. Sears of Yale University, the climate of the region seems to have been wetter than at any time since the end of the last ice age. The floods nearly destroyed the entire economy of the Valley of Mexico. In the 15th century Nezahualcóyotl, the poet-king of Texcoco, supervised for his relative Montezuma I the construction of an enormous dike of stones and earth enclosed by stockades interlaced with branches. The dike, on which 20,000 men from most of the towns of the valley labored, extended 10 miles across the Lake of the Moon from Atzacoalco on the north to Ixtapalapa on the south. It sealed off the Aztec capital and the other chinampa towns from the rest of Lake Texcoco, leaving them in a freshwater lagoon. The three stone causeways connecting the capital with the mainland were pierced in several places and floodgates were installed to provide partial control of the water level in the lagoon.

The entire chinampa zone, then, represented a gigantic hydraulic scheme based on land drainage and the manipulation of water resources. The Aztecs refined and exploited it to establish a vast empire for the glory of their gods and the profit of their rulers. Defeated peoples were quickly organized as tributaries under the watchful eye of a local Aztec garrison and military governor. Twice a year they had to render a huge tribute to Tenochtitlán-Tlatelolco. The Aztec tribute list records that every year the capital received 7,000 tons of maize, 4,000 tons of beans and other foods in like quantity, as well as two million cotton cloaks and large amounts of more precious materials such as gold, amber and quetzal feathers. In fact, in supporting the dense population of the capital, variously estimated at 100,000 to 700,000 (the latter figure is highly unlikely), tribute greatly outstripped local production in importance.

It would probably be no exaggeration to say that the chinampas gave the ancient peoples of the Valley of Mexico intermittent sway over most of the country for 1,500 years before the arrival of the Spaniards. For this reason a detailed study of all aspects of this unique system as it now operates should be made before the chinampas disappear altogether in the name of progress.

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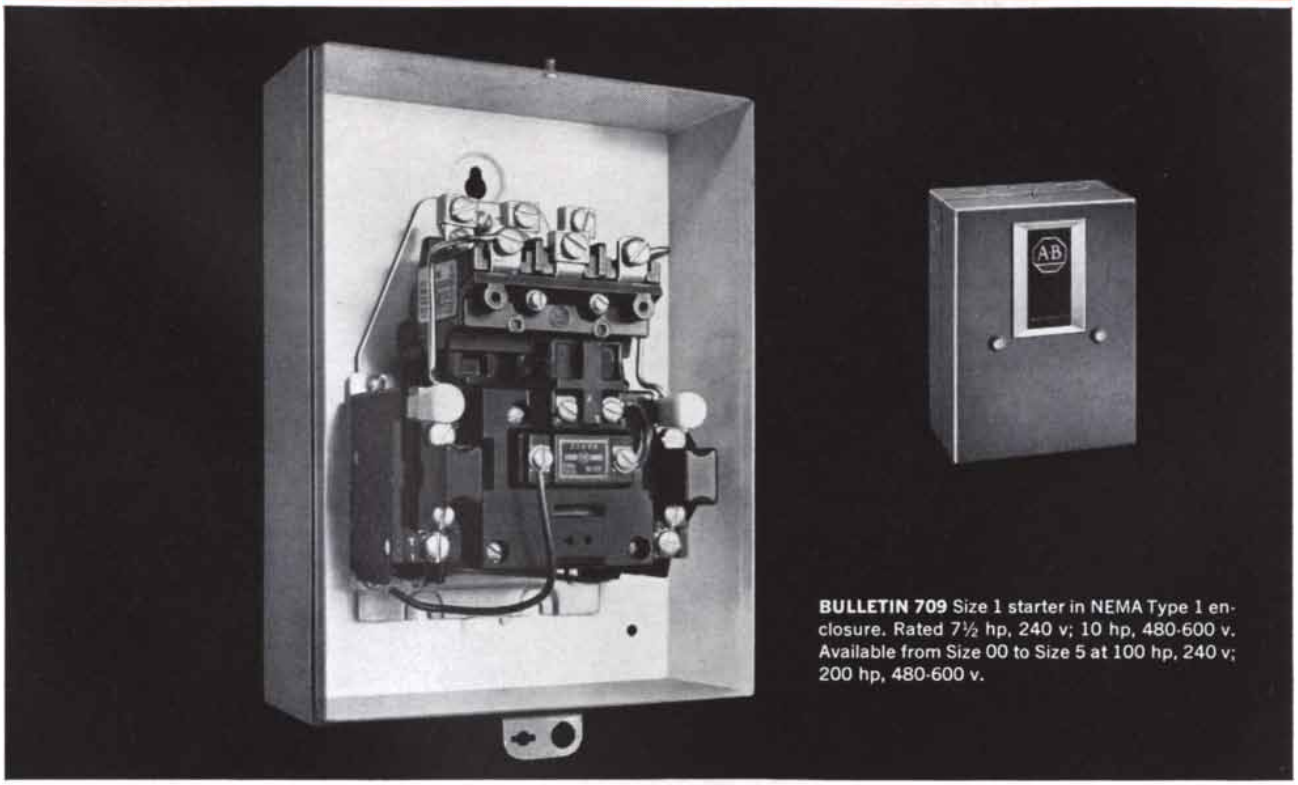

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Computer Experiments in Chemistry

By simulating the motions of atoms and molecules during a chemical reaction a powerful computer at Los Alamos has provided insight into chemical problems that cannot be achieved by laboratory experiments

by Don L. Bunker

Ever since the arrival of quantum mechanics in the 1920's it has been known that chemistry is a closed science: in principle all chemical phenomena can be deduced from the laws of quantum physics. In practice, however, most chemical problems are too difficult to be solved by the straightforward application of physical equations. That is why chemistry, although it is closed, is far from terminated. The challenge remains of explaining an enormous variety of molecular properties; they are ultimately rooted in physics, but in such complicated ways as to defy understanding. The task of understanding them nevertheless absorbs the energy and ingenuity of the contemporary chemist.

With the rapid evolution of electronic digital computers it was natural to ask if they could provide mathematical solutions to problems in chemistry that had previously been intractable. Before the advent of the computer relatively few molecular properties could be deduced directly from physical law. They were mostly properties whose definition implies the absence of atomic motions; an example of such a property is the length of the chemical bond between two atoms at rest. When atomic motions are put into the equations, even in such an uncomplicated case as the transformation of one species of molecule into another in the gaseous state, the difficulty of the problem increases enormously. For describing a simple reaction in a gas the equations of classical, or Newtonian, mechanics are almost as useful as those of quantum mechanics. But even the traditional description had to be severely curtailed if useful conclusions were to be reached.

The electronic computer has greatly simplified the calculation of the static properties of molecules, and it has brought some of the dynamic processes within range of detailed mathematical investigation. When it is used to study dynamic processes, the computer assumes a role of particular significance. In the field of chemistry known as gas kinetics there has been a long collaboration between the experimental chemist, working in the laboratory, and the theoretician, working with "models," or hypothetical molecular systems. As a result some of our knowledge of rates and other dynamic properties of chemical reactions in gases comes from experiment and some of it from the theoretical analysis of simplified systems. Because gas kinetics overlaps a line of demarcation between experiment and theory it is unusually susceptible to clarification by computer studies. The computer is employed not merely as a high-speed adding machine but as an experimental tool in itself.

A computational experiment might involve solving the physical equations for a particular theoretical model, to determine if its detailed properties really conform to what chemists have always assumed. Or one might wish to simulate an imaginary experiment that cannot be carried out in the laboratory but that would be very informative if it could be. These are only two of the most obvious possibilities; several others exist.

At first the simulation of gas reactions in order to learn something about them seems to present staggering difficulties. Any reaction worthy of attention involves at least three atoms, and they are not at rest. They can have a variety of relative positions and velocities. If some of them are combined into a molecule, the molecule may vibrate and rotate. To scan all the possible combinations of atomic positions and motions, calculating and later averaging some characteristic of the reaction, is impossible even for a modern computer. The complexity of this task can be sidestepped only by the use of "Monte Carlo" methods.

A commonplace Monte Carlo procedure, which has much in common with the Monte Carlo procedure applied to molecules, is the public opinion poll. Suppose one wishes to know who will next be elected president, and by what margin. An exact answer can be obtained only by holding an election. But perhaps an approximate prediction, good within some probable tolerance, is acceptable. If so, it can be secured by sampling the intentions of a comparatively small number of voters. It is necessary to ensure that this sample is not too small for the desired tolerance. It is also important that the voters be chosen by a strictly random method, so that they represent the electorate in an unbiased way.

By the same token one avoids the necessity of considering all the possible configurations of molecules by the stratagem of choosing representative configurations at random. One then tries to study enough configurations to make their behavior evident. It is clear that an element of luck is involved; hence the name Monte Carlo. Even if the sample is strictly random, inevitable fluctuations can conspire to produce a nonrepresentative result. In an actual chemical experiment so many billions of molecules are involved that a representative result is effectively guaranteed. When the same reaction is simulated in a computer, the numbers of "molecules" involved are so few that there is always a chance that an unusually large fluctuation will lead to a false conclusion or obscure a real one. The results must therefore be inter-

preted with circumspection. In this article I shall describe two applications of the Monte Carlo technique to problems of gas kinetics.

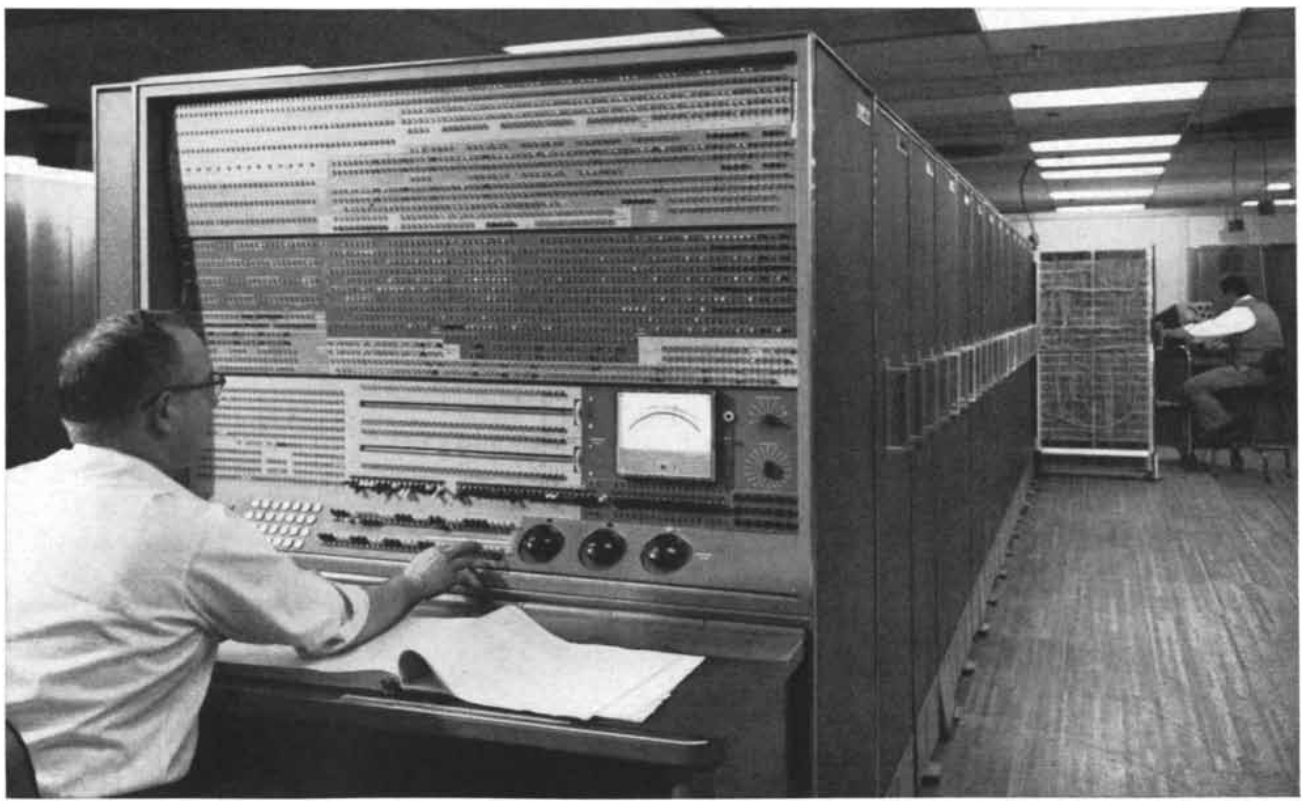
The first problem involves the reaction between two chemical substances, an event in which energy is often released. The simplest such reaction can be symbolized $A + BC \rightarrow AB + C +$ energy. A, B and C represent three atoms; B and C can be of the same species, but A must differ from C. The energy released by the reaction can appear in one of two forms or in both. It can appear as kinetic energy, represented by the velocity added to the products as they leave the site of the reaction, or as internal energy, embodied in the rotation and vibration of AB. The exact way the total energy is divided has long been of interest to kineticists. They suspect that knowledge of the division would provide information about the interatomic forces involved in the reaction. These forces are not well understood, and their theoretical calculation is extremely difficult.

The partition of the energy released in simple chemical reactions can be experimentally studied in several ways [*see illustrations on next two pages*]. In the flash-spectroscopy method, pioneered by R. G. W. Norrish of the University of Cambridge, the molecules in a reaction chamber are subjected to two closely spaced flashes of light. The first flash decomposes some of the molecules into their constituent atoms. A few microseconds later a less intense flash is set off. In the meantime some of the atoms released by the first flash have reacted with molecules to give rise to molecular products. The light of the second flash passes through the chamber and is recorded in a spectrogram. The relative amounts of light absorbed at various wavelengths provide information about the vibrational states of the reaction products.

An alternative experimental method is to inject atoms into a rapidly moving stream of gas and observe the vibrational and rotational states of the products downstream. Still another technique is represented in a remarkable series of experiments started at the University of California at Berkeley and continued at Harvard University by Dudley R. Herschbach and his coworkers. In this technique a beam of atoms in a vacuum crosses a beam of molecules. Movable detectors establish the directions taken by the reaction products and how the energy of the reaction is apportioned.

The evidence gained from these various experiments has been contradictory and hard to interpret. Sometimes much energy appears as vibration and rotation of the product molecules; sometimes little energy appears. Attempts to predict the amount of internal energy from the properties of the reacting molecules have not been very successful.

At the Los Alamos Scientific Laboratory we decided in 1962 to try to compute some order into this somewhat chaotic situation. My co-worker in this phase of the project has been Normand C. Blais. The project was made feasible by the installation at Los Alamos of a remarkable digital computer called Stretch, built by the International Business Machines Corporation. At the time of its installation in 1961 Stretch was probably the most powerful computer in existence. Its high speed and, equally important, the large number of decimal places it can use in its operations have enabled us to examine many hypothetical reactions. In the array of such reactions provided by nature there are large gaps in which no



"STRETCH" COMPUTER was used at the Los Alamos Scientific Laboratory to perform the experiments in chemical kinetics described in this article. The main arithmetic unit, shown here, contains 20 racks of electronic gear in which there are about a quarter of a million transistors. At the time of its delivery in 1961 Stretch was probably the most powerful computer in existence. To solve the complex problems posed by the author and his colleagues it had to solve the Newtonian equations of motion 150 million times.

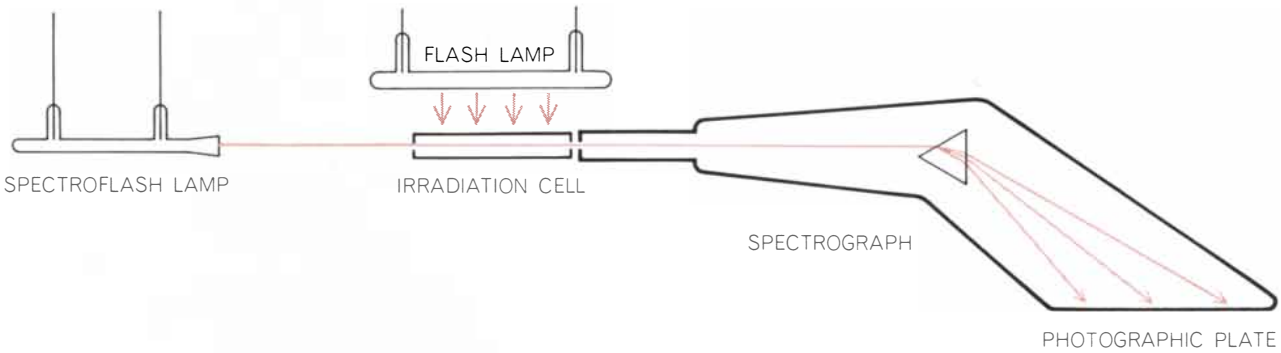
examples occur, so that it is often difficult to see what factors would determine the behavior of the missing reactions. We hoped that by filling in these gaps with imaginary reactions we might gain a comprehensive viewpoint from which generalizations could be made.

Here, briefly, are some of the factors involved in computing how energy is distributed when *A* and *BC* react to produce *AB* and *C*. In an individual reaction event there are several variables. Among them are the approach velocity of *A* and *BC*, the amount of vibrational energy contained in *BC*, the amount of rotational energy in *BC* and the distance by which *A* and *BC* would miss each other if they did not interact and continued in their initial directions. For each of these variables there is a naturally occurring distribution that is biased in one way or another [*see illustration at top of pages 104 and 105*].

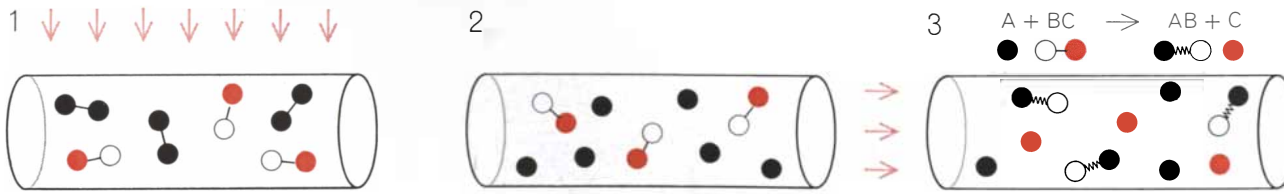
For the computer to simulate a single reaction event it must randomly select values for each of these four major variables according to their biased distribution. This is a moderately complex problem, but it can be solved by a two-step random process. Suppose we want the computer to select a value for the approach velocity of *A*. First it selects a value according to a list of random numbers (generated by the computer itself). Since all the values are not equally probable in reality, the computer uses the value or not according to the outcome of a game of chance (also played with random numbers) in which the odds for a particular value are adjusted to agree with the real distribution. In other words, in the first step the computer would select the value 57 as often as the value 17. If in reality 57 occurs twice as often as 17, in its second step the computer would throw out enough 17's to maintain the two-to-one ratio over a large number of trials.

Once the starting conditions have been chosen in this way, the ensuing "reaction" can be followed by standard numerical methods. The equations of motion are solved approximately for very short time intervals, and the trajectories of the atoms are traced step by step. If atom *A* comes close enough to molecule *BC* for interatomic forces to take effect, reaction usually occurs; the computer then determines the energy and the angle of departure of each product. The entire procedure is then repeated until the accumulated results begin to make sense.

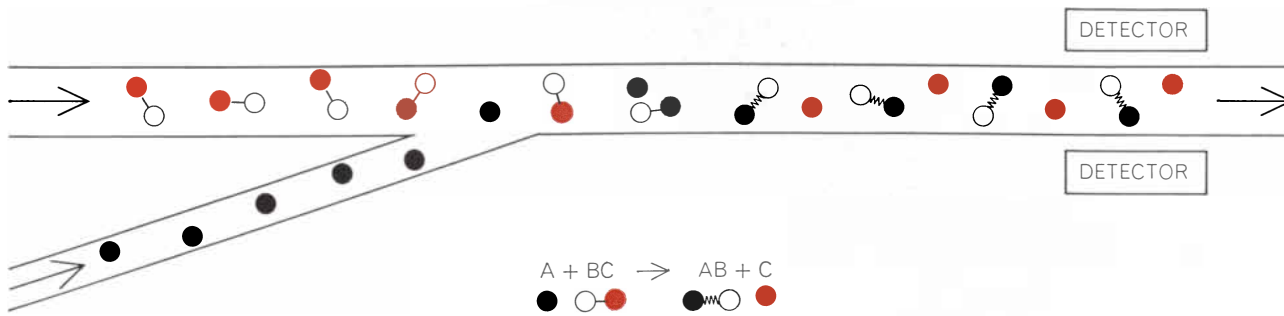
We had no assurance in advance that our results *would* make sense and that the distributions of product angle and product energy obtained in this way would resemble those of real reactions.



FLASH SPECTROSCOPY can be used to study the vibrational energy imparted to molecules by simple chemical reactions. The apparatus includes a high-intensity flash lamp to initiate the reaction and a second lamp to produce a spectrogram a few microseconds later. The amount of light absorbed at various wavelengths indicates the vibrational states of the reaction products.



SEQUENCE OF EVENTS in flash spectroscopy is schematized. An intense flash (*1*) decomposes *AA* molecules into individual atoms of *A* (*2*). These react with *BC* to produce *C* and vibrationally energized *AB*, which can be observed by a second flash (*3*).



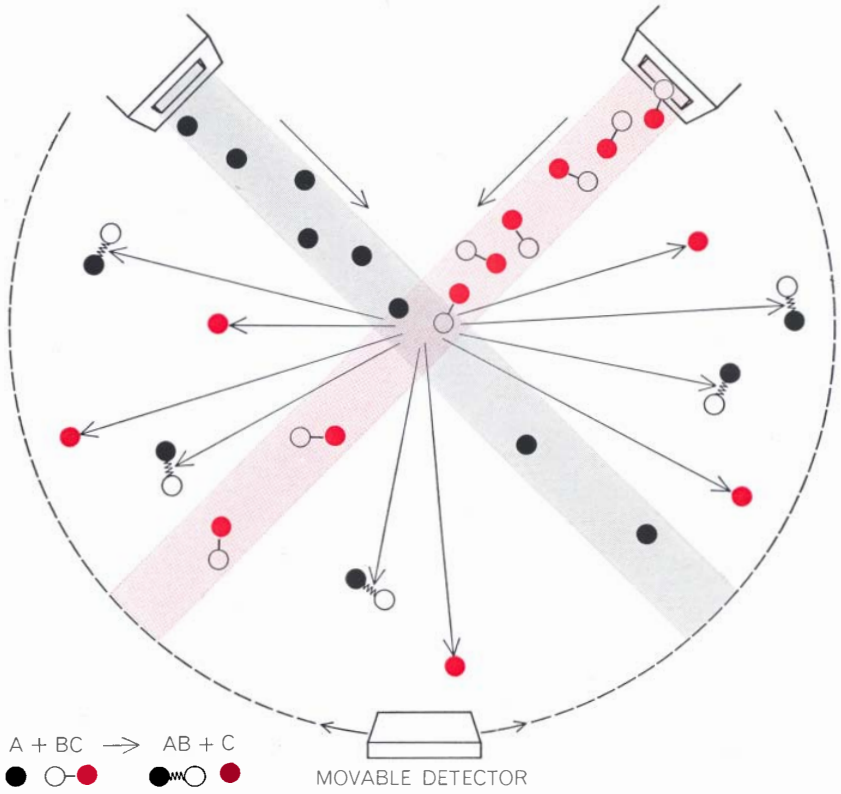
FLOW EXPERIMENT provides information about both the vibrational and the rotational states of a product molecule such as *AB*. Here a stream of *A* atoms is injected into a stream of *BC* molecules. The products are analyzed downstream from the reaction zone.

