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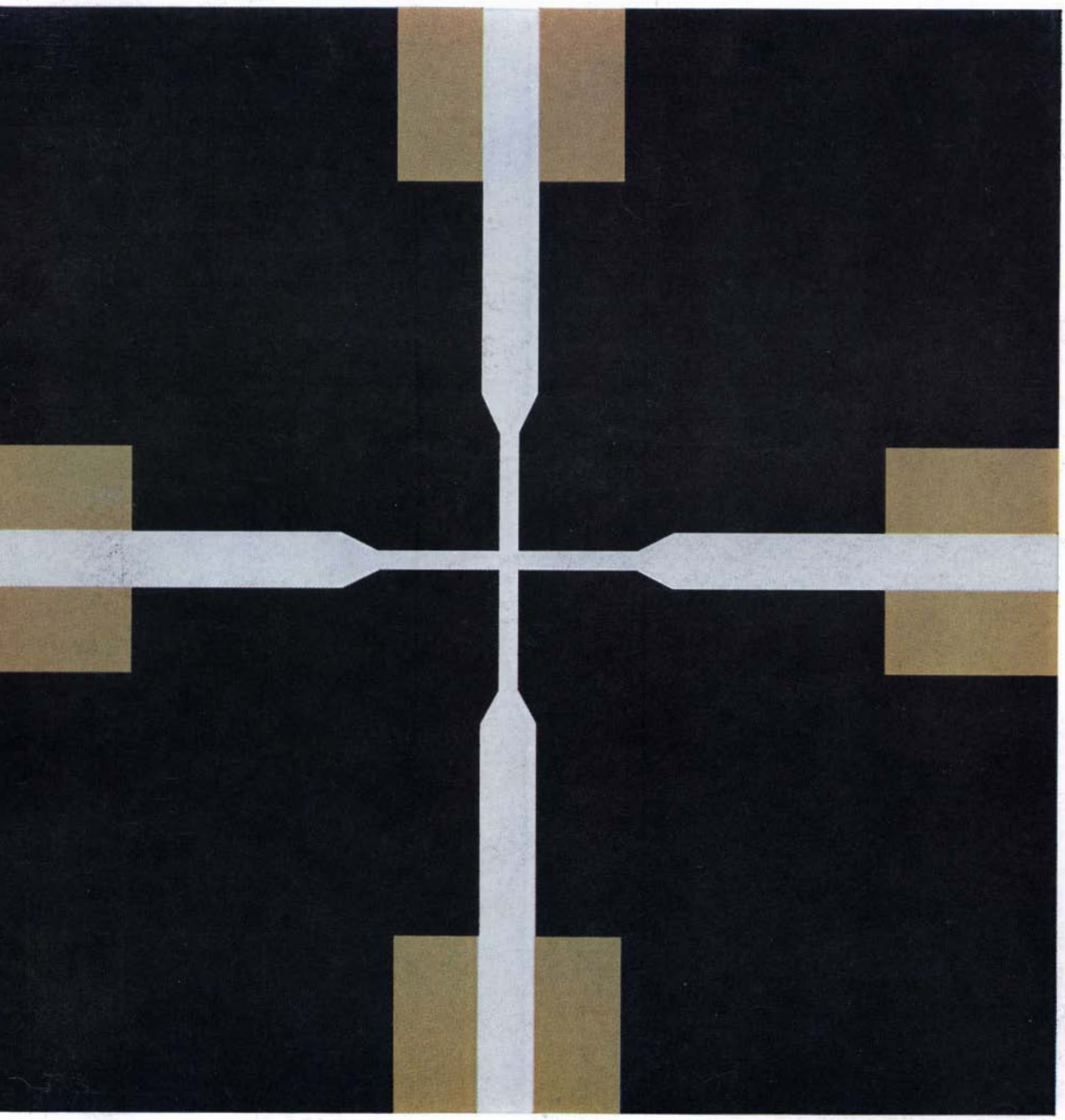

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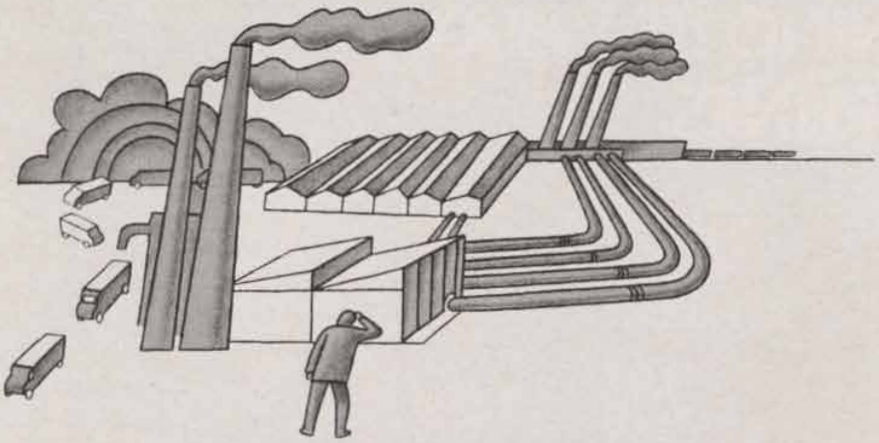