We therefore began by simulating the best laboratory experiment that had been done. Agreement between this experiment and the computed results was taken as a prerequisite for the study we ultimately wished to make.

The process we chose to imitate was the reaction of potassium (K) and methyl iodide (CH_3I), which yields potassium iodide (KI) and a methyl group (CH_3). In this reaction it is permissible to think of the methyl group as a single particle; thus the reaction is of the type $A + BC \rightarrow AB + C$. The reaction has been studied extensively by Herschbach and his associates with the molecular-beam technique. They have found that more than 80 percent of the energy released by the reaction appears in the vibration and rotation of the product KI. They have also determined the most probable recoil directions of KI and CH_3. We chose this type of experiment for simulation because both the energy disposition and the recoil direction can be computed.

In making our computer simulation the major variable we were free to select was the set of interatomic forces. The forces in an assumed set that gave agreement with the product-energy distribution, as determined by Herschbach, had the magnitude and character believed reasonable for this kind of reaction. Rather surprisingly the computed angles of recoil of the products agreed with the experimental observations regardless of what interatomic forces were assumed. In addition we gathered much information on the nature of atomic trajectories that is not accessible to experiment.

It was therefore permissible to continue. We fed into the computer an orderly array of fictitious reactions—with various combinations of atomic masses, interatomic forces and energies of reaction—and analyzed the results. Altogether we studied 50 different reactions with about 200 cases of each.



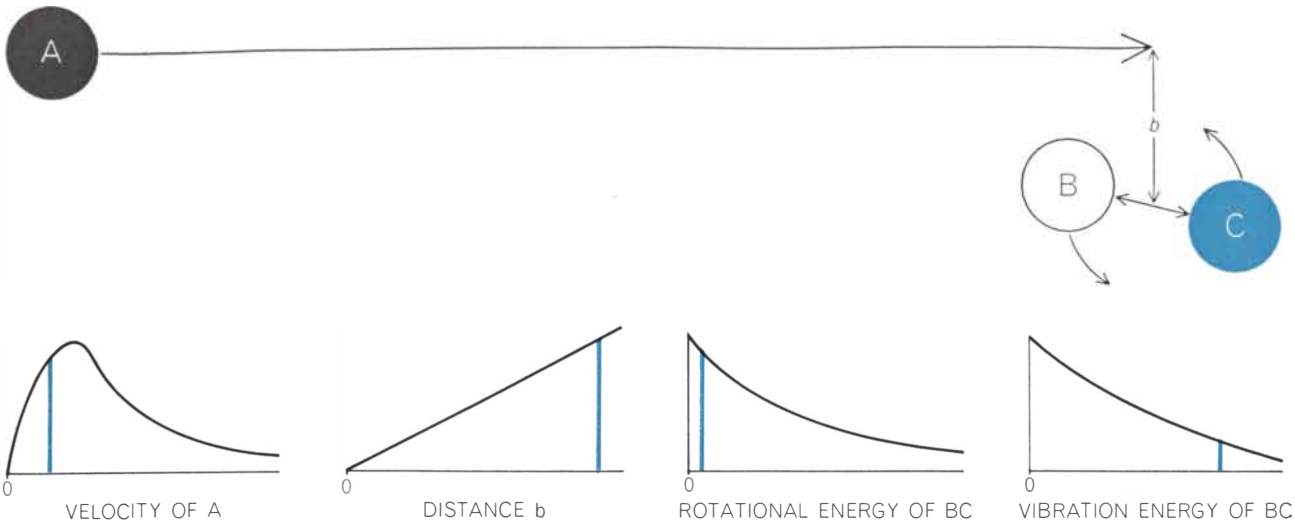
MOLECULAR-BEAM EXPERIMENT provides more information about the outcome of simple chemical reactions than can be obtained from either flash spectroscopy or the flow experiment diagramed on the opposite page. When a beam of *A* atoms collides with a beam of *BC* molecules, products *AB* and *C* emerge at various angles with various amounts of internal and kinetic energy. These angles and energies are measured with movable detectors.

At first the computed results were as confusing as the experimental ones. After a while, however, it became apparent that all the results could be grouped in three categories. The first included reactions in which the distributions of energy and product angle were strictly normal in that they resembled those experimentally determined for K and CH_3I. In the second category the energy distribution was normal but the product angle was anomalous: it was found to have a peak in a direction about 60 degrees away from the peak of the normal distribution [*see bottom illustration on next page*]. In the third category the product-angle distribution was normal but the distribution of product energy was anomalous [*see bottom illustration on page 105*].

The two kinds of product-angle distribution—normal and anomalous—can be explained on the basis of conservation laws. A molecular collision involves both energy and angular momentum, or momentum of rotation. In a chemical reaction energy and angular momentum are conserved—one is not converted into the other—but both are involved in any rotational motion the product molecule *AB* may have. The normal distribution of angles at which the products depart from the site of the reaction implies that the angular momentum is distributed in a certain way between the rotation of *AB* and that of the three atoms in the products ($AB + C$) as a group. Anomalous distributions of angle occur when these requirements cannot be simultaneously reconciled with the amount of energy available from the reaction. In these circumstances something has to give way, and since it cannot be the conservation laws it must be the form of the angle distribution. A simple pencil-and-paper calculation, involving the masses of the atoms, the temperature and the lengths of the chemical bonds in the molecules, infallibly predicts whether or not the angle distributions will be normal.

The two kinds of product-energy distribution were consistent with some long-held qualitative ideas about reaction kinetics that had been difficult to test by laboratory experimentation. It had been conjectured that the normal kind of product-energy distribution, in which molecular vibration absorbs most of the reaction energy, is associated with the kind of interatomic forces thought to be reasonable for $K + CH_3I$ and most other reactions. In such reactions the reactants are supposed to attract each other strongly and the products to repel one another weakly. The anomalous distribution of product energy had been assumed to be associated with forces of an opposite type: weak attraction of reactants and strong repulsion of products.

The Monte Carlo calculations supported the existence of these two categories, but we found that some specific exceptions must be made. The second, or abnormal, kind of force relation leads to much more unpredictable results

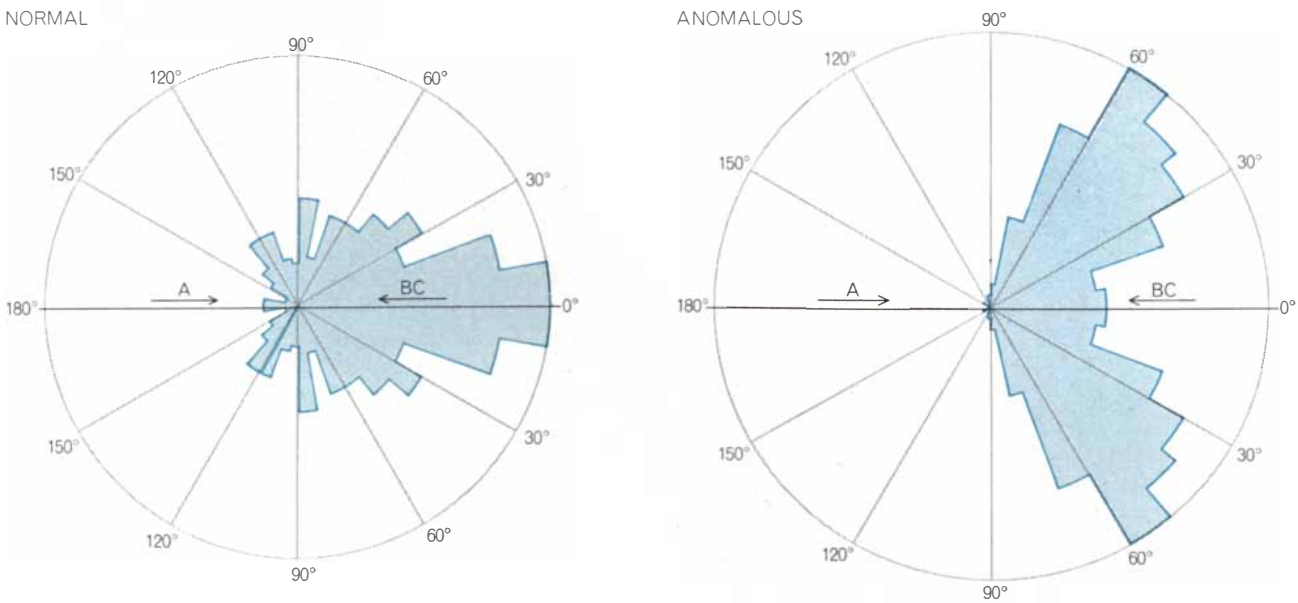


SIMPLE REACTION between atom *A* and molecule *BC* was studied with the Stretch computer. The small graphs show the natural distribution of four principal variables that influence the reaction. (Distance *b* is the distance by which *A* would miss *BC* if there were no interaction between them.) The computer's first task, using "Monte Carlo" methods, is to assign a value for each of the four variables. The colored lines indicate one randomly selected set of values. Given these values, the computer traces the motions of the reactants in a sequence of small steps until interatomic forces, programed into the computer, cause a "reaction." The positions and velocities of *A*, *B* and *C* during the reaction determine the angle at which *C* leaves the reaction (*far right*) and

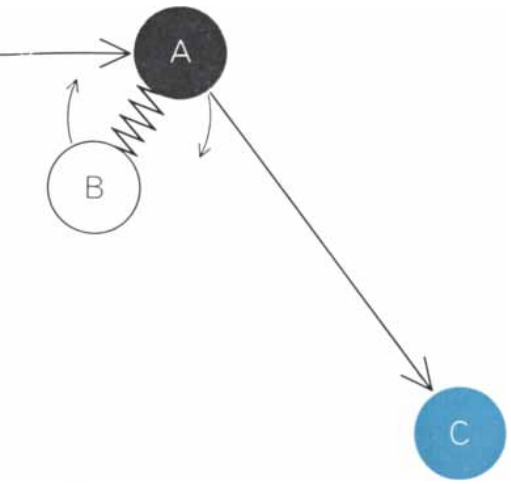
than the first. The peak of the vibration-energy distribution varies with factors (such as the amount of energy released by the reaction) to which the distribution is insensitive when the interatomic forces are of the first, or normal, type. This variation sometimes leads to a normal energy distribution when the forces themselves are abnormal. More important, in every case where the mass of *A* was much less than that of *B* or *C*, an anomalous energy distribution was obtained even though the forces were normal. This corresponds with laboratory experiments indicating that reactions involving hydrogen atoms rarely give rise to products with much vibrational energy.

In summary, it was possible (at a cost of 130 hours of computer time) to sort out and list for the first time some of the factors that determine the outcome of experiments in which *A* reacts with *BC*. Reasoning empirically from this list, one can predict what kind of energy and angle distributions to expect from a given laboratory experiment, and one can indicate what experiments might be particularly interesting. And the possibility appears on the horizon of using a combination of computer and laboratory experiments to determine what the interatomic forces actually are.

The second kind of problem we have studied with the computer concerns the rate of decomposition of single



PRODUCT-ANGLE DISTRIBUTION was computed for the reaction depicted at the top of page. Here the angle of emission of *C* is plotted with respect to the center of mass of the products; the actual emission is symmetrical about the *A-BC* axis. Normally *C* is ejected mostly forward (*left*). In a few cases the conservation laws dictate an anomalous distribution (*right*). The colored line at 120 degrees (*left*) shows the emission angle when the initial conditions are those indicated by color in the graphs at the top of the page.



the internal (vibrational and rotational) energy of *AB*. The computer repeats the reaction several hundred times to determine the distribution of the angle of emission of *C* and of the internal energy of *AB*, as shown at the bottom of these two pages.

molecules. The first kind of problem ignored the speed of reaction; it was concerned primarily with energy disposition and product trajectories. The problem of decomposition rates is a more central one in gas kinetics and has been studied intensively for more than 40 years. During this time much theoretical work based on simple models has been done. Experiments in this area are difficult, and even now there is a dearth of good experimental results. As a consequence computer studies are more useful for testing theoretical models than for extending and rationalizing the findings of the laboratory.

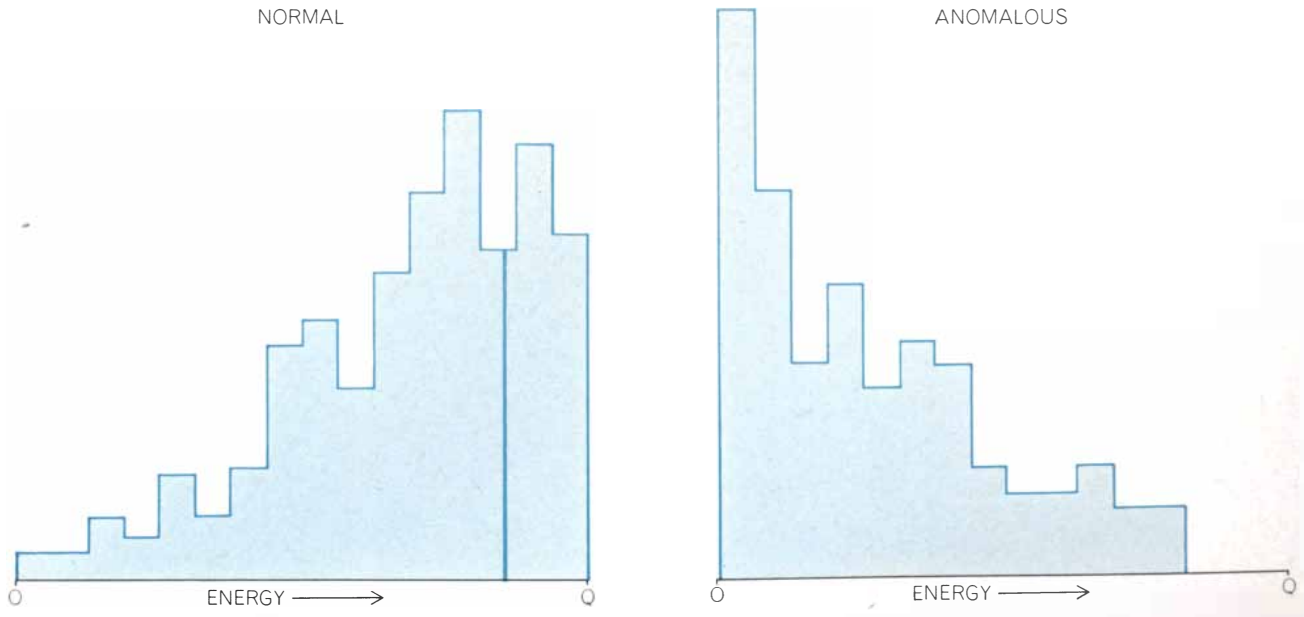
The simplest one-molecule reaction that exemplifies this reaction-rate problem again involves three atoms: $ABC + \text{energy} \rightarrow AB + C$. This kind of reaction—the fragmentation of a single molecule—is of central interest because until its rate can be explained there is little hope of quantitatively predicting the properties of the more complex multistage processes in which molecules are often involved.

Only a highly condensed sketch can be given of how the ideas of the past 40 years have led up to today's principal unanswered question in this area of gas kinetics. At the end of the 1920's it was understood, as a result of the work of Frederick A. Lindemann (later Lord Cherwell) and Cyril N. Hinshelwood in Britain and Oscar K. Rice, H. C. Ramsperger and Louis S. Kassel at the California Institute of Technology, that two overlapping processes are involved in one-molecule reactions. The *ABC* molecule must acquire enough energy to break one of its bonds and then accumulate that energy in the bond destined to break. The first step is regulated by the frequency of collision of the *ABC* molecule with other molecules in the gas. The rate of the second is dependent on the vibrational motions of the energized *ABC* molecule.

A molecule has several vibration frequencies, corresponding to various possible motions of the atoms with respect to one another. These frequencies can be determined by spectroscopy in the infrared region of the spectrum; in the 1920's this had not been extensively done, so the early theoretical models of one-molecule reactions had to be very simple. All the frequencies were given the same arbitrary value, and a general assumption was made about the migration of energy among the corresponding modes of vibration. On this basis calculations were made of the rate at which the breakable bond was energized. The overall reaction rate depended on this energization rate and the rate at which energy was supplied by collisions. The resulting theory stood almost unchanged for 20 years.

By 1950 so much information had been gathered by spectroscopists that the vibrational properties of almost every kinetically interesting molecule were known. It was time to inject this knowledge into the theory of molecular reaction rates. One of the attempts to do this is largely represented by the work of R. A. Marcus of the Polytechnic Institute of Brooklyn. His theory is an extension of the earlier one of Rice, Ramsperger and Kassel; the combined theory is often referred to by the initials RRKM. An alternative theory has been developed by the mathematician N. B. Slater of the University of Hull.

The Slater theory includes both an



INTERNAL ENERGY DISTRIBUTION is shown for the product molecule *AB*. Internal energy includes both vibrational and rotational energy. *Q* is the total energy available; if it exceeds the internal energy, the excess appears as kinetic energy in the separation of *AB* and *C*. Normally (*left*) most of the total energy appears as internal energy. (The heavy colored line is the energy when the initial conditions are those previously depicted in color.) Under certain conditions the energy distribution is anomalous (*right*).

improved mathematical formulation of the interaction of collisions and vibrational motion and a specific recommendation for taking the known vibrational properties of molecules into account. Nowadays it is doubtful on various grounds whether the second of these features can be maintained. The first, however, led Slater to notice and vigorously point out an untested assumption present in all theories of one-molecule reactions.

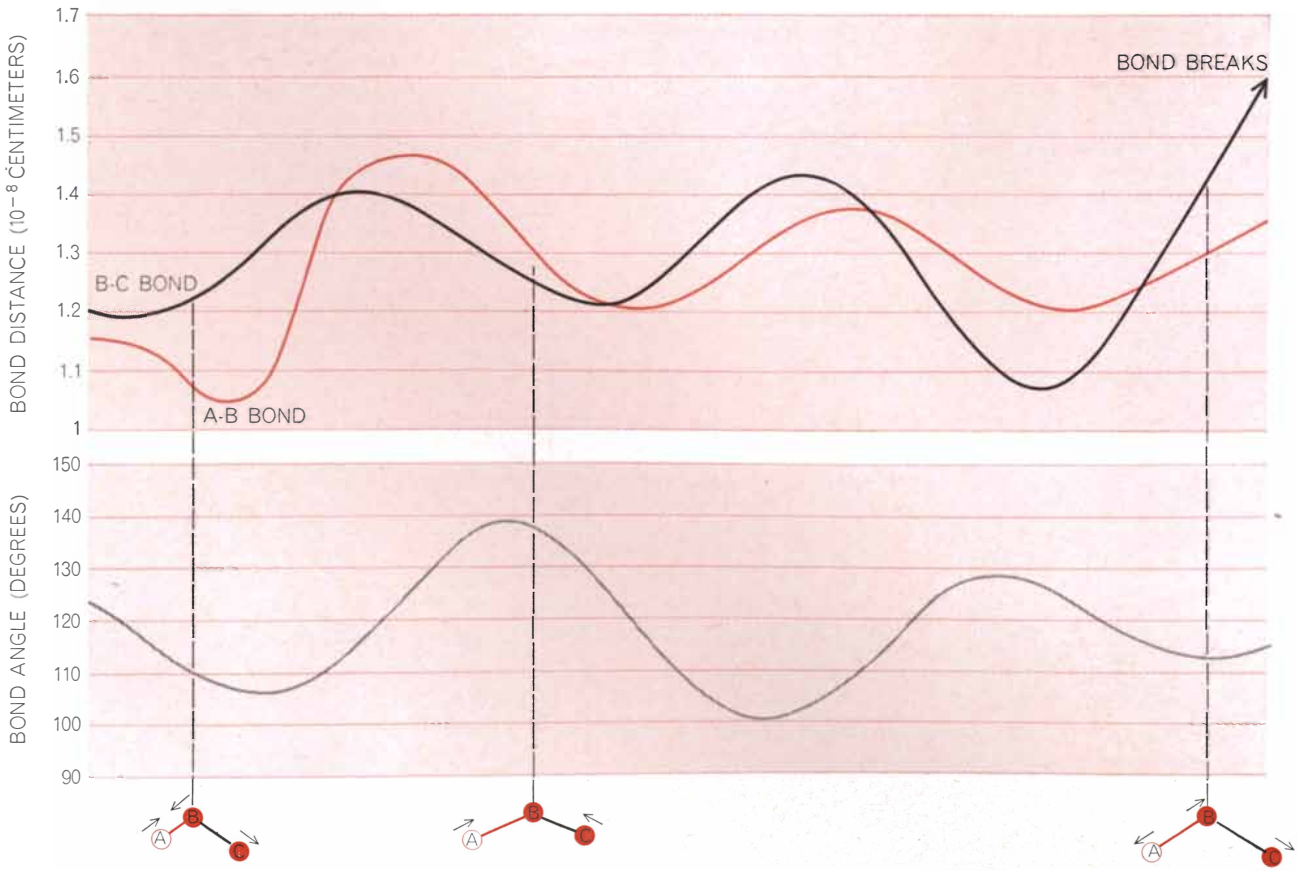
The assumption that came to Slater's attention can be explained as follows. Consider two molecules with the same energy (enough for each of them to break apart) but with different internal atomic velocities and positions. Is there any way to tell from these velocities and positions which molecule will break apart first? Slater correctly observed that up to that time everyone had implicitly assumed there was not. This assumption is called the random-lifetime assumption. If the random-lifetime assumption is untrue, then the RRKM theory is also untrue.

Since no one had succeeded in conclusively testing this assumption by direct experimentation, we decided to determine if it could be tested with the computer. Several computer studies bearing indirectly on the question had already been made. The first computer analysis of the trajectories of atoms during any kind of reaction had been published in 1958 by F. T. Wall, L. A. Hiller, Jr., and Jacob Mazur of the University of Illinois. Similar investigations, specifically concerned with one-molecule reactions, were undertaken in several laboratories. The first results, obtained by Everett Thiele and David J. Wilson of the University of Rochester, appeared in 1961.

Much was learned from these studies. They illuminated the nature of molecular motion and they confirmed a growing suspicion among experimenters that the RRKM method of dealing with molecular vibrations was preferable to the Slater method. Because these studies dealt with isolated reaction events, however, they gave no indication of whether or not the random-lifetime assumption was tenable. Only Monte Carlo calculations of the distribution of molecular lifetimes could do that.

At Los Alamos we considered this problem to be so important that we began planning our attack on it in early 1960, a full year before the Stretch computer was delivered to us. The problem was easy to state. The computer must select representative three-atom molecules, follow their internal motions by the solution of the Newtonian equations and determine how much time elapsed before the molecules came apart. Exchange of energy by collision would not be considered, since only one molecule at a time could be studied. Each molecule would be assumed to contain enough vibrational energy to break apart if most of the energy were concentrated in one of its two bonds.

In contrast to the first problem described in this article, we could assign interatomic forces with considerable certainty because only a single molecule was involved. The compensating disadvantage is that very few randomly chosen molecules come apart in the length of time that it is practical to follow their behavior even with a high-



FRAGMENTATION OF A MOLECULE has also been studied with the Stretch computer. The problem is to compute the lifetime of a three-atom molecule, *ABC*, that has acquired enough energy to break one of its interatomic bonds. Initially the total energy is divided between the two bonds in a manner insufficient to break either. The top pair of curves indicates how the energy redistributes itself between the two bonds; the bottom curve shows the concurrent change in bond angle. Eventually enough energy accumulates in one of the bonds (here *B-C*) to break it. The curves are based on one of some 30,000 reaction events computed by Stretch.

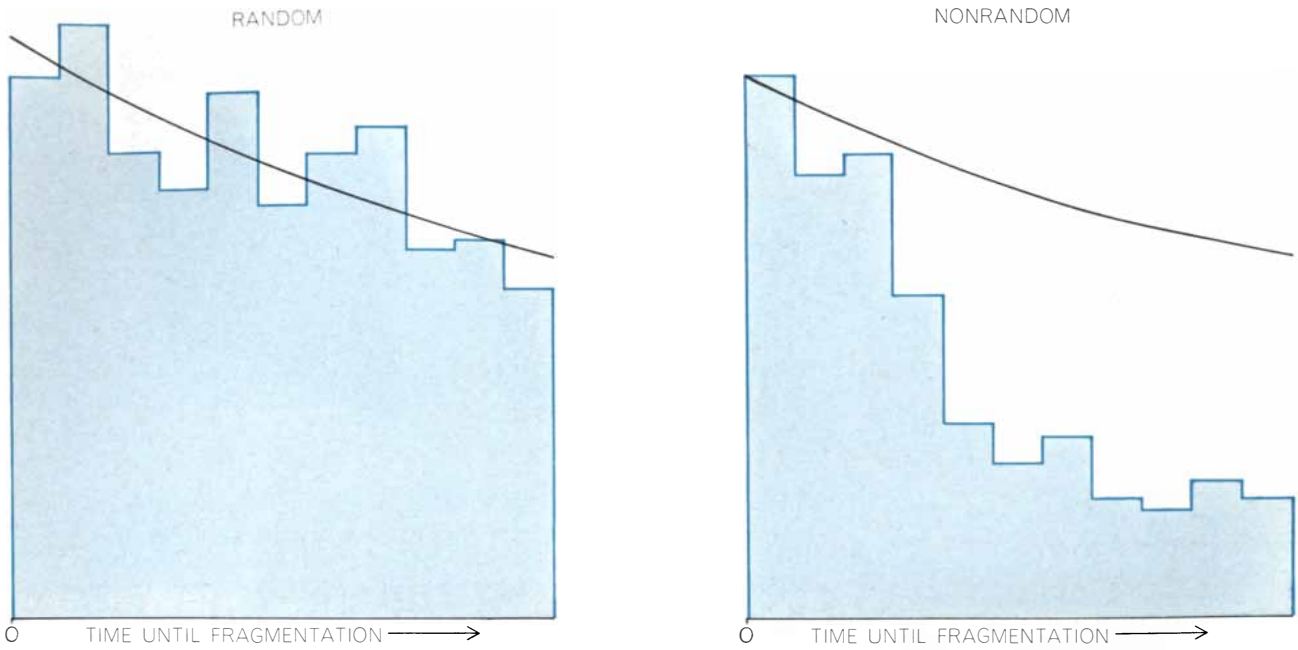
speed computer. This means that an enormous number of molecules have to be considered. Selection of the representative molecules is also much more difficult than in the first example. The probabilities of initial atomic positions and velocities all depend on one another, so that the game of chance involved in their selection has to be played in a geometry of many dimensions. This gave us some trepidation about our ability to solve the overall problem. By the time Stretch arrived, however, we had evolved a method of finding representative molecules in a time no longer than that required for computing their subsequent motion.

In the course of the next two years 200 hours of computer time were expended on calculating how long it takes energized three-atom molecules to break apart. The resulting distributions of lifetimes for various model molecules comprise 30,000 reaction events, but there were 10 times that number of trajectories that did not lead to reaction. To trace out all these trajectories in a sequence of small steps the equations of motion had to be solved 100 million times. Our procedure for the selection of starting conditions consumed more than 100 billion random digits, all of which had to be manufactured by Stretch.

This effort led to some pleasant results, although at first they seemed disastrous. The random-lifetime assumption was confirmed for a large number of hypothetical molecules. But there was a group of molecular models that persistently refused to conform to it. Randomness can be deduced from the distribution of lifetimes. If the distribution curve declines exponentially, the lifetime is random; otherwise it is not [*see illustration on next page*].

The conditions that lead to nonrandom lifetimes baffled us at first, but it was clear that at least one sufficient condition is the occurrence of vibrations that differ greatly in frequency. This was a disturbing observation, since it implicated the hydrocarbon molecules with which much of the laboratory experimentation has been concerned. If their lifetimes were actually nonrandom, much work on the interpretation of their reaction rates in terms of the RRKM theory would be invalidated.

Having characterized the lifetime distributions as well as we could, and verified that the RRKM theory is numerically accurate whenever the random-lifetime assumption is true, we were in a position to reconsider the theory



LIFETIMES OF ENERGIZED MOLECULES exhibit two different distribution patterns, as shown by computer studies. When a three-atom molecule is supplied with enough energy to break one of its bonds, the elapsed time before the molecule breaks up usually follows a random distribution (*left*). In this case the distribution follows a descending exponential curve, characteristic of the decay of radioactive atoms. Under certain conditions, clarified by the computer studies, the lifetime distribution is nonrandom (*right*).

of one-molecule reaction rates. In a short time we found it was possible to devise a theoretical model that predicts whether or not a particular molecule will have a random-lifetime distribution. Why was this not done years before? The reason is that a variety of plausible models are possible, and until the Monte Carlo results were available a choice could not be made among them. We could not apply such a theoretical treatment to real molecules until we could demonstrate that it explained the computed results.

Our conclusions about real molecules are simple to state. Departure from the random-lifetime approximation is not general. Badly behaved lifetime distributions will occur for only a few molecules, and then only under very special experimental conditions. No experiment in which they would be expected has ever been carried out. We can therefore endorse the RRKM theory without reservation for all reactions to which it has so far been applied. On the other hand, it is possible to create in the laboratory the conditions for which the RRKM theory fails, so we can also suggest some experiments that should have novel results.

These two studies have been described in some detail to illustrate the variety of ways computational experiments may interact with, and draw together, theory and laboratory experiment. In our work they have elicited details that, in laboratory chemical processes, are averaged into inaccessibility because of the large number of molecules present. They have been used to introduce organization into a set of experimental observations, so that the combined results can be subjected to theoretical speculation or used to predict the outcome of other experiments. They have suggested many experiments whose special interest might not otherwise have occurred to anyone. We have been able to test theoretical models of chemical processes, leaving some of them in a better state of justification than before. New theoretical work has been suggested by the calculations and the means of verifying its accuracy has been provided. No doubt many other possibilities exist. Certainly many other problems of chemistry are susceptible to this still rather unfamiliar kind of attack.

An interesting aspect of these computational experiments, apart from their versatility, is the way in which they unexpectedly inject a human element back into an experimental science that is becoming largely one of instrumentation. To anyone familiar with the way a computer problem is most often solved this may seem a preposterous statement. The usual procedure is to formulate the problem in an artificial language, which is then translated into a program by the machine itself, after which the machine solves the problem automatically in the absence of the formulator.

Computational experiments, however, cannot be conducted in this manner. The complexity of this kind of scientific problem always exceeds the ability of the computer to solve it. Any failure to use the computer at maximum efficiency is therefore directly reflected in the quality of the answers. For this reason it is necessary to operate the computer under the direct and continuous supervision of someone who is familiar with both the physical process being simulated and the details of the computer program (which means that artificial programing languages are ruled out). Any unusual or unexpected result—and there are a great many in any research problem—has to be detected promptly, translated into physics and used as the basis for a spot revision of the strategy of the calculation. The success of this process depends heavily on the intuition and tactical skill of the operator. In our case, even though correct decisions were not invariably taken, hundreds of hours of computing time were saved by this kind of man-machine interaction. Without it many of our results would have been out of reach.

Computational experiments, then, furnish a useful and also an entertaining method of arriving at new physical insights. They have already demonstrated that they can supplement laboratory experiment and theory, and eventually they may equal them in importance.

ELECTRO-OPTICAL COLOR DETECTIVE. One problem in perfecting the manufacture of advanced communications equipment is that many operations require visual observation beyond human limits. To find the solution, Western Electric, the manufacturing and supply unit of the Bell Telephone System, has been exploiting the science of electro-optics, which simulates functions of the human eye. Electro-optical devices—combining a light source, an optical system, a photoelectric sensor, and an electronic logic with a mechanical control system—can already do extremely delicate positioning, monitoring, and selecting operations. For example, one such device (see photo) uses a system of filters and a twin-plate photo-emissive cell to automatically select two conductors out of a group of six, purely by the colors of their insulations. Another way Western Electric engineers are helping Bell telephone companies give America the very best in communications service. **WESTERN ELECTRIC**

MATHEMATICAL GAMES

Curious properties of a cycloid curve

by Martin Gardner

Do the tops of the tires on a moving car go faster than the bottoms? This odd question will start as many ferocious parlor debates as the old problem about the man who walks around a tree trying to see a squirrel on the opposite side of the trunk. As he walks, the squirrel scurries around the tree, keeping its belly against the trunk so that it always faces the man but with the trunk constantly hiding it from view. When the man has circled the tree, has he also gone around the squirrel?

William James, considering this weighty metaphysical problem in the second chapter of his book *Pragmatism*, concludes that it all depends on what one means by "around." Similarly, the tire question cannot be answered without prior agreement as to precisely what all the words mean. Let us say that by "top" and "bottom" of the tire we mean those points on the tire that are at any given moment close to the top or bottom, and that by "go faster" we refer to the horizontal velocity of those points in relation to the ground. Surprising as it may seem, points near the top do move faster than points near the bottom.

This can be demonstrated by a simple experiment with a coffee can. Cover the bottom of the can with white paper. Using a dark crayon, draw about eight diameters, like the spokes of a wheel, on the circular sheet. Place the can on its side and roll it back and forth past your line of vision. Do *not* follow the can with your eyes; keep your gaze fixed on a distant object so that your eyes do not move as the can rolls by. You will find that the black spokes are visible only in the lower half of the wheel. The upper half is a gray blur. The reason is that the spokes in the upper half are actually moving past your eyes at a much faster rate than the spokes in the lower half. This was such a familiar phenomenon in horse-and-buggy days that artists often indicated the motion of wheels by showing distinct spokes only below the axles.

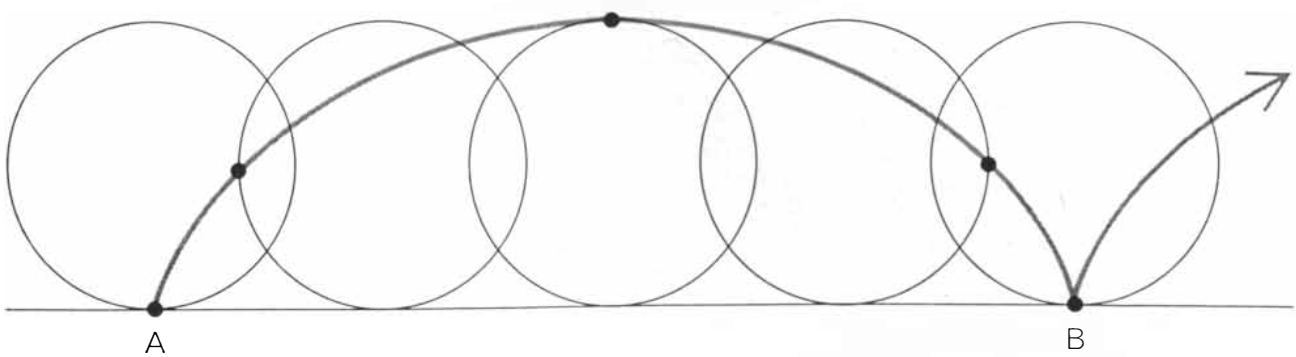
The illustration below traces the motion of a point on the circumference of a circle as it rolls without slipping along a horizontal line for a distance *AB* that is equal to the circumference of the circle. The position of the circle is shown after each quarter-turn. Assume that the circle rolls with uniform speed. It is easy to see that the point is motionless for an instant on the ground at *A*, gradually increases in speed, reaches its maximum at the highest spot and then accelerates negatively until it touches ground again at *B*. If the wheel continues to roll, the point will trace a series of arches, coming to rest for an instant at the bottom of each cusp. The velocity of the point along the curve conforms to what physicists call a simple harmonic motion. On wheels that have flanges, such as the wheels of a train, points on the flange actually move *backward* while they execute a tiny loop below the level of the track.

The generic name for a curve traced by a point on any type of curve when it rolls without slipping along any other type of curve is "roulette." In this case a circle rolls on a straight line to generate one of the simplest of roulettes, the cycloid. It has been called the "Helen of geometry," not only because of its beautiful properties but also because it has been the object of so many historic quarrels between eminent mathematicians.

No one knows who first recognized the cycloid as a curve worth studying. There is no mention of it before 1500. The first important treatise on the curve was written in 1644 by the Italian physicist Evangelista Torricelli, a student of Galileo's. Fourteen years later Blaise Pascal, who had abandoned mathematics for a life of religious contemplation, found himself suffering from a terrible toothache. To take his mind off the pain he began thinking about the cycloid. The pain stopped. Regarding this as a sign that God was not displeased with his thoughts, Pascal spent the next eight days in furious research on the curve. His remarkable results were issued first as a series of challenges to other mathematicians and then as a treatise on the cycloid.

One of the simplest questions to ask about the cycloid—although by no means the easiest to answer—is: How long is it? Assume that the generating circle has a diameter of 1. The base line *AB* will, of course, be pi, an irrational number. Everyone expected the length of the curve to be irrational also. Sir Christopher Wren, the distinguished English architect, apparently was the first to show (in 1658) that the length of the cycloidal arch, from cusp to cusp, is precisely four times the diameter of the circle.

The area below the arch had been

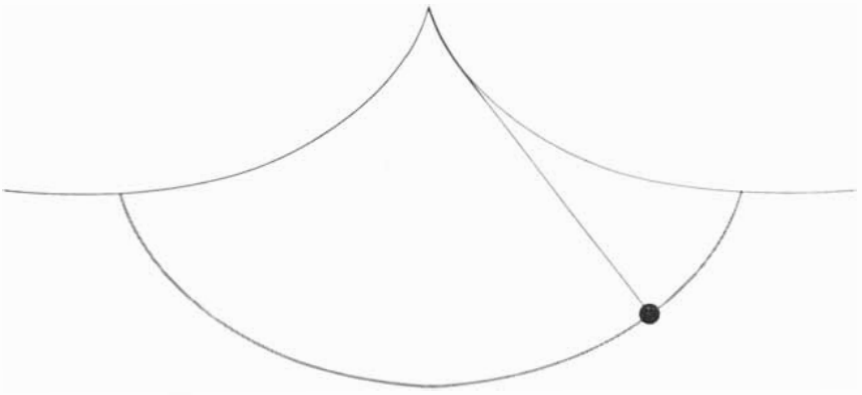


How a cycloid is generated by a point on a rolling circle

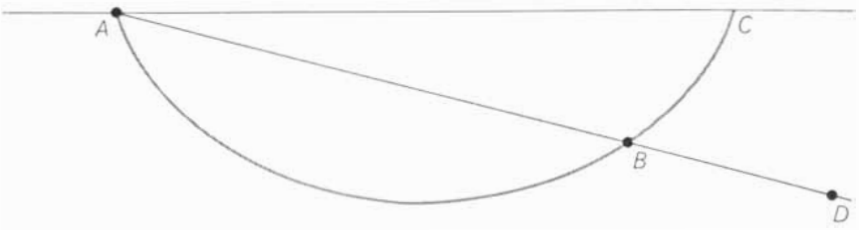
measured previously and it too had been a surprise. Galileo had guessed the area to be pi times the area of the generating circle, an estimate obtained by the direct method of cutting the arch from thin material and comparing its weight with that of the circle cut from the same material. Torricelli astounded his colleagues in Italy by proving that the area under the arch is exactly three times the area of the circle. Actually this had been shown earlier by the French mathematician Gilles Personne de Roberval, but Torricelli did not know it. In France, René Descartes insisted that the entire problem was trivial. He worked out a simpler way to find the area and challenged Roberval to construct tangents to the cycloid. This led to a long, bitter dispute between the two men. Today all these problems are solved in first-year calculus classes (where the curve is called the "student's curve" because the answers are so simple), but in the 17th century calculus was still primitive.

The mechanical properties of the cycloid are as remarkable as its geometric ones. In high school physics one learns that the time it takes a pendulum to swing back and forth is the same regardless of how wide the swing is, but this is only approximate. When the swings are wide, there are slight deviations. In what path should a pendulum swing so that its period is exactly the same regardless of amplitude? Such a curve, called an isochrone, was first discovered by the Dutch physicist Christian Huygens, who published his discovery in 1673. If we turn two cycloidal arches upside down, as shown in the top illustration at the right, and let a pendulum on a cord swing between them, the pendulum will trace what is called the involute of the cycloid. It turns out that the involute is another cycloid of the same size, and that the cycloidal pendulum is isochronal.

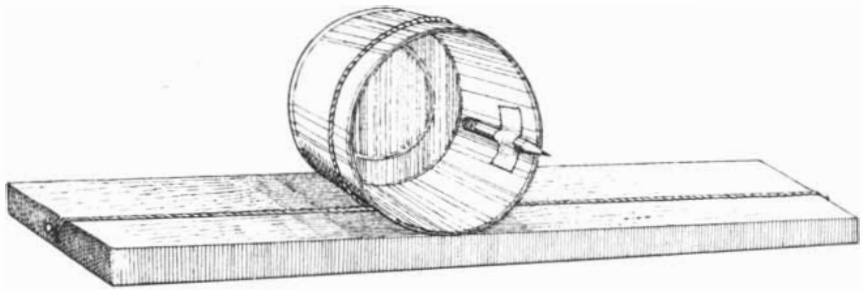
For small swings a circular arc is so nearly the same as the central portion of a cycloid that the circular pendulum is almost isochronal, but if the swings vary even a small amount, the "circular error" is cumulative. For example, if a seconds pendulum has a circular arc of two degrees, an increase to three degrees will cause it to lose about .66 second per day. Huygens constructed a pendulum clock—the first ever made—using a flexible pendulum that swung between two cycloidal cheeks. Unfortunately friction on the cheeks produced a greater error than the cycloidal path corrected; clockmakers found it more practical to arrange things so that a circular pendulum would keep a constant amplitude.



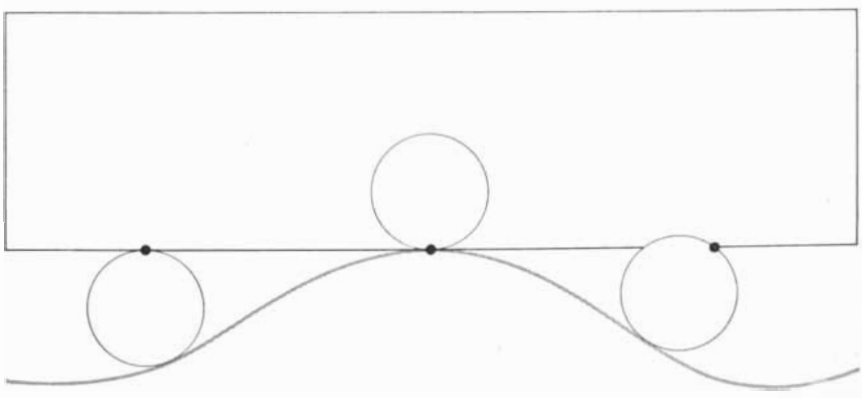
Isochronal pendulum between cycloidal cheeks traces a cycloid



Constructing the curve of quickest descent between A *and* B



Coffee-can device for drawing a cycloid

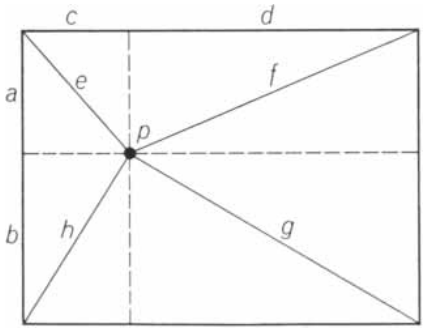


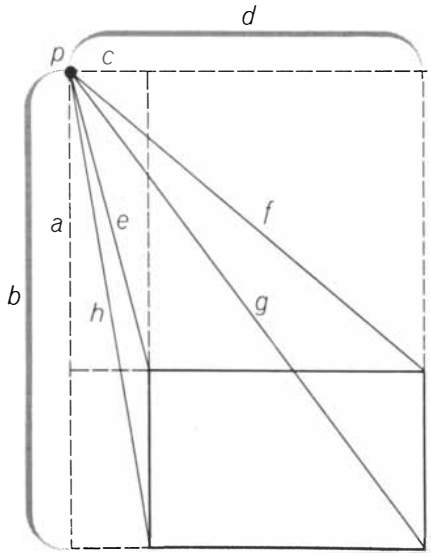
On what kind of curve will the car remain level?

It was Huygens who also discovered that the cycloid is the tautochrone, or curve of equal descent. Imagine a marble rolling without friction down an inverted cycloid. No matter where you start it on the curve, it will reach the bottom in the same length of time. Consider a bowl with sides that curve in such a way that any cross section through the center of the bowl will be a cycloid. Marbles placed at various heights on the sides of the bowl and released simultaneously will reach the center of the bowl at the same instant.

Each marble moves with a simple harmonic motion, as does the isochronal pendulum.

The brachistochrone, or curve of *quickest* descent, was not discovered for another score of years. Suppose you are given two points: *A* and *B*. *B* is lower than *A* but not directly below it. The problem is to find a curve connecting *A* and *B* such that a marble, rolling without friction, will travel from *A* to *B* in the shortest possible length of time. This problem was first posed in 1696 by Johann Bernoulli, the Swiss mathematician and physicist, in *Acta Eruditorum*, a famous scientific journal of the day. It was first solved by Johann's brother Jakob (with whom Johann was feuding), but it was also solved by Johann, Leibniz, Newton and others. Newton solved it, along with a related problem, in 12 hours. (The problem reached him at 4:00 P.M.; he had the solution by 4:00 A.M. and sent it off in the morning.) The brachistochrone turned out to be, as the reader has no doubt guessed, the cycloid. Johann Bernoulli's proof has become a classic of nonrigorous, intuitive reasoning. He found the problem equivalent to one concerning the path of a light ray refracted by transparent layers of steadily decreasing density. The interested reader will find his elegant proof clearly explained in *What Is Mathematics?* by Richard Courant and Herbert Robbins, as well as in Ernst Mach's earlier work, *Science of Mechanics*.



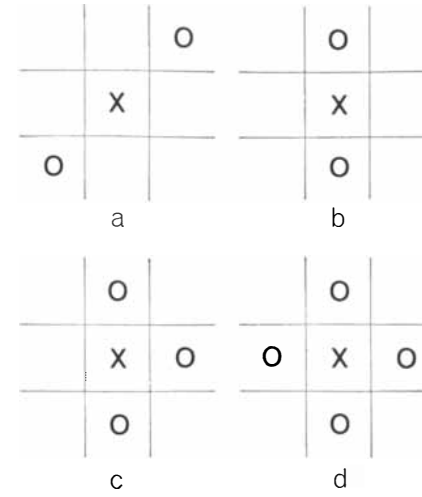


Solution to oil-well problem

Suppose we are given two points, *A* and *B* [*see second illustration from top on preceding page*], and we wish to find the brachistochrone that connects them. What we must find first is the radius of the circle that, when rolled against line *AC*, will generate a cycloid starting at *A* and passing through *B*. To do this we place a circle of any size whatever under *AC* and mark a point on its circumference at *A*. The circle is rolled along *AC* until this point crosses *AB*. Assume that it crosses at *D*. Since all cycloids have similar shapes, we know that *AD* is to *AB* as the radius of the large circle we have just used is to the radius of the smaller circle we seek. This smaller circle, rolled along *AC*, will generate a cycloid from *A* to *B*.

Note that in this case the marble actually rolls *uphill* to reach *B*. Nevertheless, it reaches *B* in a shorter time than it would by rolling along a straight line, the arc of a circle or any other curve. Even when *A* and *B* are on the same horizontal level, a frictionless marble rolls from *A* to *B* in the shortest possible time. (On a straight horizontal line, of course, it would not roll at all.)

An industrious reader should have little difficulty constructing a model for demonstrating the brachistochrone. To draw a large cycloid the coffee can mentioned earlier can be used. A piece of string looped once around it and fastened to the ends of a plank will keep the can from slipping as it rolls along the plank [*see third illustration from top on preceding page*]. A black crayon is taped to the inside of the can so that when the can is rolled along a wall the crayon will trace a cycloid on a sheet of paper fastened to the wall. Using this trace as a pattern, one can bend stiff wire into a cycloid down which a heavy nut will slide or a double cycloidal track down which a marble will roll. The track can also be formed by the cut edges of two rectangular sheets of plywood or heavy cardboard, mounted vertically, with small strips of wood glued between them to keep the edges separated just enough to carry the marble. Similar tracks should be made to carry a second marble down a circular arc and a third marble down a straight line. The three tracks are placed side by side so that the marbles can be released simultaneously by a pencil held horizontally. (Steel balls can be held by electromagnets and released by pushing a button.) If the three tracks lead into one horizontal track, three differently colored marbles will invariably enter the single track in the same order: the cycloid marble will lead, followed by the marble traveling on the circular arc and then by the one on the straight line.



The ticktacktoe problem

The cycloid has other mechanical properties of interest. It is, as Galileo guessed, the strongest possible arch for a bridge, and for this reason many concrete viaducts have cycloidal arches. Cogwheels are often cut with cycloidal sides to reduce friction by providing a rolling contact as the gears mesh.

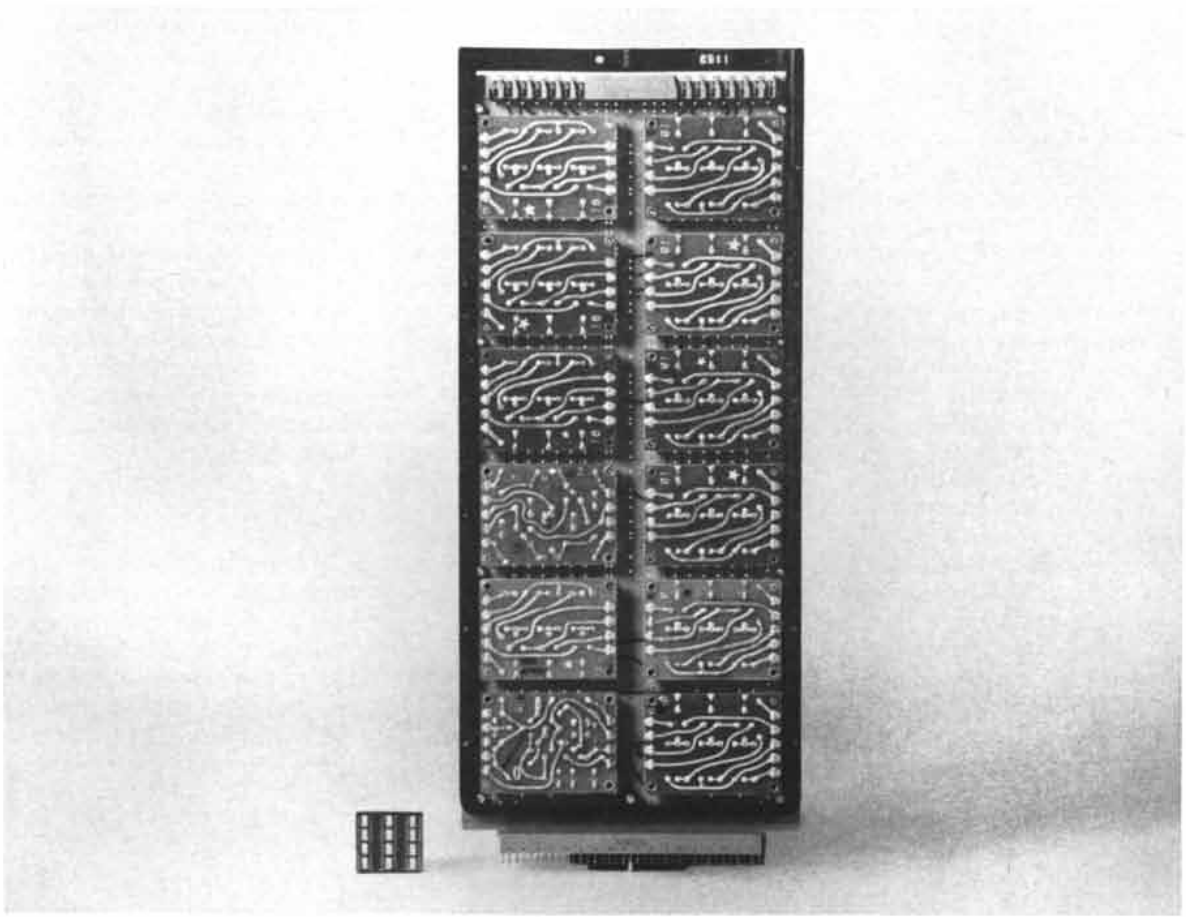
We have seen how a circle, rolled on a straight line, generates a cycloid. Stanley C. Ogilvy reverses this situation in one of his books by asking: Along what kind of curve can a circle be rolled so that a point on its circumference traces a straight line? To dramatize this question, imagine a railroad car with each wheel attached at its rim to the axle, as shown in the bottom illustration on the preceding page. How shall we curve a track so that when this curious car is rolled along the track it will remain level at all times and never bob up and down? The answer (not a cycloid!) will be given next month.

The solutions to the series of short problems presented in this department last month follow.

1.

The moon can be circled with a consumption of 23 tankfuls of fuel. See last month's circle diagram in checking out the following steps:

1. In five trips, take five containers



The small one is our '64 module.

Both these modules are from ITT military computers.

Both perform the same function.

But while the large unit is an excellent example of miniaturization, the small one exemplifies *microminiaturization*—and the packaging of microcircuits by ITT.

Many companies make microcircuits, the small and remarkably reliable electronic devices that are replacing miniaturized circuits just as transistors replaced vacuum tubes.

But the extension of microcircuit reliability to equipment or systems has been a major problem, primarily because of interconnections and heat.

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to point 90, return to base (consumes five tanks).

2. Take one container to point 85, return to point 90 (one tank).

3. Take one container to point 80, return to point 90 (one tank).

4. Take one container to point 80, return to point 85, pick up the container there and take it to point 80 (one tank).

5. Take one container to point 70, return to point 80 (one tank).

6. Return to base (one tank).

This completes all preliminary trips in the reverse direction. There is now one container at point 70, one at point 90. Ten tanks have been consumed.

7. Take one container to point 5, return to base (half a tank).

8. In four trips, take four containers to point 10, return to base (four tanks).

9. Take one container to point 10, return to point 5, pick up container there and leave it at point 10 (one tank).

10. In two trips, take two containers to point 20, return to point 10 (two tanks).

11. Take one container to point 25, return to point 20 (one tank).

12. Take one container to point 30, return to point 25, pick up container there and carry it to point 30 (one tank).

13. Proceed to point 70 (two tanks).

14. Proceed to point 90 (one tank).

15. Proceed to base (half a tank).

The car arrives at base with its tank half filled. Total fuel consumption: 23 tanks.

2.

Oil is found at an underground spot 21,000 feet from one corner of a rectangular farm, 18,000 feet from the opposite corner and 6,000 feet from a third corner. How far is it from the fourth corner?

Consider first a spot p on the surface inside the rectangle shown at the top of the illustration at the bottom left on page 112. Adding two broken coordinate lines provides a set of right triangles. Because $e^2 = a^2 + c^2$ and $g^2 = b^2 + d^2$, we can write the equality

$$e^2 + g^2 = a^2 + c^2 + b^2 + d^2 .$$

And since $f^2 = a^2 + d^2$ and $h^2 = b^2 + c^2$, we can write

$$f^2 + h^2 = a^2 + d^2 + b^2 + c^2 .$$

The right sides of both equations are the same, therefore

$$e^2 + g^2 = f^2 + h^2 .$$

Exactly the same analysis applies to the bottom diagram, in which point p is outside the rectangle. If you think of p in either diagram as belowground, this will lengthen certain sides of the right triangles involved, but the relations expressed by the equations remain unchanged. In other words, regardless of where point p is located in space—above, below or even on the edge or corner of the rectangle itself—the sum of the squares of its distances from two opposite corners of the rectangle will equal the sum of the squares of its distances from the other two corners. Applying this simple formula to the three distances given yields 27,000 as the fourth distance.

3.

When ticktacktoe players are allowed to play either a naught or a cross on each move, the first player can always win by first taking the center cell. Suppose he plays a cross. The second player has a choice of marking either a corner or a side cell.

Assume that he marks a corner cell. To avoid losing on the next move he must mark it with a 0. The first player replies by putting a 0 in the opposite corner, as in diagram *a* in the illustration at the top right on page 112. The second player cannot prevent his opponent from winning on his next move.

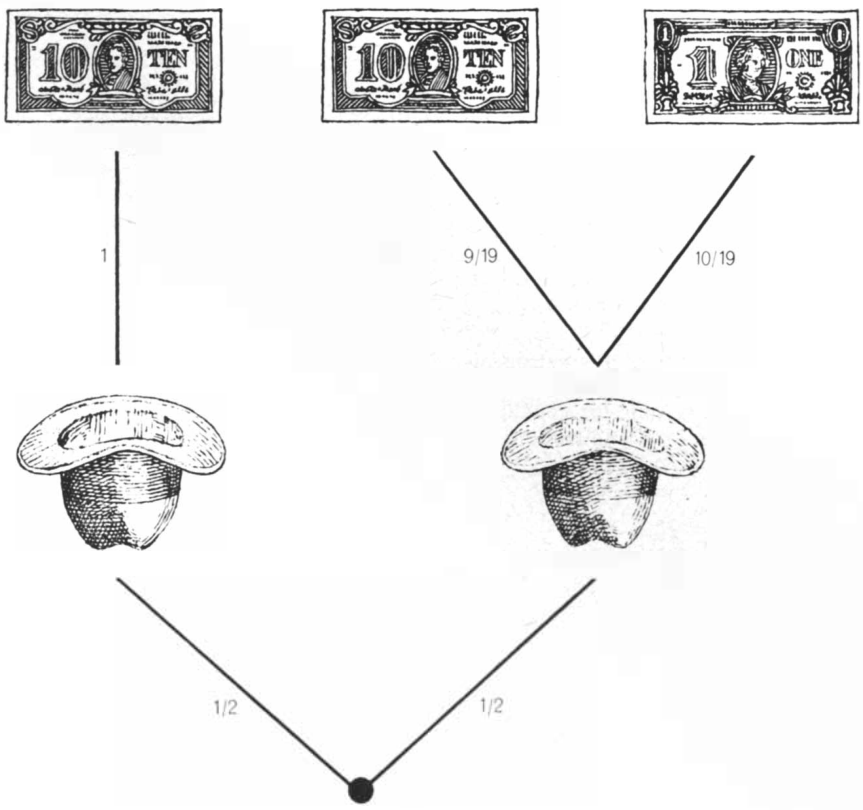
What if the second player takes a side cell on his second move? Again he must use a 0 to avoid losing on the next move. The first player replies as shown in the next diagram [*b*]. The second player's next move is forced [*c*]. The first player responds as shown in the final diagram [*d*], using either symbol. Regardless of where the second player now plays, the first player wins on his next move.

4.

With as few as 16 different coins one can express any value from one cent to 100 cents as the sum of no more than two coins. The coins are: 1, 3, 4, 9, 11, 16, 20, 25, 30, 34, 39, 41, 46, 47, 49, 50. This solution is given, without proof that it is minimal, in Roland Sprague's *Recreation in Mathematics,* recently translated from the German by T. H. O'Beirne.

5.

The boy maximizes his chance of drawing a $10 bill by putting a single $10 bill in one hat, the other 19 bills



Probabilities in hat problem

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(nine $10 bills and 10 $1 bills) in the other hat. His chance of picking the hat with the $10 bill is one in two, and the probability of picking a $10 bill from that hat is 1 (certain). If he picks the other hat, there is still a probability of 9/19 that he will draw a $10 bill from it.

This simple stochastic process is shown in the illustration on page 114. The probability that he will draw a $10 bill from hat A is $1/2 \times 1$, or $1/2$. The probability that he will draw a $10 bill from hat B is $1/2 \times 9/19$, or $9/38$. The sum of the two probabilities, 14/19 (or almost 3/4), is his overall probability of getting a $10 bill.

6.

Henry Ernest Dudeney, in his posthumously published *A Puzzle-Mine,* was able to achieve 12 good English words by placing letters on the nine-cell square like this:

G E T
A I A
S U P

The words are: get, teg, sup, pus, pat, tap, gas, sag, pig, gip, sit, aia. If the contraction " 'tis" is permitted, the number is 13. I have little doubt that many readers will better this by using more unusual words. Results will be reported in this department in September.

7.

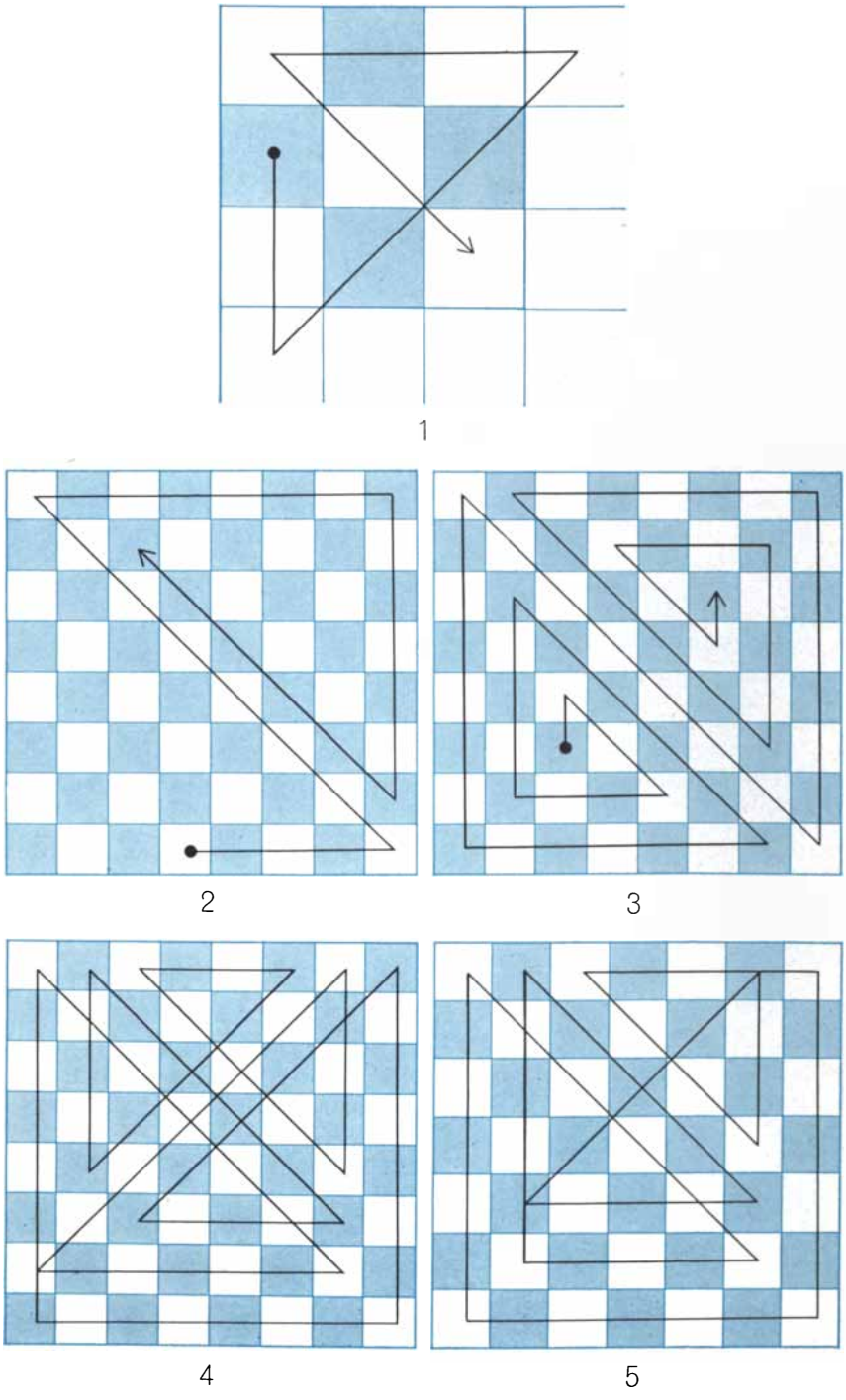
Five objects can be ranked according to weight with no more than seven weighings on a balance scale:

1. Weigh A against B. Assume that B is heavier.
2. Weigh C against D. Assume that D is heavier.
3. Weigh B against D. Assume that D is heavier. We now have ranked three objects: $D > B > C$.
4. Weigh E against B.
5. If E is heavier than B, we now weigh it against D. If E is lighter than B, we weigh it against A. In either case E is brought into the series so that we obtain a rank order of four objects. Assume that the order is $D > B > E > A$. We already know (from step 2) how the remaining object C compares with D. Therefore we have only to find C's place with respect to the rank order of the other three. This can always be done in two weighings. In this case:
6. Weigh C against E.
7. If C is heavier than E, weigh it against B. If C is lighter than E, weigh it against A.

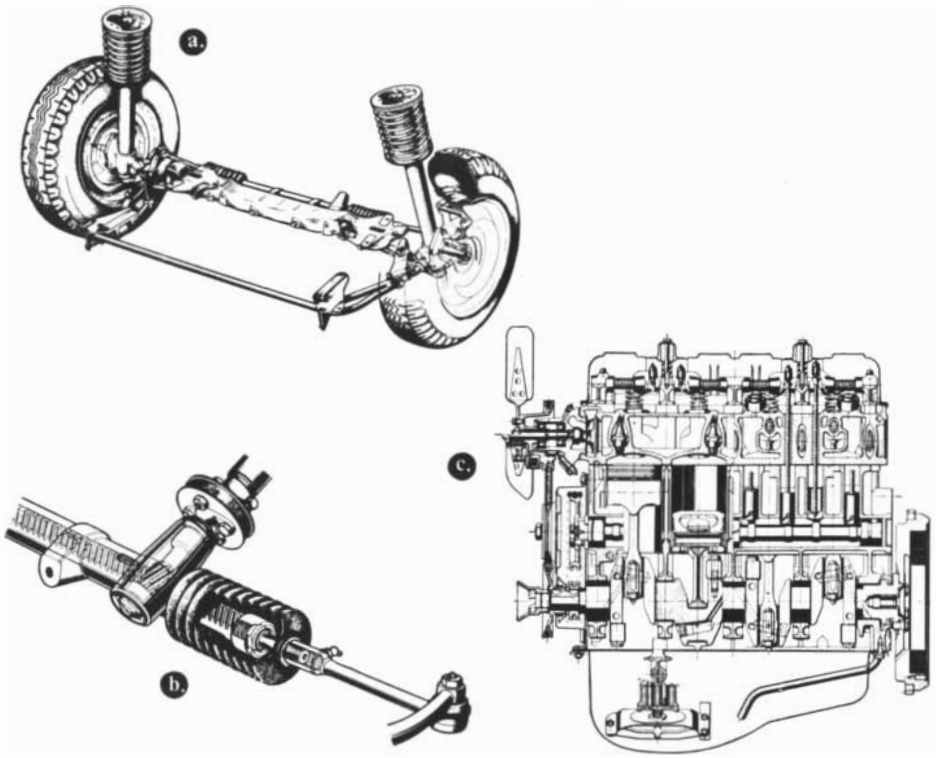
The general problem is discussed by Lester R. Ford and Selmer M. Johnson, both of the Rand Corporation, in *The American Mathematical Monthly* for May, 1959 (pages 387–389).

8.

Answers to the five queen's-tour problems are shown at the left. In the fourth and fifth problems there are solutions other than those shown, but none in fewer moves. If you solved the third problem by moving first to the lower right corner, up to the upper right corner, along a main diagonal to the lower left corner, up to the upper left and then right seven squares, you found a path almost (but not quite) as long as the one shown.



Solutions to queen's-tour problems



Technically speaking . . . THIS IS PEUGEOT

Over the many years Peugeot has been manufacturing fine cars, it has pioneered many engineering advances. Consider just a few of the recent innovations achieved by Peugeot.

(a.) Suspension System, 404 Sedan: A single lower-A-arm (wishbone) is attached by ball joint to the underside of the wheel hub. The upper member is a strut running upward from ball joint to body-frame. Encircling this strut is a coil spring containing a tubular shock absorber. In addition, an antiroll bar is employed to provide even greater solidity on curves. This assures lateral stability. Front and rear springs are synchronized to meet the effect of road irregularities at the same moment. The entire vehicle rises as a platform to minimize pitching.

(b.) Steering, all 404 models: Peugeot employs the highly efficient rack-and-pinion type steering gear. Similar to that used in racing cars, this steering system eliminates "play," and gives the driver remarkable control under all driving conditions. The Peugeot turns in only 31′2″, a far smaller turning circle than most of today's smaller cars.

(c.) Engine, all 404 models: Peugeot has a five-bearing crankshaft for even greater performance and durability. The engine is slant-mounted 45° to the right. This configuration means that the hoodline can be low, there is ample room to place induction and exhaust manifolding where it belongs—rather than where it fits—and that all components requiring service can be mounted for easy access with the bulk, not the weight, of the engine off-center. The Peugeot's light engine is designed for good torque and power characteristics without sacrificing longevity. Cylinders are wet sleeved which permits the use of hard, low-friction material for cylinder walls in conjunction with a softer, castable metal for the block.

The induction system is tuned by balancing volumes and capacities of the system to the frequency of the valves at 2250 rpm to develop additional horsepower at peak torque.

Another power increasing feature is a resonator incorporated into the front end of the exhaust manifold. This has the effect of slightly increasing torque at lower speed ranges of 2000-2500 rpm by timing some of the exhaust pulsations to reduce back pressure, which eliminates what would otherwise be a flat spot in the torque curve and also reduces high-pitched frequencies encountered during deeeleration.

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THE AMATEUR SCIENTIST

On constructing high-speed cameras for photographing fleeting events

Conducted by C. L. Stong

To observe fleeting phenomena such as explosions, shock waves and the flight of bullets, an experimenter must supplement his visual perception in some manner, as with an ultrahigh-speed camera. The kind of apparatus depends on the subject to be observed, the speed at which the event occurs, the quantity of information desired and the amount the experimenter wishes to pay. If the object is self-luminous, as in the case of a wire exploded by an intense pulse of electric current, the camera must be equipped with a high-speed shutter for isolating the interval of interest; nonluminous subjects can be lighted by an appropriately timed flash. The camera may or may not require a lens. For example, a lens would be unnecessary if the experimenter used a silhouette technique, in which a shadow falls on light-sensitive film; such a technique might be used for obtaining information about the flight of a bullet.

In short, the basic design of the camera is dictated by the nature of the problem. Thus an amateur seldom builds a high-speed camera until he has the specific details of a problem clearly in mind. Woody Gannaway, a student at Arkansas Polytechnic College, is an exception. Two years ago he set out to explore high-speed photography as an end in itself. He is currently working on an apparatus that will take a picture in about a ten-thousandth of the time required for the fastest mechanical shutter to click.

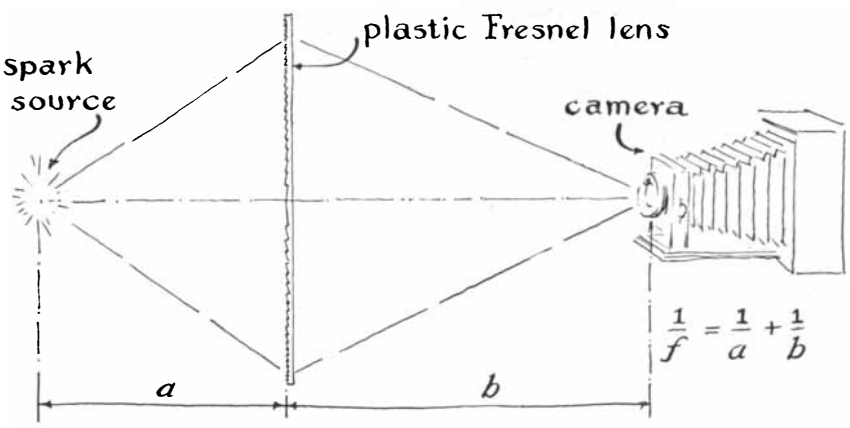
"My interest in high-speed photography," writes Gannaway, "began when I read an article in 'The Amateur Scientist' [November, 1957] about high-intensity underwater sparks. At the time I was active in an amateur rocket club and on the lookout for a method of photographing rocket exhaust gases. The article described a camera equipped with a Kerr-cell shutter—a high-speed device that briefly rotates the plane of a beam of polarized light so that the light will pass through a filter that normally stops it—to photograph the explosion of a small wire used for initiating the spark. It seemed to me that the apparatus could be modified easily for observing the rocket gases. Accordingly I spent the summer collecting parts and assembling my apparatus. By August I had taken my first photograph at a speed of 20 microseconds. The technique proved so engrossing that the design and construction of high-speed cameras became my sole hobby. I have not yet found the time to make a picture of a rocket exhaust and it appears unlikely that I ever shall.

"Before venturing into the construction of a shutter I experimented with electronic flash sources, primarily because a flash of short duration is easier to contrive than a shutter of comparable speed. The ordinary electronic flash sold by dealers in photographic supplies operates no faster than about a ten-thousandth of a second. By appropriate modifications I increased the speed of comparable apparatus to 20 microseconds. For a test subject I used a model-airplane propeller that was turned at the rate of 100 revolutions per second by a motor from a sewing machine.

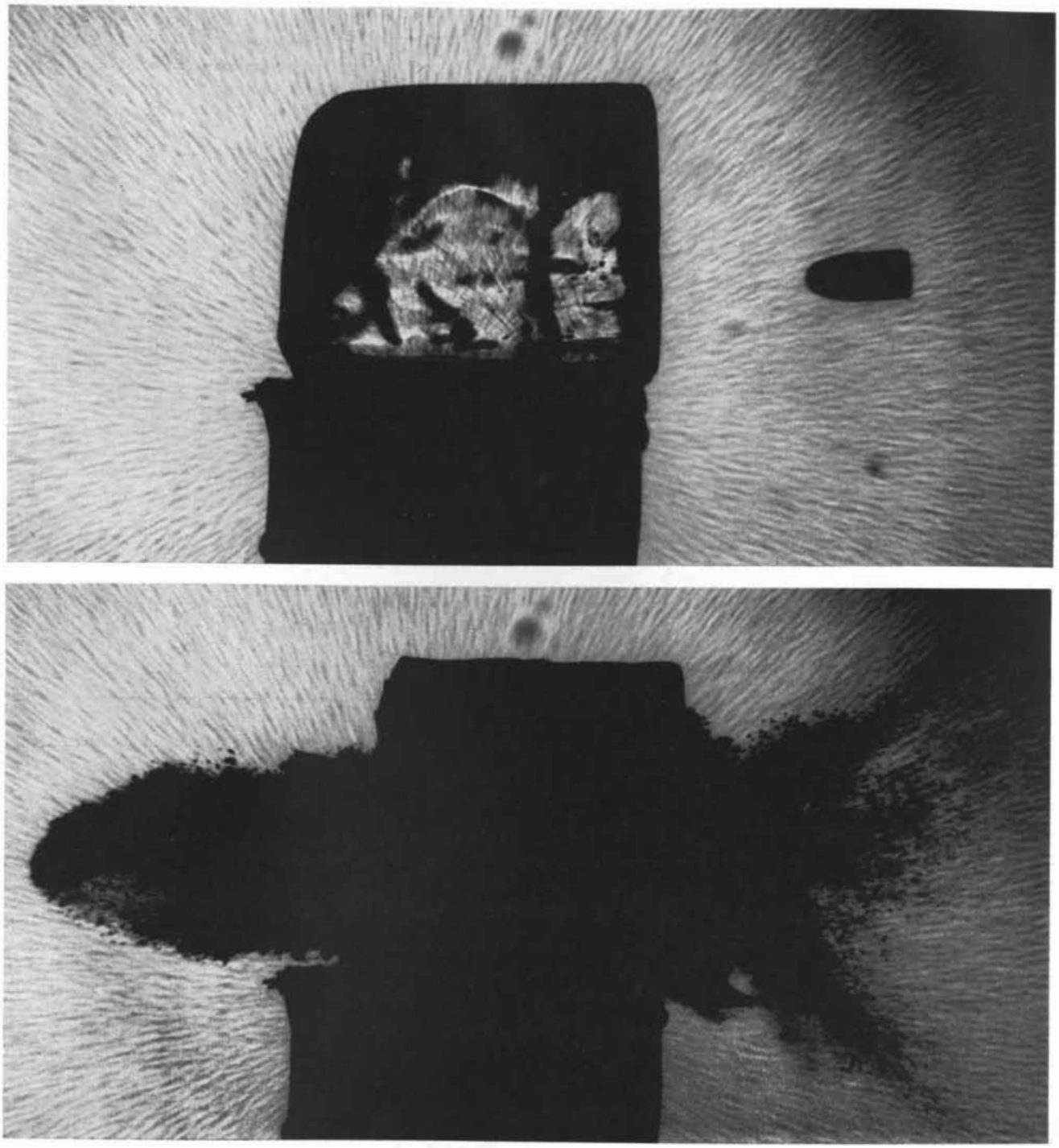
"The speed at which a gas-discharge lamp of this type flashes is governed in general by the electrical resistance and inductance of the circuit, by the size and quality of the capacitor that supplies energy to the lamp and by the electric potential to which the capacitor is charged. For the shortest flash one must minimize resistance, inductance and capacitance and use the maximum voltage the circuit can tolerate. Both resistance and inductance are minimized by the use of short, heavy, ribbon-shaped conductors for connecting the capacitor to the lamp. Through these procedures I succeeded during the following winter in reducing the flash interval to about one microsecond. I made pictures of .22-caliber rifle bullets shattering ice cubes.

"Subsequently I built an apparatus for producing intense flashes of light by a spark discharge. I also made a number of Kerr cells. Such cells have been operated at intervals as short as five nanoseconds (five billionths of a second). The best of mine had a top speed of 10 nanoseconds. In 10 nanoseconds a wave of light in a vacuum is able to travel approximately 10 feet.

"The first tool the beginner in high-speed photography should construct is a 'shorting stick': a strip of dry, var-



Schematic arrangement of a spark camera

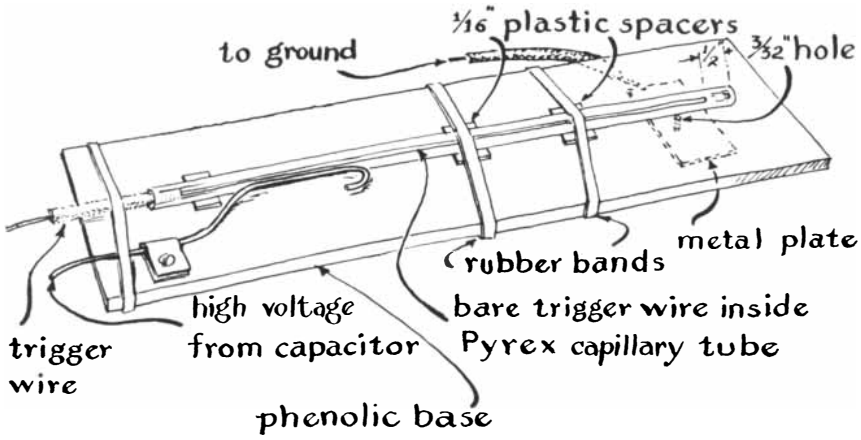


Bullet approaching and striking an ice cube

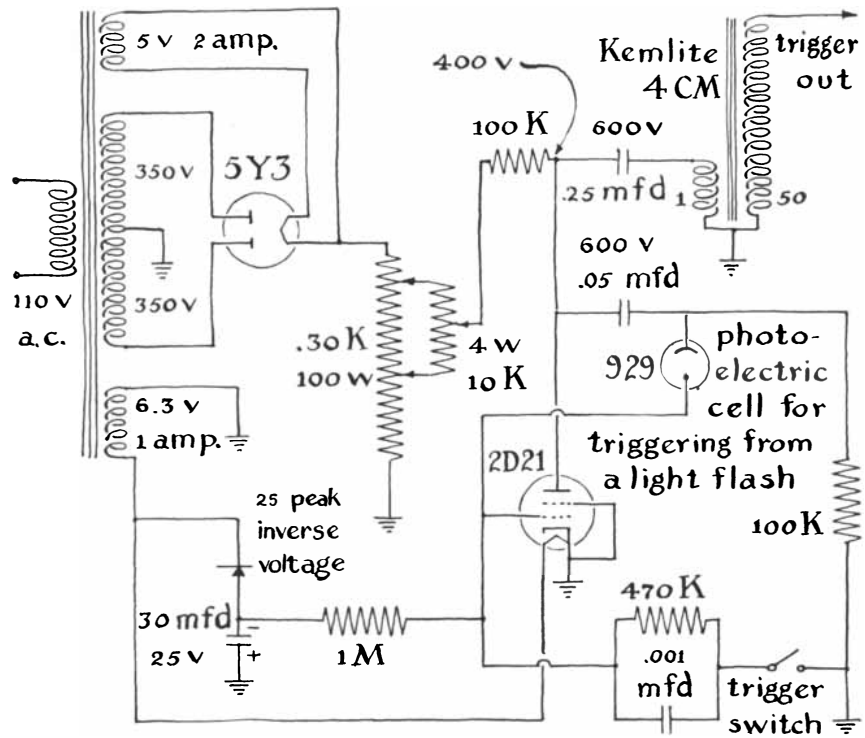
nished wood some 36 inches long with a strip of metal at one end to which is connected a wire terminating in a large alligator clip. The tool is used for discharging capacitors. The alligator clip is connected to a ground, and the experimenter, grasping the wooden handle, touches the metal strip to the 'hot' terminal of the capacitor. *Never touch the terminals of a high-voltage capacitor until it has been discharged.*

"The three basic systems I shall describe have certain elements in common. In each system the energy that creates the flash or operates the shutter is in the form of a high-voltage charge stored in a capacitor. Energy for charging the capacitor is drawn from a power supply: a transformer equipped with a rectifier for converting alternating current to direct current. The discharge of the capacitor is controlled by a triggering apparatus that can be operated manually but in most experiments is automatically actuated by the event being photographed. To make a picture of a bullet in flight, for example, a microphone that picks up the sound of the shot can trigger the camera.

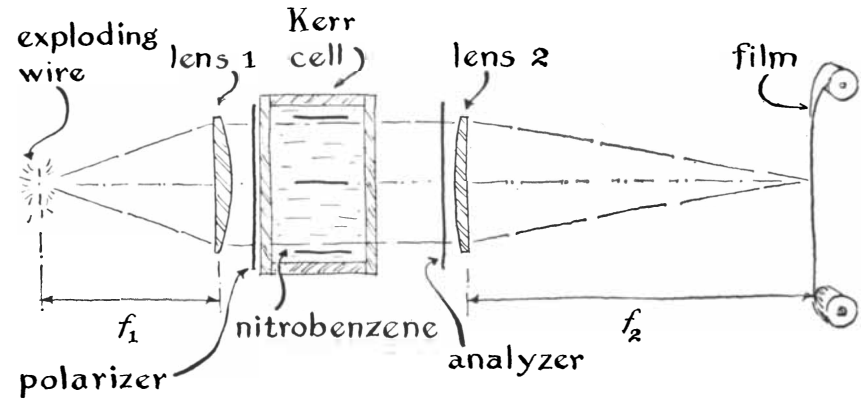
"My first system, the one that operated at the 20-microsecond exposure rate, was equipped with a power supply that delivered 6,500 volts through a 4.7-megohm resistor to a two-microfarad capacitor that was rated at 7,500 volts maximum. To keep the cost of materials



Details of the guided-spark unit



A spark-gap trigger circuit shown schematically



A method of arranging a Kerr-cell shutter

down I rectified only half of the alternating-current cycle. Design formulas for the construction of power supplies can be found in the *Radio Amateur's Handbook*, published by the American Radio Relay League and available from most dealers in amateur-radio supplies. The capacitor of this system was discharged through a manual circuit breaker into a Sylvania Type 1073 (now R4330) flash tube. I operated the circuit breaker, a surplus item, by means of a handle insulated with 10 layers of inner tubing. The flash tube is designed for 2,000 volts between the anode and the cathode; it will flash when 10,000 volts is applied between a trigger terminal and the anode. I applied a single, 6,500-volt pulse directly to the anode and cathode. Accordingly the tube fired without trigger excitation. This tube, as well as the comparable Type VVX-1, is designed to dissipate 200 watt-seconds of energy.

"The total energy available for the flash depends on both the capacity and the voltage. The relation is expressed by the formula $W_s = CV^2/2$, where the energy in watt-seconds (W_s) is equal to half the product of the capacity, in microfarads, multiplied by the square of the voltage (V), in kilovolts.

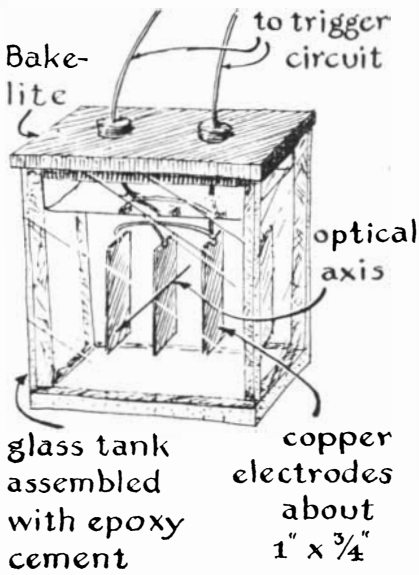
"In these tubes the glass helix—the part containing the gas in which the discharge occurs—is protected by a heavy glass envelope. For triggering the discharge a short length of wire is wrapped around the middle of the helix. High voltage applied between the trigger wire and an electrode at the end of the helix ionizes the gas and creates a conductive path through the tube. I have yet to find a flash tube with an adequate wrapping of trigger wire. For this reason, and to provide additional cooling for the helix, I break the protective envelope by wrapping a rag around it and gently hammering the end opposite the base until the outer glass breaks. I then add a half-dozen turns of trigger wire to the helix. Occasionally in this process the ceramic base of a tube cracks; I patch it with epoxy cement.

"Switches for operating the trigger circuit can take a variety of forms, depending on the event to be photographed. Eventually I substituted a high-voltage relay for the circuit breaker. The contacts closed and triggered the flash when current was applied to the relay coil. I used the relay for making my first pictures of a speeding bullet. To actuate the relay I connected its control coil to the power through a

special switch made of two sheets of heavy aluminum foil separated by 1/8-inch plastic tape. The foil sandwich was set at a right angle to the path of the bullet. The electrical path through the switch was completed when the bullet punctured the sandwich, connected the two sheets of foil and energized the relay. The inertia of the relay introduced a time delay, initiating the flash an instant after the bullet penetrated the foil switch. I tried to use the switch directly in the high-voltage discharge circuit, but the experiment did not work because the flash occurred before the bullet had time to move into the field of view.

"My power supplies all employ Type 8013 or 8020 high-voltage diode vacuum tubes as rectifiers. The Type 8013 is rated at 2.5 volts, five amperes filament current and an average plate current of 20 milliamperes at a peak inverse potential of 40,000 volts. The 8020 is rated at five volts, six amperes filament current and an average plate current of 100 milliamperes at a peak inverse potential of 40,000 volts. The plates are designed for overloads during short pulses of seven times the continuous load. The tubes are costly if bought new but they can be picked up on the surplus market at present for about $4 each. My high-voltage transformers and capacitors are also surplus items.

"My second system involved shadowgraph photography. For the spark gap needed in that technique I used a discarded Type 724B vacuum tube with the end filed off to admit air. These tubes make ideal spark gaps because



Details of a Kerr cell

the electrodes are properly spaced and consist of metal that resists erosion. They can be bought as surplus items at reasonable cost. It is doubtless possible to improvise an adequate spark gap from almost any metal, but the intense sparks may alter the width of the gap and necessitate frequent adjustment. The electrodes should be spaced about .05 inch apart. I energized the gap with a .1-microfarad capacitor charged to 15,000 volts, and I triggered the discharge by means of an electronic circuit that will be described below.

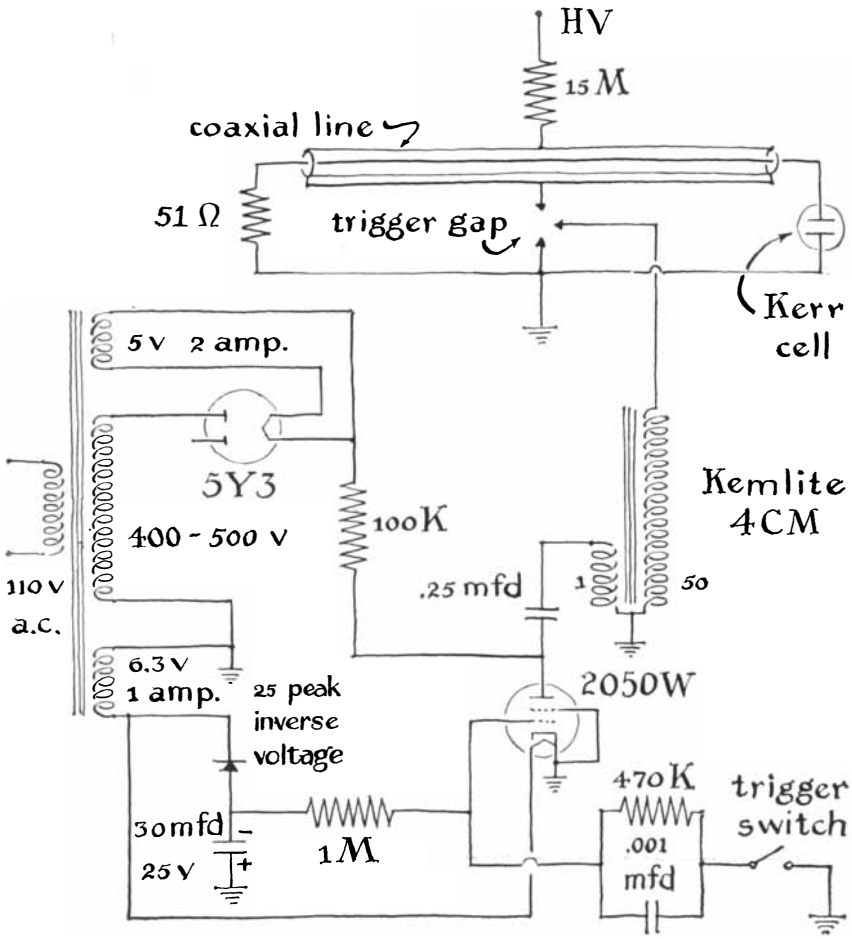
"The optical system for making shadowgraphs consists of the spark, a wide-aperture lens and the camera. Objects close to the wide-aperture lens cast sharp shadows on the film when the lens of the camera is properly focused. I used an inexpensive wide-aperture lens of the Fresnel type, obtained from the Edmund Scientific Co. of Barrington, N.J. The spark gap was mounted on the wall. The Fresnel lens was supported by a wooden frame in a position such that its optical axis passed through the center of the spark gap. It was spaced from the spark gap a distance equal to twice its focal length. The lens of the camera was located on the other side of the Fresnel lens, as shown in the accompanying illustration [*page 118*]. Assuming a to be the distance from the spark gap to the Fresnel lens and b the distance from the lens of the camera to the Fresnel lens, the elements are properly spaced when they satisfy the formula $1/f = 1/a + 1/b$, where f is the focal length of the Fresnel lens. The magnification is b/a. A single-lens reflex camera is ideal for work of this type. I use an old four-by-five-inch Crown Graphic bought for $15. For the best shadowgraph pictures the camera must be moved slightly inside distance b and a little to one side so that the iris diaphragm cuts just inside the cone of light projected by the Fresnel lens. The lens of the camera is then adjusted in such a way that an object close to the side of the Fresnel lens toward the camera is focused sharply on the ground glass.

"To align the optical system I hold one hand with fingers spread slightly apart in front of the camera lens. The flash, when triggered in the dark room, appears on my hand as a disk of light. Using the disk as a guide, I then adjust the position of the camera so that the cone of rays falls on the edge of the iris of the camera lens.

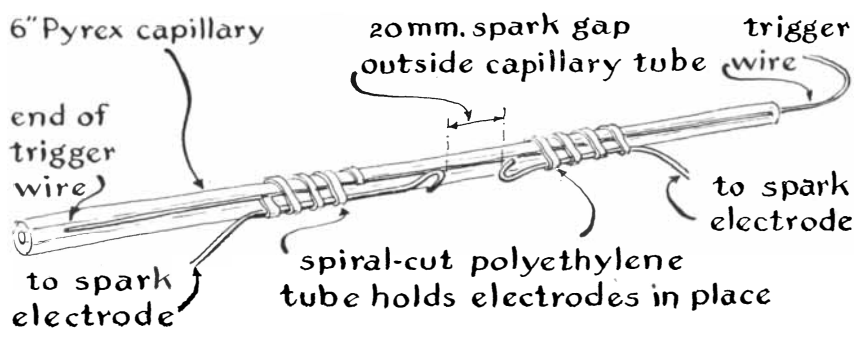
"Both the camera lens and the Fresnel lens must make right angles with the optical axis. When they are in proper adjustment, the Fresnel lens projects a uniformly lighted image on the ground glass. To make the adjustment I simply orient the elements in sequence until the image is evenly lighted. I used a four-watt-second capacitor when making photographs of bullets and ASA 400 film, which I develop to high contrast. The opening of the iris varies from $f/16$ to $f/22$.

"The gun is clamped securely at several points. A box filled with damp sand to receive the spent bullet serves as the target just beyond the field of view. The amplified pulse from the microphone that picks up the sound of the shot operates the electronic trigger. The time at which the flash is triggered in relation to the instant at which the gun is fired can be varied by altering the distance between the microphone and the muzzle of the gun. The position the microphone should occupy must be determined by experiment.

"When all is in readiness, the photograph is made by pulling the trigger of the gun. It is assumed that the experimenter will observe all the traditional



A Kerr-cell trigger circuit shown schematically

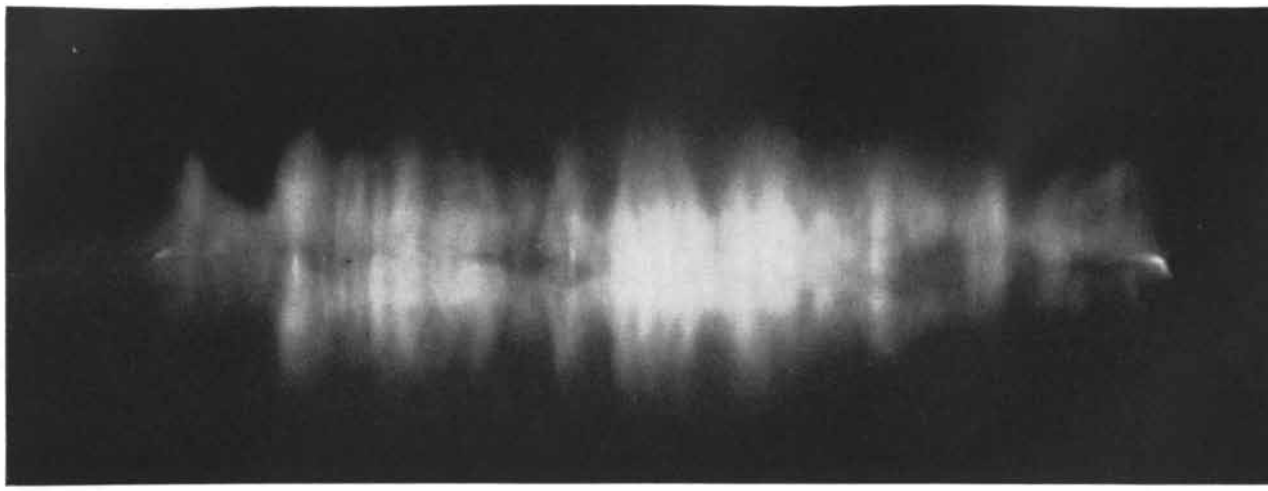


Arrangement of the spark trigger switch

precautions when handling firearms. The accompanying photographs [*page 119*] show a .22-caliber rifle bullet approaching from the right and crashing into an ice cube. The photographs were made by the system described at a flash speed of 1¼ microseconds.

"I next built a version of the guided-spark unit that was developed by Harold E. Edgerton of the Massachusetts Institute of Technology. In this apparatus [*see top illustration on page 120*] the path of the spark is confined to a slender glass tube. All but a small portion of the spark is masked; hence it acts somewhat as a point source and improves the sharpness of shadows with respect to those made with an open spark gap. The parts are mounted on an opaque base of sheet plastic two inches wide, six inches long and 1/8 inch thick. On one side of the base I mounted a glass tube with an inside diameter of two millimeters and an outside diameter of seven millimeters, about five inches long. The glass was attached to the phenolic plastic by epoxy cement; it can also be held by rubber bands. A bare wire for triggering the spark runs through the tube to within half an inch of one end. Another wire, secured by a clamp, runs parallel to and in contact with the outside of the tube. The position of the outer wire can be altered by releasing the clamp. A metal plate about 3/4 inch wide and 1½ inches long is cemented to the underside of the base near the end of the trigger wire. A hole some 3/32 inch in diameter is drilled through the center of the metal plate and the base so that its axis intersects that of the glass tube on the upper side of the base. This hole serves as the aperture for transmitting light from the spark. The metal plate connects to the negative terminal of the capacitor. The adjustable wire adjacent to the glass tube connects to the positive terminal of the capacitor. The guided spark produces photographs of splendid resolution.

"Pulse sources of 15,000 volts and higher are used for triggering spark gaps and flash tubes. Ordinary induction coils of the type used in automobile ignition systems work well as trigger coils. The primary winding of the coil is connected through a set of breaker points and the associated capacitor to an appropriate source of power such as a storage battery. When the breaker points operate to send a pulse of direct current through the primary winding, inductive reaction causes a pulse of high voltage to appear across the secondary winding. In the electronic trig-



An exploding wire photographed with a Kerr-cell shutter

Spark crossing a gap in a 10-nanosecond exposure

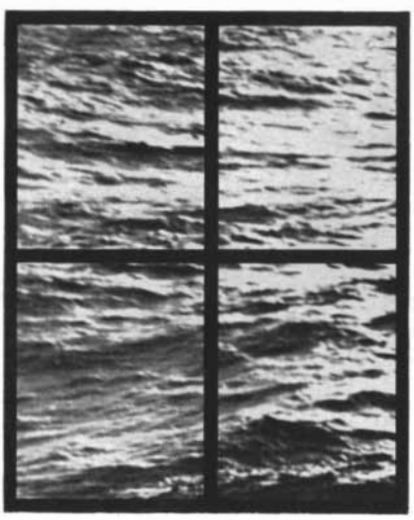
ger system I substitute a thyratron tube for the breaker points. The tube acts as a direct-current switch. When its grid is grounded by the operation of a push button, or is grounded in effect by a pulse of energy from some other source, the stored charge in a capacitor associated with the plate circuit of the thyratron discharges through the primary of the induction coil and initiates the high-voltage triggering pulse, as indicated by the accompanying wiring diagram [*middle of page 120*]. I use either of two types of thyratron tube, a 2D21 for pulsing the primary of a specially designed induction coil at 400 volts or the Type 2050W for exciting a similar coil at 800 volts. The higher voltage is used for operating Kerr cells.

"Theoretically the Kerr cell is capable of operating within an interval of .1 nanosecond. The central element of the cell is a small glass box filled with a special transparent fluid and fitted with two or more electrodes [*see illustration on page 121*]. When there is an electric field between the electrodes, the fluid rotates the directions in which waves of light traversing the cell vibrate. If the cell is sandwiched between a pair of plastic polarizing sheets that restrict the vibration of light to a single plane and the orientation of the sheets is crossed so that the permitted planes of vibration are at right angles, minimum light transmission occurs because light entering the assembly through one sheet cannot penetrate the other. An appropriate electric field applied to the electrodes causes the fluid in the cell to rotate the plane of the incoming light 90 degrees. The waves can then pass through the second sheet of polarizing material.

"The cell transmits light as long as the electric field is maintained across the electrodes. In effect, the electric potential opens the 'shutter.' The relation between the voltage required to rotate the axis of polarization 90 degrees and the arbitrary variables of the cell is $V_0 = 300d\sqrt{1/2Lk}$, where V_0 is the required potential in volts, d the spacing between the plates in centimeters, L the length of the light path under the influence of the electric field in centimeters and k the Kerr constant of the fluid in the cell. Nitrobenzene, a yellowish fluid, is most often used in Kerr cells. The Kerr constant of nitrobenzene is .00004 electrostatic units.

"Nitrobenzene is a deadly poison, both in the form of liquid and in that of vapor. The fluid is readily absorbed by the skin and can seriously damage the blood even when it is absorbed in minute amounts. Nitrobenzene is also a vigorous solvent; before the advent of epoxy cements Kerr cells were commonly made of one piece of glass

THE WINDOW IN THE OCEAN HAS GROWING PANES



That window of knowledge in the ocean is getting bigger all the time. At Vitro, teams of scientists are involved in oceanography, both under Navy contract and in-house R&D. They are performing basic studies into the science of the sea, designing instruments for deep submergence, and analyzing and cataloging oceanographic data. It was a background in acoustics, instrumentation and operations research that helped qualify Vitro for the Navy ASWEPS program.

Among many specific Vitro accomplishments are: operations analyses applied to ocean environment . . . datum buoys for airborne ASW . . . velocimeters . . . wire coils and miniature coax for weapons guidance, underwater communications and telemetry . . . underwater vehicles . . . and underwater range operations.

Despite complexity of the problems, real progress is being made in the study of this environment. For more information on Vitro capabilities in oceanography, contact Owen E. Cunningham, Vitro Laboratories, 14000 Georgia Avenue, Silver Spring, Maryland, (301) 942-7200.

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because nitrobenzene dissolves most cements. I used Borden's epoxy cement successfully to assemble a cell.

"I equipped some of my cells with three electrodes and others with four, connected as alternate pairs. In the case of the three-electrode arrangement the outer plates are strapped together. The copper plates can be an inch long and 3/4 inch wide and are spaced 1/4 inch apart. My cells were equipped with Type HN-22 linear polarizers. Two sheets of the material crossed at 90 degrees transmit only about a millionth of the incident light. When both sheets are in the same plane of polarization, the transmission increases to about 12 percent. The Type HN-32 linear polarizer can also be used. It has a crossed transmission of about one part in 100,000 and an open transmission of about one in four. My polarizers were obtained from Burke and James, Inc., 321 South Wabash Avenue, Chicago, Ill. 60604.

"For protection the polarizing sheets were sandwiched between glass slides of the type used for 35-millimeter color photographs. I taped one slide to the Kerr cell with its plane of polarization set at 45 degrees from the vertical. The second slide fits into a rotatable holder supported by the lens barrel of the camera. I rotate this slide from maximum light transmission through the Kerr cell when focusing the camera. Then, before making a picture, I direct the beam of a 35-millimeter slide projector through the cell and adjust the rotatable holder for minimum light transmission. The cell is supported close to the camera lens by a pair of sturdy metal supports that extend from the lens board of the camera. To mount the collimating lens on the other side of the cell I use the front assembly from another Crown Graphic. This fits the track of the camera and simplifies the alignment and spacing of the lenses.

"In addition to the electronic trigger, the circuit that operates the Kerr cell contains an electrical network for delivering a properly proportioned and appropriately delayed pulse of high voltage to the electrodes of the cell, together with a spark gap that acts as a triggering switch in the high-voltage circuit. The pulse-forming network consists of a length of coaxial cable. It transmits a pulse equal in amplitude to the changing voltage. The unit is assembled as shown [*see upper illustration on page 122*].

"The spark-gap switch connects between the center of the braided outer conductor and the ground. The electrical characteristics of the coaxial cable I use are such that the speed at which an electric pulse would travel in a vacuum is retarded by one nanosecond per eight inches of cable. For a 10-nanosecond pulse the coaxial cable of the pulse-forming network was made 80 inches long. The cable was bought as a surplus item and has no markings, but its characteristic impedance is 54 ohms. The length of an output pulse conducted by the cable is equal to the electrical length of the line. The open time of the Kerr cell is about half the time of the applied electric pulse.

"The terminating resistor of the network must dissipate part of the 15,000-volt pulse. In the case of my apparatus the resistor, which must approximate the characteristic impedance of the coaxial cable, was assembled from three 17-ohm, two-watt carbon resistors connected in series. The assembly was placed in a plastic container and immersed in molten sulfur.

"To tell if the circuit is working I connect a small neon bulb in series with a four-megohm resistor and hook the combination in parallel with the cell. If the neon lamp flashes in the darkened room, I know that the cell has been pulsed.

"The Kerr cell is a notoriously inefficient shutter. The minute amount of light available during the brief interval of exposure is further reduced by losses in the nitrobenzene and polarizers. For this reason I used Royal-X (Kodak) film processed in Acufine developer for twice the recommended development time. It is relatively easy with this apparatus to make enlarged photographs of such events as the explosion of a fine wire subjected to an intense current pulse. The accompanying photograph [*see upper illustration on page 124*] shows the point reached in the explosion of a 3/4-inch length of wire during a 10-nanosecond interval some 80 nanoseconds after the high-current pulse was applied to the wire. The second photograph shows the progress of an electric spark across a 1/2-inch gap 150 nanoseconds after a .1-microfarad capacitor charged to 15,000 volts was connected to the gap. The principal arc appears at the positive electrode of the gap [*right*]; a faint glow surrounds the negative electrode [*left*]. The exposure time was 10 nanoseconds.

"Anyone wishing more details about these experiments may correspond with me directly at this address: Box 573, Arkansas Polytechnic College, Russellville, Ark. 72802."

SILICOLOGY

Silanes and Silicones Show New Versatility As Adhesion Promoters

In working with users and producers of adhesives, caulking compounds, sealants, and paints, our laboratories have come up with many new applications for silanes and silicones as adhesion promoters. Some are used as primers; others as integral blend additives.

All have demonstrated particular ability in improving the adhesion of a variety of substances to glass and metals. Many are excellent anti-oxidants and promote adhesion effectiveness under conditions of high humidity and in the presence of water. For example, a silicone primed bond of rigid urethane foam-to-aluminum maintained adhesiveness for 14 days in a water immersion test, without failure.

An interesting use is the bonding of polyethylene to aluminum foil to prevent vapor loss from food and tobacco storage pouches. Silicones and silanes are being used as prime coats to improve the adhesiveness of polysulfide caulking compounds used to weather-seal skyscraper windows, automotive windshields, and in various marine applications.

Our A-1100 silane (gamma-aminopropyltriethoxysilane) is used as an integral blend additive, eliminating the need for primers when bonding epoxy-based inks to glass. Ink adheres to the glass substrate even when subjected to boiling detergent solutions. This same silane showed similar success in bonding acrylics to glass and other substrates. It also reduces the moisture sensitivity of the phenolic resin binder used to adhere metal to glass for light bulbs.

Silicones can assure water-tight joints between sealants and glass and metal surfaces.

One of our silicone adhesive promoters, UNION CARBIDE Y-2300, is used as a primer. It greatly improves the adhesion of silicone rubber and butyl rubber to copper in such applications as molded electrical transformer equipment. A colorless solution of a reactive silicone, Y-2300 can be applied by brushing, flooding or wiping. It also acts as an anti-oxidant. In laboratory tests using Y-2300, copper sheet retained 90% of its original non-oxidized color after 1000 hours at 200 deg. C.

Neither our silanes nor our silicones are "sticky" in the common meaning of the term. They simply make other substances adhere to one another better. This could be further support of the popular theory that adhesive force is the familiar intermolecular force that exists between all molecules; that the only requirement for adhesion is intimate molecular contact. Whatever the reason, they work.

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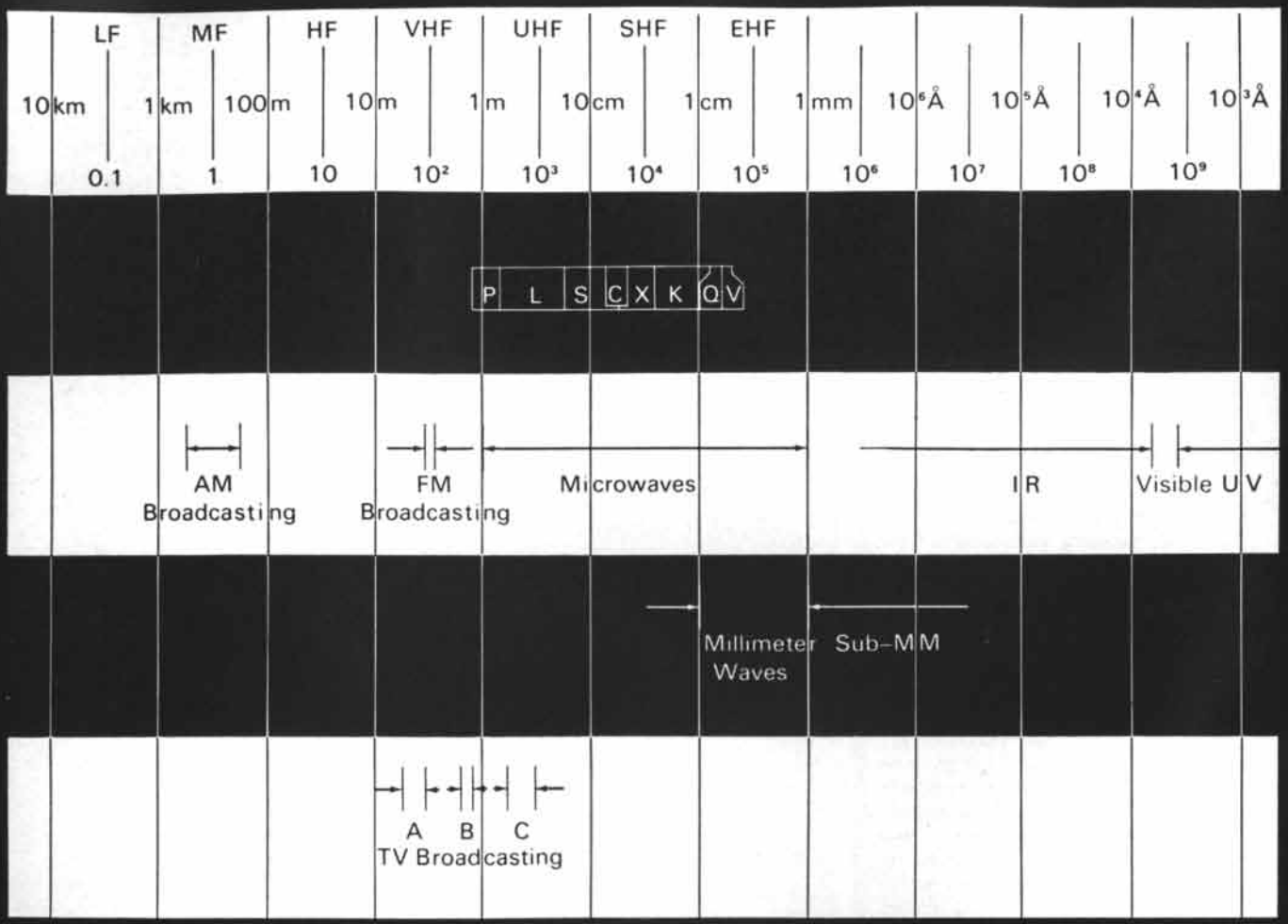

BOOKS

A collection of facts from social science and what they reveal about social science

by Jules Henry

HUMAN BEHAVIOR: AN INVENTORY OF SCIENTIFIC FINDINGS, by Bernard Berelson and Gary A. Steiner. Harcourt, Brace & World ($11).

This book consists of 1,045 behavioral science "findings," the term the authors—one a noted sociologist who is now vice-president of the Population Council and the other a psychologist at the University of Chicago School of Business—use for "propositions, generalizations, laws, or principles." The authors say that in order for a finding to be included in the book it has to be supported by what they call "hard" evidence, that is, statistics. This criterion is not always followed. The authors want to present to the average educated and professional individual an "inventory" of "hard" knowledge in psychology, sociology and anthropology; the first half of the book is psychology and the second is sociology, with pages here and there devoted to anthropology, a soft science aspiring to be hard. The findings are arranged in brief statements, each having a retrieval number, and are usually followed by an explanation that is often backed up by a table or graph. Chapter headings cover the range of psychological topics (learning, perception, motivation etc.) and conventional sociological ones (the family, organizations, ethnic relations etc.). There is also a chapter titled "Culture."

Since it is impossible to give this brontosaurus of a book a detailed examination in a mere review, I shall write a series of little essays about it. In this way I hope the reader will learn in general what is in the book and what my feelings about it are.

The first essay might be called "The Nature of Intellectual Failure in the Behavioral Sciences." The publication of *Human Behavior* provides what is needed to consolidate a general theory of intellectual failure in the behavioral sciences. From this book I derive the following factors as most significant in such failure: (1) Inability to distinguish truism from discovery. (2) Insensitivity to platitude. (3) Insensitivity to tautology. (4) Confusion of causal sequence—putting the cart before the horse. (5) Misperception of variables, that is, perceiving the crucial variables to be x, y and z when they are really a, b and c. (6) The delusion of precision, or imagining instruments to be sharper than they are and throwing away large but very important minor percentages. For example, in a calculation that breaks at 40 percent and 60 percent the hypothesis is "proved" by the 60 percent and the divergent 40 percent is disregarded. (7) Issue-avoidance. (8) The drawing of simpleminded parallels. For example, a raccoon conditioned to react to a card in a certain way tears up the card when the stimulus is altered; this is then compared to a young woman tearing up the letters of a faithless lover (page 270). In another example (page 253) small children isolated for 20 minutes are labeled "deprived" and those treated with extreme solicitude and approval for the same length of time by the experimenter are labeled "satiated"; experimental results obtained with the "deprived" and "satiated" children are then interpreted as if the two groups paralleled truly deprived and satiated children. (9) Multiparaphrasis. I have had to coin this term to cover the case in which an author rephrases or quotes something previously rephrased by a writer rephrasing somebody else. Thus on page 391 the authors quote Leslie A. White, who quotes R. A. Millikan, who has paraphrased Karl Marx without acknowledgment. Multiparaphrasis exists in particularly noxious form when the original paraphraser does not mention the source of his idea, so that neither the second paraphraser nor the multiparaphraser knows where the idea came from in the first place. (10) Failure to observe the law of homologous extrapolation. For example, when I extrapolate Boyle's law, established in the laboratory, to the explosion of a gas in an internal combustion engine, I apply the law under conditions essentially homologous with the laboratory situation, because in all essentials the two are comparable. But when I extrapolate the laws of rat or pigeon learning to man, I break the law of homologous extrapolation because rats and pigeons are not homologous with man. This is the gravest failure of the chapters on psychology; in these chapters (particularly Chapter 5 and Chapter 6) a large number of the proofs of human behavior are derived from experiments with lower animals. (11) Lack of an existential concept of man. In order to think straight one has to be able to confront hopelessness first; as Martin Heidegger put it, one has to be resolute before one's own death in order to have a concept of life and of man. I would say that in this book the authors confront nothing—not nothingness but nothing. All their apparent errors of judgment—the 11 points already mentioned—derive from the fact that they avoid human existence.

It is likely that there are other factors in the syndrome of intellectual failure in the behavioral sciences; it is also likely that all the factors need not be present in any one book or paper in order to establish its presence. For example, one can fail badly enough, I think, simply by being insensitive to truism, platitude and tautology. Let me specify what I mean by these first three points.

Truism is detected by changing the key affirmations in any proposition to negations. If the change makes the proposition utterly unbelievable, the original proposition is a truism. Consider the following: "If one is poor, economic issues are important to him" (page 570). By altering this to "If one is poor, economic issues are unimportant to him" the truistic nature of the proposition stands forth. Although this proposition is so obviously truistic that the test is unnecessary, it is useful in more complicated statements, particularly those masked by scientistic lingo. For example:

"Communications will be most effective—that is, will secure the response

most in line with the intention of the communicator—when they are in accord with audience predispositions; when they tell people what they (most) want to be told" (pages 540-541).

Applying the test, we get:

Communications will be least effective—that is, will secure the response least in line with the intention of the communicator—when they are in accord with audience predispositions; when they tell people what they most want to be told.

Since it is unbelievable that communication will be ineffective when people are being told what they want to hear, the statement is a truism. Thus truism is ragamuffin scholarship. I give a few more truisms below; there are many, many more in the book.

"Between generations, the weaker the parents' feelings on a matter, the less influence they exert on their children."

"A basic finding in social psychology is that the attitudes a person holds depend in part upon his social contacts and particularly upon the groups in which he holds membership."

"Opinions, attitudes and beliefs within a group are particularly subject to influence by the most respected and prestigious member(s) of the group, the opinion leader(s)."

"Given consistent support from historical, parental, group and strata characteristics, opinions, attitudes and beliefs are unlikely to change at all."

Often it is difficult to draw a precise distinction between platitude and truism because they look so much alike. I list a few of the latter:

"The social consequences of technological change are typically much more substantial in less developed societies than in advanced ones."

"People tend to see and hear communications that are favorable or congenial to their predispositions...."

"...rumors tend to be heard by people to whom they are congenial...."

Platitudes, like truisms, are often inflated by verbalism; for example, the following on page 266:

"When the real world and the motives of the subject are at odds, behavior is first designed to bring the real world into line with the motives. But when this is impossible, for external or internal reasons, the discrepancy (or dissonance, as it is now called) can be reduced by appropriate changes in the perception of reality."

It is difficult to find "pure" platitudes, and the above might turn out to be truisms if they were more carefully analyzed. Tautology is clearer; its difference from truism consists in the fact that in tautology the consequent repeats the antecedent in somewhat different language. Here are some examples:

"The more people associate with one another under conditions of equality, the more they come to share values and norms and the more they come to like one another."

"The greater the attractiveness of the group for its members, as compared to other groups, the more important its goals or other properties...are for the individuals in it...."

"The higher the rank of the member within the group, the more central he will be in the group's interaction and the more influential he will be."

More should also be said about the failure to observe the law of homologous extrapolation—point 8 on my list. Extrapolation from animals to humans leads to absurdity, sometimes compounded by ignorance. Consider the following: The distinguished psychologist B. F. Skinner—inventor of the Skinner box, an automatic baby-tender that makes it unnecessary for parents to touch their babies—discovered that a pigeon will tend to maintain or return to whatever activity it was engaged in at the moment it received food (reinforcement) from the experimenter. This is the famous "operant conditioning." Skinner says: "Conspicuous responses which have been established in this way include turning sharply to one side, hopping from one foot to the other and back, bowing and scraping, turning around, strutting and raising the head" (page 156). The authors of *Human Behavior* say: "By the same laws of instrumental conditioning, such schedules can produce what we would call superstitious behavior in lower animals as well as in human beings.... Note the conspicuous human responses perhaps established in the same way: rain dances, outfielders touching third base on the way to the dugout, men carrying 'lucky' charms...."

Before comparing with conditioned pigeons the Zuñi Indians performing rain dances and Murngin tribesmen of Australia performing rites for guaranteeing the wet and dry seasons and multiplication of life, it is necessary to examine the *Zeitgeist* of our time in order to understand why comparison of humans and lower animals is not angrily brushed aside or ridiculed but on the contrary has become the only truth in the most prestigious province of psychology: animal experimentation. I would urge that it is because man has lost his sense of being human, and that the modern world has made him lose it because the less he has of it the more willing he is to do what he is told.

Zuñi Indian rain dances are accompanied by prayers and songs outstanding for their musical and poetic sophistication; by beautifully made prayer sticks; by sand paintings, austere preparation of the mind for the ritual, superb costuming (including masks) and so on. The dancing lasts for days on end. Australian rites lack the broad sophistication and taste of those of the Zuñi, yet the sacred symbols used in the rites have found their way into art museums. The Australian rites also last a long time (sometimes for years) and are accompanied by varieties of dances and impersonations, by the telling of legends, the display of tribal symbols and so on. Comparison of these rituals with a pigeon leaping from foot to foot thus seems remote. It does not explain the origin of the gods for whose benefit the Zuñi dance. Furthermore, the inference that connected gods to dance and rain was an intellectual event, mediated by perception, thought and memory and by the magico-religious world view. Similar considerations apply to the Australians. The development of a rain dance (or any ritual) can by no means be explained as a simple reinforcement of one item in a relatively undifferentiated array of activities.

My second essay is titled "What Is Researchable?" On pages 29 and 30 the authors say:

"Some phenomena are inherently out of the scope of direct scientific observation: behavior that is private (sexual behavior, arguments between husband and wife) or asocial (criminality and trickery) or protected by custom (certain religious matters) as well as the vast amount of behavior that simply does not exist in directly observable form (ideas, attitudes, feelings, beliefs)...."

"Thus a great deal of behavioral science is based on (usually solicited) verbal reports of what has happened, what is expected to happen, how one felt, what one thought, and other conditions internal to the subject: 'I voted Democratic'; 'I was rarely spanked'; 'The light is getting brighter'; 'The blot reminds me of a turtle'; 'I hate my wife'; 'I want to get ahead'; 'That's the way we do things around here'; 'I thought it reasonable to go along with the others.' "

Ordinarily an investigator avoids making final judgments about what is inherent in phenomena. He knows fairly well what is inherent in his instruments and in his position (he is in the

"Those who hate war must have the power to prevent it."

So said James V. Forrestal. And he *gave* us this power, just as he understood its necessity. The nation's first Secretary of Defense, he was principal architect of the defense establishment as it stands today.

Forrestal's name recalls a ceaseless determination to save the country from its postwar complacency. He is remembered, too, as the dynamic administrative shipwright of our two-ocean armada in wartime, as one of the first to recognize the true nature and dimensions of Communism's menace, and as the diarist of a critical period in our history—when his wise and firm counsel proved invaluable to our national purpose.

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U.S. rather than in Sinkiang, on the earth rather than in outer space), but it is his conviction, based on experience, that what is "out of the scope" of observation in the phenomena today may be within scope tomorrow when he has a new instrument, or a new way of using an old one. Even if it were true that the phenomena mentioned by the authors in the above paragraphs were out of the scope of direct observation now, scientific sophistication cautions against the view of inherence. It is not true, however, that most of the phenomena mentioned above are "out of the scope of direct scientific observation." For example, I have observed in detail and published the sexual behavior of Pilagá Indian children. Bronislaw Malinowski reported the observed sexual behavior of adults. Many aspects of sexual behavior are perfectly open even in our society—like the tight heterosexual lock in some forms of social dancing. Even the most sacred rites of tribal peoples have been penetrated by determined anthropologists.

Are arguments between husband and wife really out of the scope of direct scientific observation? I have witnessed many during my residence in the homes of families I have studied. As for "trickery," it is everywhere in the world; all you have to do to observe it is to try to buy a bona fide piece of furniture in certain stores or sit in on a high school class taking an examination. Sometimes the authors do not remember on one page what they said on another. For example, on page 28 "Anthropologist lives in primitive culture for a year, collects material on the religious life of the natives" is an illustration of a "type of direct observation" that can be made, whereas on page 29 it is said to be "out of the scope of direct scientific observation."

What is the meaning of the statement that ideas, attitudes, feelings, beliefs "simply [do] not exist in direct observable form"? As one watches people in any meeting—say the meeting of a bible-study group—one sees them express freely ideas and attitudes. When they are engaged in ordinary conversation, at work, in an argument or at a committee meeting, their attitudes and feelings are right before us. Surely they are more "observable" there than in solicited behavioral science interviews.

Let us look at the next paragraph. If I show a person a Rorschach card and he says that the blot on it reminds him of a turtle, he may be giving his first perception, but it may also be the 21st or the 51st or the 101st, depending on how long he waits before speaking. He usually gives me a censored report because often people do not want to, or are unable to, verbalize first associations with the blots. On the other hand, when, in answer to a question about his childhood, an adult says, "I was rarely spanked," what does the answer mean? Even assuming that he wants to tell the truth, how can we be sure he remembers correctly? Since even under the best circumstances answers to questions are affected by censorship, by faulty recall and so on, what is behavioral science based on? If much of life is out of the scope of direct scientific observation, and a great deal of what is left is based on censored and otherwise distorted answers to questions, then many of the findings in this book must be phantom. And since contemporary social science is becoming aware that its world has been one of shadows, emphasis is now being placed on direct observation of the human animal functioning in its native habitat.

My third (and last) essay is: "How to Win Political Friends and Influence People, or the Doctrine of Political Phoniness." In the sections of *Human Behavior* on "political behavior" the lack of an existential concept of man leads to a conspicuous failure. On page 417 it is stated:

"In a modern democratic industrial country, with substantial social heterogeneity, political parties must appeal to a range of social groups in order to secure a majority."

The authors explain this truism as follows:

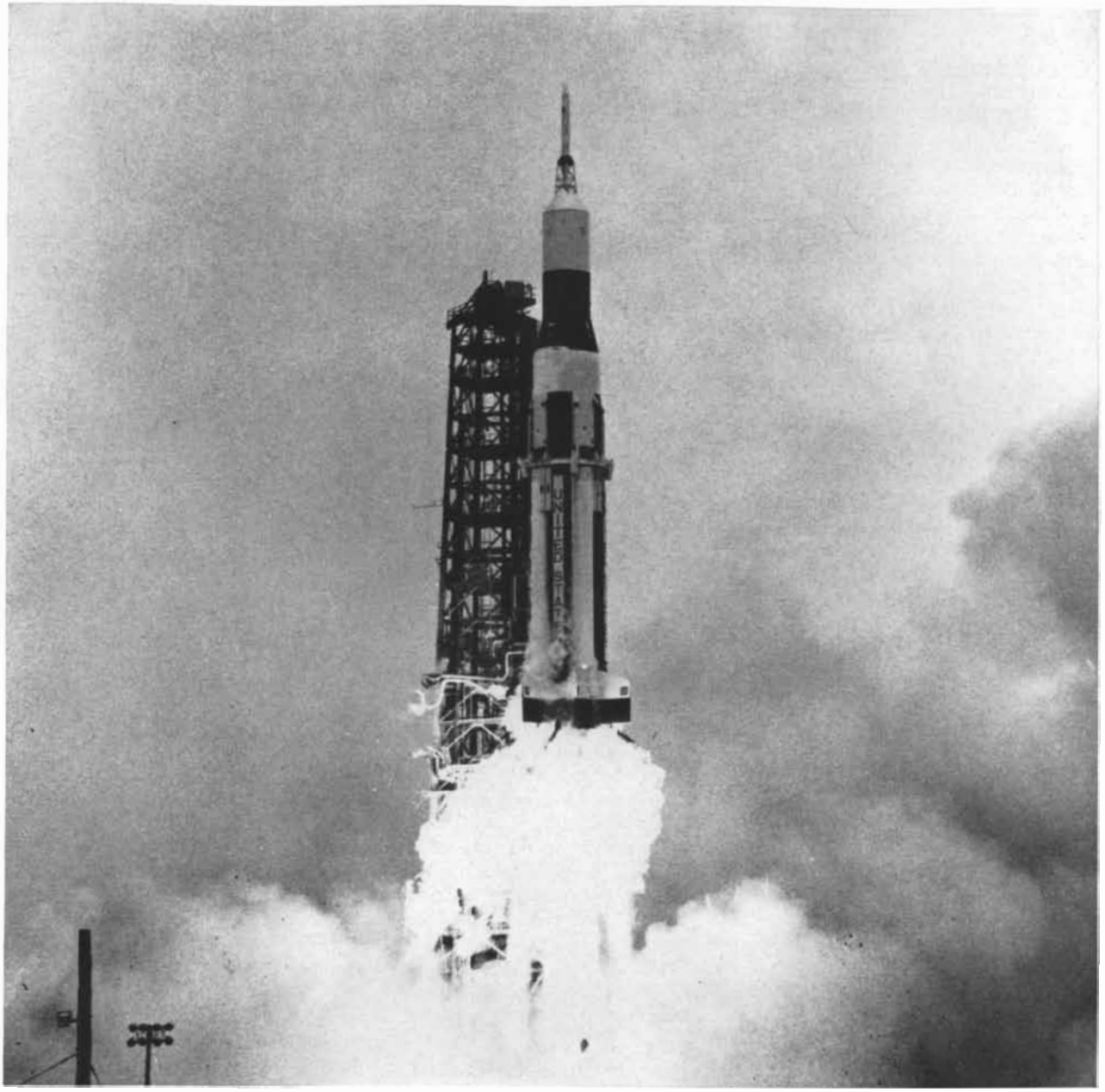
"This finding means, for example, that conservative parties must stress issues which do not divide people along class lines in order to extend their support down the social pyramid; that radical parties in democratic countries must soften their doctrine to extend their appeal upward; that agrarian parties must extend their appeal to urban groups; and so on. Partly as a corollary, business groups in democratic countries tend to maintain ties with all major political parties, for the obvious reasons."

This is a doctrine of political phoniness. What makes it phony is that emphasis is not on issues but on "appeal," and the reason is that in the U.S. the central problem for the parties is not so much the issues but their ability to get votes. This merely underscores what we all know, namely that across the nation, in village, city and state capital, politics is not leadership and not the embodiment of an idea in an organization but a game in which canniness, abetted by opinion polls and good television makeup, amplifies "appeal" and gets the vote. In the U.S. it is really only at the national level that politics retains remnants of its ancient meaning.

As a matter of fact, in the U.S. the emphasis in the so-called science of politics is so much on party appeal that the authors seem unclear about what a political "consideration" is (page 418). For example, their table on page 419, which purports to illustrate the range of agreement on political considerations between Republicans and Democrats, lists (among others) the following considerations as political: "Communist spies are a threat to this country"; "Negroes are generally lazy and ignorant"; "Jews are generally dishonest in business dealings." A political "consideration" is one in which a change of party might really make a difference in the conduct of national business because political parties are (presumably!) the organized expression of significant public issues. In the U.S., however, the connection between politics and the above "considerations" ranges from tenuous to nonexistent.

Indeed, what is striking about the 20 pages on "parties, governments and systems," their 51 propositions, their subpropositions and their explanations, tables and graphs is that the authors turn their backs on the nature of political institutions. How such institutions can realize man's hope is ignored in favor of a few aspects of some "hard" trends in party power. The good life, the raising of the standard of living, the elimination of political humiliation apparently do not exist for behavioral science. The quest begun in Plato's *The Politics* has been given up. In its place is a map of political opportunism.

I have tried to give the reader my reaction to the book as a whole. There are some good things in it. The chapter "Ethnic Relations" is, on the whole, good; the arguments against racial differences in capacities are well presented, and the argument on race prejudice is on the side of the angels. There is much excellent material on child development, although here again the presentation is marred by reference to rat data, by poor tables and by retrospective materials gathered from interviews. The sections on sensory deprivation take advantage of the recent fine work in the area and are therefore worthwhile reading. There is an excellent presentation of some major findings of the *Gestalt* school of perception, where an



Raytheon computer to be moon guide for Apollo

The first launching of an Apollo spacecraft by the sixth successful Saturn I booster brings into sharp focus the accelerating pace of the Apollo program and its accompanying technological advances.

Among the most sophisticated instruments to be used by the Apollo astronauts will be their guidance and navigation computers and displays. Produced by Raytheon's Space and Information Systems Division, and co-developed by Raytheon and the Massachusetts Institute of Technology's Instrumentation Laboratory, the sixty pound, one cubic foot general purpose computer has been designed to meet the National Aeronautics and Space Administration's unparalleled reliability requirements throughout all phases of the complex missions of Apollo's Command and Lunar Excursion Modules.

The computer, which uses integrated logic throughout, boasts a 25,000 word memory with the astonishing density of 3000 bits per cubic inch. Its extremely small size and modular construction are based on package design techniques developed in the Polaris MK-2 guidance program, another successful Raytheon/M.I.T. venture.

The Raytheon display and keyboard is the astronauts' control point for the guidance and navigation of their vehicle. All vital maneuvering and navigation commands are processed and executed through the computer and telemetered back to earth for continuous ground monitoring.

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enormous amount of ingenious and painstaking research has been done on human beings. Where data are available from learning in humans they tend to be suggestive, although all too often based on the learning of meaningless material.

On the other hand, the sections on "creativity" are depressing—they seem to be the work of uncreative people. It seems to me that, no matter how hard I think about the various characteristics of creativity given in *Human Behavior*, they will never enable me to understand the difference between Johann Sebastian Bach and Johann Christian Bach.

And so it goes. It is not so much that there are not some useful chunks of information in the book, but rather that one is oppressed by the fragmentation of everything and the piling up of truism, and by the fact that one is led constantly to wonder about the difference between precision and triviality. A page before the end the authors state:

"Indeed, as one reviews this set of findings, he may well be impressed by another omission perhaps more striking still. As one lives life or observes it around him (or within himself) or finds it in a work of art, he sees a richness that somehow has fallen through the present screen of the behavioral sciences. This book, for example, has rather little to say about central human concerns: nobility, moral courage, ethical torments, the delicate relation of father and son or of the marriage state, life's way of corrupting innocence, the rightness and wrongness of acts, evil, happiness, love and hate, death, even sex."

The authors are the best critics of their own work.

Short Reviews

ON THE ACCURACY OF ECONOMIC OBSERVATIONS, by Oskar Morgenstern. Princeton University Press ($6.50). A second, completely revised edition of Morgenstern's sharp-edged, deflating and often entertaining study of the pretensions and errors of economic statistics. Any number of circumstances can distort the raw data on which statistics are based: experiments may be poorly designed, information may be concealed, observers may be inadequately trained or downright dishonest, measuring instruments may be defective, proper controls may be impossible, and so on. Once the mischief has been done it does not make much difference how sophisticated the mathematical techniques are; the results are likely to be wrong. More than a century ago Karl Friedrich Gauss remarked that "the lack of mathematical insight shows up in nothing as surprising as in unbounded precision in numerical computers." Morgenstern confirms this observation by examples of specious accuracy in statistical statements: the U.S. Army during the Korean War published enemy casualties to a thousandth of 1 percent—at a time when our losses "were not well known even by the thousands of men"; in 1951 the Austrian finance ministry stated that the population of Salzburg province was 327,232—4.719303 percent of the entire population of Austria. (The classic example of the higher accuracy is that of the man who, when asked the age of a river, replied that it was 3,000,021 years. When it was inquired how he could give such accurate information, he said that 21 years earlier it had been given as 3,000,000 years.) Absurdities of this kind arise at almost every turn in both social and economic statistics. Their importance lies not only in that once the mathematical rituals have been performed the experts begin to believe their own figures, but also in that major decisions of government and industry are often based on them. Estimates of Soviet missile production (the notorious "missile gap"), which have fluctuated wildly in the past three or four years, of Soviet troop concentrations in Cuba, of Soviet agricultural production, of U.S. unemployment, of our rate of economic growth, of the beneficent effects of tax cuts are among recent instances of the tragicomedy of statistical errors, which gets more elaborate in an age of computers.

ETRUSCAN CULTURE: LAND AND PEOPLE, by Axel Boëthius and others, in collaboration with King Gustaf Adolf of Sweden. Columbia University Press ($42.50). This lavish volume gives an account of archaeological research and studies conducted at the Etruscan site of San Giovenale by members of the Swedish Institute in Rome. The King of Sweden, who is much interested in archaeology, promoted and took an active part in the work, and on his 80th birthday the Swedish edition of this book was presented to him. The present volume, a revised and enlarged version, contains much information not only about the excavations of the Swedish Institute but also about all aspects of Etruscan civilization over its life-span of approximately 600 years from around 650 B.C. The illustrations, highly diverse in style and scope, include handsome examples of Etruscan art, maps and charts, photographs of the mod-

RECENT findings

RESEARCH LABORATORIES

Ford

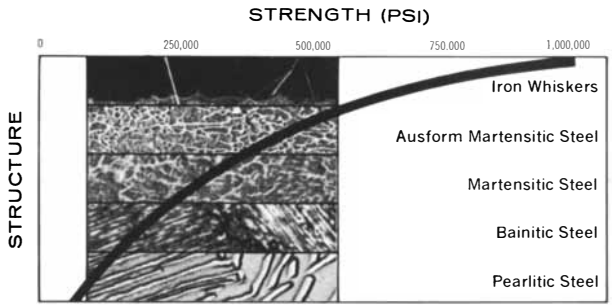
MOTOR COMPANY

AUSFORMED STEELS

Crystalline solid research has led to a Ford Motor Company process for making ultra-strength martensitic steels (300,000 to 500,000 psi) with high ductility.

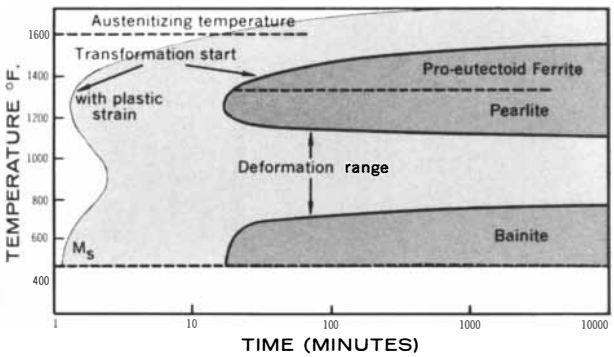
The growing demand for low weight, very high strength, tough structures in modern technology is unquestioned. The abundance of steel, its favorable economics and unique range of properties make it a most logical subject for investigation of techniques to raise its useful strength limits.

One of the products of the research at Ford Research Laboratories in the area of strengthening mechanisms was the introduction of ausformed steels. Mechanical working of metastable austenite prior to transformation to martensite resulted in tensile strengths over 450,000 psi with high ductility. The discovery of a stable dispersion of fine alloy carbides in the austenite after deformation was an important contribution to the understanding of the strengthening mechanisms.



Ausform steels, reflecting the fine martensitic grain size, are stronger in bulk samples and have better engineering properties for many applications than conventionally treated steels.

These steps are required in ausforming: 1. Austenitize to dissolve carbides; 2. Cool austenite rapidly to 800-1200° F. to avoid transformation; 3. Deform with 50-90% reduction in area by forging, rolling or extrusion; 4. Quench and temper. Early studies were conducted with high alloy compositions; however, the process is applicable to any steel with austenite sufficiently stable to allow heavy deformation. This opens the way to commercial applications and the use of lower alloy, more economical steels.



The ausform process is defined as the plastic deformation of metastable austenite at a temperature in the so-called "bay" that exists in certain alloy steels between the transformation bands of pearlite and bainite. The increased stability of this bay region of austenite is largely achieved by the use of chromium and other strong carbide formers as alloy constituents.

Ausformed steels are now being used in military applications for making rocket cases. Commercial components for vehicles, such as leaf springs (with a 30% weight saving), torsion bars and piston pins have been designed and manufacturing procedures are under development. Ausformed steels have also been used experimentally for tooling. Punches for both hot shearing and cold heading applications have shown significant potential for savings.

The key to the fracture behavior of ausform steels lies in the fibered structure which resists crack growth.

The full potential of martensitic steels is still unrealized. We believe, however, that the ausform process is a significant step towards the ultimate goal of our research.

PROBING DEEPER TO SERVE BETTER

Ford

MOTOR COMPANY

The American Road, Dearborn, Michigan

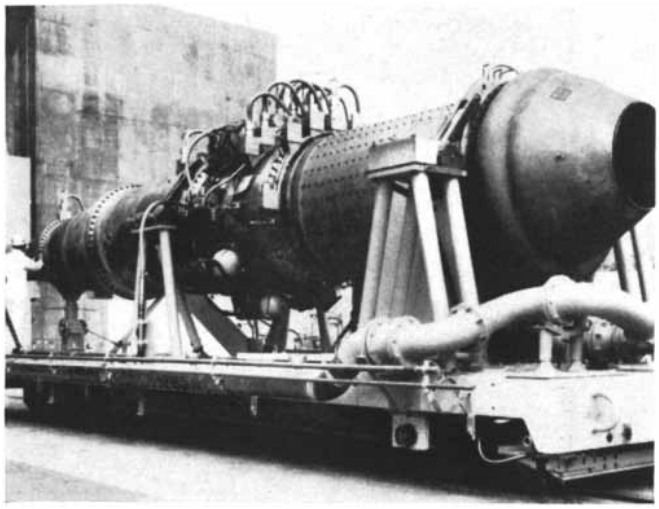
ern landscape and the ways of the inhabitants, and a pictorial record of the day-by-day labors at the excavation. Specialists have criticized some of the summary articles, particularly certain interpretations of the origins and history of Etruscan civilization, but none could deny that the volume offers an intellectual repast fit for a king.

ARCHITECTURE IN TRANSITION, by Constantinos A. Doxiadis. Oxford University Press ($7.50). COMMUNITY AND PRIVACY: TOWARD A NEW ARCHITECTURE OF HUMANISM, by Serge Chermayeff and Christopher Alexander. Doubleday & Company ($5.95). Both books start out with generalized indictments of urban sprawl and chaos and both prescribe their cures, without really diagnosing the disease. Doxiadis, the Greek city planner, says cities are bad because architects failed them by concentrating on individual buildings. He would turn architects into Renaissance men versed in "ekistics"—a broad knowledge of all the disciplines involved in human ecology—and have them assume responsibility for the total man-made environment. His solution for the expanding metropolis is to build it like a strip development along a central traffic artery and call it a "dynopolis." Chermayeff and Alexander, who teach architecture at Yale and Harvard respectively, devote half their book to telling us that cities are inhuman without analyzing why. In the second half they concentrate on the individual house and laboriously list the problems of separating children and automobiles from adult living quarters. Then they run the list through a large computer, but they do not make clear just what came out. Both books abound with rather meaningless charts. We need an urban rebirth. But neither "dynopolis" nor houses designed for privacy nor architects who want to be Renaissance men are likely to bring it about.

ZOOLOGICAL PHILOSOPHY, by J. B. Lamarck. Hafner Publishing Company ($7.75). This long-out-of-print book, first published in 1914, is an English translation of Lamarck's exposition of the theory of evolution. His central notion consists of two parts, the first a rejection of the belief in the fixity of species and the second the concept of the inheritance of acquired characteristics, that is, functionally produced modifications due to some environmental cause that requires the organism to exert certain of its parts to a greater or lesser extent than would be the case if this cause were not present. For all its shortcomings Lamarck's view was, as the historian William Dampier said, "the first connected and logical theory" of evolution. The translation by Hugh Elliot and his introduction summarizing Lamarck's work are admirable.

PSYCHOANALYSIS AND FAITH: THE LETTERS OF SIGMUND FREUD AND OSKAR PFISTER, edited by Heinrich Meng and Ernst L. Freud. Basic Books, Inc., Publishers ($4.95). An English translation by Eric Mosbacher of an exchange of letters (spanning the period from 1909 to 1938) between Freud and a Swiss Protestant clergyman who was the first pastor to use the techniques of psychoanalysis to help his parishioners and reputedly one of only two nonmedical analysts to practice before World War I. Most of the letters are Freud's, Pfister's having been destroyed or lost. Only a few appear here, reconstructed on the basis of his notes. Anything Freud wrote is bound to engage one's attention for its literary, personal, historical or intellectual interest. But the bulk of this correspondence is pretty marginal stuff, relating to contemporary quarrels, publication problems, organizational intrigues and the like, and the general reader will not find it entrancing.

METEORITES, by Fritz Heide. The University of Chicago Press ($6.50). This is a distinguished introductory survey. The author, who is professor of mineralogy and petrography at the University of Jena, has compressed into a volume of 135 pages a wealth of information about meteorites without hurrying or crowding the reader. The main topics are the fall of meteorites and the nature of meteoritic matter. Considerable attention is given to descriptions of the world's principal meteorite craters and to various hypotheses that attempt to explain why the craters contain no sizable chunks of the projectiles that excavated them. In each case the total mass of the meteoritic material in and around the crater falls far short of that of the original projectile. For example, the great crater at Canyon Diablo in Arizona, whose maximum diameter is 1,295 meters and whose depth measured from the rim is 174 meters, is thought to have been produced by a meteorite about 20 meters across. But the meteoritic material found at the crater comes to no more than a few hundred tons. The most plausible assumption is that the mass of the meteor that made the hole was very large, that its energy therefore was so great that the atmo-



TORY IIC ramjet reactor ground test system developed by Lawrence Radiation Laboratory for the Atomic Energy Commission.

Nuclear Control Servomechanisms for TORY IIC Ramjet Reactor

Full power tests of the TORY IIC are being conducted by the Lawrence Radiation Laboratory at the Atomic Energy Commission's Nevada Test Site. Six electropneumatic servomechanisms developed by the Research Laboratories Division of The Bendix Corporation are being used in controlling the TORY IIC reactor.

These control rod servomechanisms operate at a temperature slightly in excess of 1000° F. in a high acoustic vibration and high-level nuclear radiation environment. Conventional servo actuators, generally electromechanical or hydraulic, are unable to provide satisfactory performance while withstanding the environment without massive shielding and cooling equipment.

Bendix, under Atomic Energy Commission contract directed by the Lawrence Radiation Laboratory, has investigated the use of electrically controlled pneumatic servos culminating with the development of linear

Servo actuator system used in TORY IIC.

servo actuator systems used in control of the TORY IIC reactor. Each actuator includes an electropneumatic servo valve, pneumatic motor, transmission, electromechanical feedback transducer, and pneumatic scram pistons.

These actuators are the only ones known capable of operating at a temperature of over 1000° F. and represent a technological advance applicable to the nuclear ramjet program and also to conventional chemically fueled air breathing engines when supersonic speeds require controls with extreme temperature capability.

Bendix Research embraces a wide range of technology including acoustics, nuclear, solid state physics, quantum electronics, mass spectrometry, photoelectronics, electron beam and tube technology, measurement science, applied mechanics, energy conversion systems, dynamic controls, systems analysis and computation, navigation and guidance, microwaves, digital techniques, data processing and control systems. Motivation: to develop new techniques and hardware for The Bendix Corporation to produce new and better products and complete, integrated, advanced systems for aerospace, defense, industrial, aviation, and automotive applications. Inquiries are invited. We also invite engineers and scientists to discuss career position opportunities with us. An equal opportunity employer. Write Director, Bendix Research Laboratories Division, Southfield, Michigan.

Research Laboratories Division

THE Bendix CORPORATION

WHERE IDEAS UNLOCK THE FUTURE

sphere was quite unable to brake its cosmic velocity, and that it struck the earth's surface with such force that it exploded and was vaporized to a gas cloud. This, perhaps, is why few large projectiles have ever been found and none are likely to be. Many illustrations.

CONCISE DICTIONARY OF AMERICAN BIOGRAPHY. Charles Scribner's Sons ($22.50). Like its distinguished parent, the multivolume *Dictionary of American Biography,* this book contains 14,870 biographies of Americans who "have made memorable contributions to our national life" and who died before December 31, 1940. The length of the articles has been considerably reduced; the majority of the entries give little more than vital statistics, information on occupation and a concise statement of the subject's outstanding achievement. There are, however, many fully satisfying memoirs about men whose work, to be comprehensible, has to be explained in detail. Thus, for instance, the reader will not be disappointed in the treatment of John Adams or James Blaine, William or Henry James, Charles Sanders Peirce, Jefferson or Lincoln, Joseph Henry or Patrick Henry, Samuel Morse, Boss Tweed, James Whistler, Simon Newcomb or Walt Whitman. A first-rate reference tool.

JANE'S FIGHTING SHIPS: 1963–64, compiled and edited by Raymond V. B. Blackman. The McGraw-Hill Book Company ($39.50). The less useful navies become and the more their craft become anachronisms, the noisier become the naval enthusiasts. The maxim "Who rules the sea rules the world" may have had meaning in Nelson's time, but it is as appropriate to contemporary circumstance as "Damn the torpedoes" or "You may fire when ready, Gridley." This never makes any difference to either the naval staffs or *Jane's.* The 66th-year issue has been extensively revised and amplified and contains no fewer than 490 new illustrations. The dove of peace will not quiver with delight on learning that whereas the 1946 *Jane's* listed 52 navies, the present issue features 96.

THE RADICAL TRADITION, by R. H. Tawney. Pantheon Books ($4.95). A collection of 12 essays on various themes of politics, education and literature published over a period of 40 years by the late economic historian, best known for such major works as *Religion and the Rise of Capitalism* and *The Acquisitive Society.* The essays are not, by and large, the best of Tawney, but a few, such as one on social history and literature, are handsomely written and superbly controlled, exhibiting his special quality, as the late Hugh Gaitskell described it, of combining learning with passion.

TUNNELS, by Gösta Sandström. Holt, Rinehart and Winston, Inc. ($6.95). A knowledgeable, well-written and often engrossing history of tunnels from the ancient Egyptian rock temples to the great new passage through Mont Blanc completed in 1962. Sandström is sufficiently expert and articulate to make the complex technology of modern tunnel building as palatable to the reader as the more dramatic events in the annals of building tunnels. Good illustrations.

THE SOUTHERN APPALACHIAN REGION, edited by Thomas R. Ford. University of Kentucky Press ($10). A comprehensive survey by a group of scholars of this economically stricken region including more than 80,000 square miles in Kentucky, Tennessee, West Virginia, Virginia, Alabama, Georgia and North Carolina. The contributions consider population problems, the different portions of the economy, the character of local government, state and regional planning, educational needs, health and health services, social problems and welfare services, and the folk arts of the region.

THE CIRCULATION OF THE BLOOD AND OTHER WRITINGS BY WILLIAM HARVEY, edited, translated and introduced by Kenneth J. Franklin. Everyman's Library, E. P. Dutton & Co. ($1.95). In addition to giving a fresh translation from the Latin of Harvey's pathbreaking work *Movement of the Heart and Blood in Animals* (1628), this volume contains Harvey's two later disquisitions on the circulation of the blood, his last will and testament and *The Anatomy of Thomas Parr*—Harvey's observations on the dissection of a Shropshire farmer, a lad who was said to have lived to the age of 152 years and nine months.

RESTORATION OF FUNCTION AFTER BRAIN INJURY, by A. R. Luria. Pergamon Press ($10). A translation from the Russian of a monograph on the aftereffects of brain injury. Luria, who was trained in psychology and medicine and has had extensive experience with war wounds of the brain, has made important contributions to this

Freeman

BOOKS IN SCIENCE

The Language of Nature

AN ESSAY IN THE PHILOSOPHY OF SCIENCE

David Hawkins, *University of Colorado*

1964, 372 pages, $7.50

Written in an informal style, this disquisition on the philosophy of science is intended as much for scientists as for philosophers. It presents an original analysis of a wide range of scientific topics and leads the reader through a search for unifying ideas among them.

"Dr. Hawkins has written a philosophy of science in a felicitous style. The ideas are clearly developed and the author exhibits not only a fine knowledge of science, but—what is even more enjoyable—a richness of literary and philosophical background in the history of ideas. His range in science—from the natural through the social—is broad and quite deep. The illustrations in the book are also stimulating and tasteful. The bibliographical commentaries are a nice bonus."

C. W. BEREUDA, University of Oklahoma

Modern Quantum Theory

Behram Kurşunoğlu, *University of Miami*

1962, 518 pages, $14.00

A systematic presentation of the modern aspects of quantum mechanics, particularly as the subject has developed during the last fifteen years.

"I thank you very much for sending your text-book on modern quantum theory. I was very interested to see that you represent the traditional quantum theory in a form which is very suitable in view of the later development. The students who study your book will probably find it much easier to learn modern quantum field theory and its group-theoretical aspects after studying your book."

W. HEISENBERG, Max-Planck-Institut für Physik und Astrophysik

"... into a single book the author has synthesized many of the fundamental concepts of modern theoretical physics."

NEAL MOORE, in the American Journal of Physics, October 1963

College Chemistry

AN INTRODUCTORY TEXTBOOK OF GENERAL CHEMISTRY

Linus Pauling, *California Institute of Technology*

Third Edition.
1964, 832 pages, $8.25

A new edition of a world-renowned introductory textbook.

"The book is excellent and a considerable improvement over the second edition through a good job of updating, yet it has the same clarity and authority."

WILLARD F. LIBBY, University of California, Los Angeles

"I think that Pauling's revision of College Chemistry represents a major advance in textbooks for an introductory chemistry course. I believe that it will produce the same kind of change in this course that the first edition of this book made some years ago. I am particularly pleased with the introduction to thermodynamics, statistical distributions and quantum mechanics in an early chapter of the text. But more than that I am pleased by his applications of thermodynamic principles throughout the remainder of the book. The principles are not introduced simply as a 'frosting on the cake'; they permeate the body of the text in many applications . . . [I am] enthusiastically adopting the book."

WILLIAM SPINDEL, Rutgers University, Newark

Computational Methods of Linear Algebra

D. K. Faddeev and V. N. Faddeeva. Translated by Robert C. Williams from the 1960 Russian edition

1963, 621 pages, $11.50

A systematic presentation of both classical and recently developed numerical methods as applied to linear algebra, with many numerical examples.

"This is a superb book in both theory and computational procedures."

THOMAS L. WADE, Florida State University

"This is an excellent book. The predecessor, in paperback form, is already a 'classic,' and this edition extends both the material and the presentation significantly."

DANIEL DREW, University of California Extension, Lockheed Missiles and Space Company

Molecular Biology of Bacterial Viruses

Gunther S. Stent, *University of California, Berkeley*

1963, 474 pages, $9.50

An introduction for nonspecialists, designed to prepare the reader for more advanced or specialized works.

"This brilliantly written book is by Gunther Stent, one of the few people who could conceivably have done the job. Stent combines the qualities of an outstanding scientist with those of an outstanding teacher, and he has put into some 470 pages a distilled essence of molecular biology as it is approached through bacterial viruses. Any undergraduate, graduate, or postdoctoral student with even a sketchy background in biochemistry and cellular biology can use this book to tremendous advantage . . ."

E. A. ADELBERG, in Science, January 24, 1964

Fluvial Processes in Geomorphology

Luna B. Leopold, *U.S. Geological Survey*, M. Gordon Wolman, *The Johns Hopkins University*, and the late John P. Miller, *Harvard University*

1964, 522 pages, $10.00

Remarkable advances have been made in the past decade in the application of analytical and experimental techniques to the study of running water and its effects. This book concentrates on these developments and differs from virtually all previous books on the subject in its emphasis on geomorphic process rather than the history of land forms.

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difficult subject. His chapter on the restoration of speech and the methods of retraining is as fascinating as it is moving.

AERODYNAMICS, by Theodore von Kármán. McGraw-Hill Book Company ($2.45). A reissue of a short book that sketches the history and principles of flight. No one knew more about aerodynamics than Theodore von Kármán, no one contributed more to the modern development of the subject and no one wrote about it with such elegance and effortless clarity. Illustrations.

THE THEORY OF ATOMIC SPECTRA, by E. U. Condon and G. H. Shortley. Cambridge University Press ($3.95). A soft-cover reissue of a noted monograph first published in 1935. Much has happened in this field in the past quarter-century that would have to be covered if the book were written today, but it still stands on its own.

Notes

AN INTRODUCTION TO THE PHILOSOPHY OF SCIENCE, by Arthur Pap. The Free Press of Glencoe ($7.95). A lucid, thoughtful discussion of the philosophical problems of the sciences by an uncommonly able philosopher who died in 1959 at the age of 37.

GEORGES CUVIER, ZOOLOGIST, by William Coleman. Harvard University Press ($4.75). A study of the scientific work and thought of the pre-Darwinian zoologist Georges Cuvier, who, although he was a determined advocate of the fixity of species, made contributions of the highest order to comparative anatomy, zoological classification and vertebrate paleontology.

ATLAS OF ELECTRON MICROSCOPY: BIOLOGICAL APPLICATIONS, compiled by F. Scanga. American Elsevier Publishing Company, Inc. ($37.50). This large atlas contains several hundred beautifully reproduced electron micrographs dealing with microorganisms and the structure of different types of cells in various tissues and organs.

A FIELD GUIDE TO ROCKY MOUNTAIN WILDFLOWERS, by John J. Craighead, Frank C. Craighead, Jr., and Ray J. Davis. Houghton Mifflin Company ($4.95). This volume in the "Peterson Field Guide Series" covers the Rocky Mountain wild flowers from northern Arizona and New Mexico to British Columbia.

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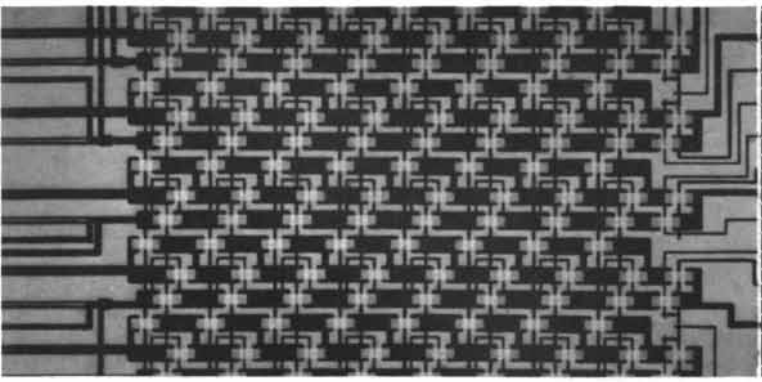
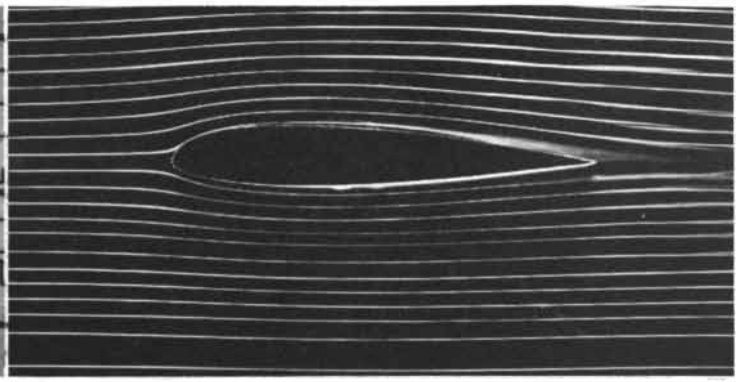
$$F \propto \frac{M_1 M_2}{r^2}$$

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





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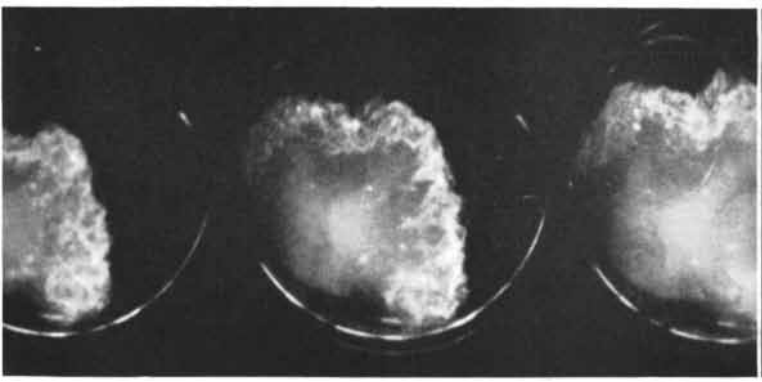
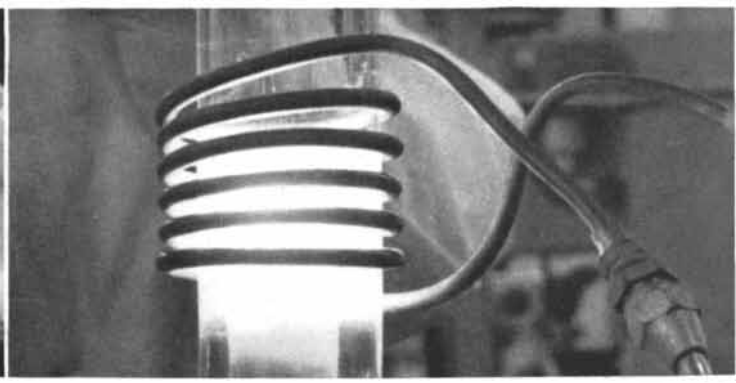
$$L = \omega \frac{dm}{dt}$$





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

$$E = h\nu$$

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