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ARTICLES



DEPARTMENTS





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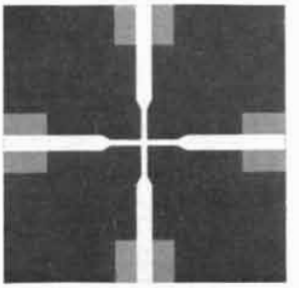

## THE COVER

The design on the cover is actually a photograph of a simple electronic device called a Josephson junction. The junction consists of an inch-square glass plate bearing two superposed superconducting tin films (*silver-colored strips*) separated by an insulating layer of tin oxide only 40 billionths of an inch thick. The gold-colored rectangles are used for making electrical contact with the films. The metals are deposited on the glass by passing them in the form of hot vapor through a succession of masks inside a vacuum chamber. The oxide layer is formed by exposing the bottom strip to a small amount of oxygen. The Josephson junction is the heart of a recent experimental study that has yielded an extremely accurate new determination of the ratio $e/h$ ($e$ is the charge of the electron and $h$ is Planck's constant). How the device is used to measure $e/h$ and how this measurement has in turn influenced the values of other important physical constants is explained in the article "The Fundamental Physical Constants," which begins on page 62.

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# SCIENCE/SCOPE

A lightweight 1500-watt oriented solar array, built by Hughes for the U.S. Air Force's Aero Propulsion Laboratory, Wright-Patterson AFB, will be the primary experiment aboard a Space Experiment Support Program satellite scheduled for launch in September 1971. The FRUSA (Flexible Rolled-Up Solar Array) power system consists of two 16 x 5.5-foot panels that are contained in a 10-inch-diameter cylinder at launch.

The solar panels will be unrolled in orbit to their 32-foot length, oriented toward the sun, and held rigidly by parallel extension arms. The arms will be formed from metal ribbons unreeled through dies that turn them into stiff tubes (then flatten them into ribbons again when the array is retracted). Ten deploy-retract cycles will be attempted during the 180-day flight.

A U.S. Navy Phoenix missile blasted a jet fighter drone out of the skies off the California coast recently in the missile's first test flight carrying a live warhead. It was launched at an altitude far above the target in order to demonstrate the ability of the AWG-9 missile control system to pick out targets from ground clutter that would handicap a conventional radar. The range was described as "far short of maximum, yet much greater than that of any existing operational air-to-air guided missile."

This success marks another major milestone in the flight test program for the Phoenix and the AWG-9, which Hughes is building for the Navy's new F-14A fighter. Earlier tests included supersonic and long-range launches, high-altitude launches against high-altitude targets, and the first successful multiple launches against two widely separated targets.

An advanced modular computer designed to meet military command-and-control requirements has been developed by Hughes. Designated H4400, it can be expanded to include up to eight processor and 16 memory modules per computer. Such a system can perform more than 4 million operations per second and store more than 8.5 million bits of information. Advanced features include automatic fault isolation, automatic reassignment of a malfunctioning module's tasks, and extensive use of medium- and large-scale integrated circuits. Each module weighs 40 pounds and is housed in a standard package whose volume is 0.9 cubic foot. A comprehensive software package has been developed.

RF circuit design engineers are needed now at Hughes. Responsibilities will include circuit design of digital data transmission and/or RF equipment and determination of optimum hardware configurations. Requirements: BSEE (MS desirable), U.S. citizenship, at least two years of recent experience in the detailed circuit design of RF circuits in the 3-300 mhz range. Please write: Mr. R.A. Martin, Hughes Aerospace Divisions, 11940 W. Jefferson Blvd., Culver City CA 90230. An equal opportunity employer.

31 tactical air-control operations centers and two training systems, now in production at Hughes, will enable the U.S. Air Force to respond to fast-changing battlefield situations. The centers -- consisting of computer, displays, communications equipment, and air-supported inflatable shelters -- are packaged in 13-foot-long rectangular modules which can be moved by cargo plane, helicopter, or truck. The Hughes HM 4118 high-speed digital computer can operate in almost any military environment.

# LETTERS

Sirs:

I write briefly in comment on the article "Medieval Uses of Air" in the August issue of your journal. Its author, the eminent historian of medieval technology, Lynn White, Jr., states that the windmill was virtually unknown in Islam and was "independently" invented "in the North Sea region of Europe by A.D. 1185." Professor White knows better than anyone the controversy that surrounds the origins of the European windmill, and I'm sure it would be of interest to your readers to ascertain from him, if possible, why these statements are at such variance with recent work in this area of research. In 1935 Marc Bloch asserted in an essay on the advent and triumph of the water mill (*Land and Work in Medieval Europe*) that the windmill "was probably borrowed from the Arab world, coming into the West about the end of the 12th century." This opinion has recently been in part confirmed by a German specialist, Klaus Rockenbach, in an article in the *Archiv für Kulturgeschichte* L (1968), where he states that the latest research in the history of the windmill has dispelled all previous doubts about the Eastern origins of the windmill at the time of the (first) Crusades. However, he gives as the date of the first documentary evidence of the northern European (French) windmill the year 1105. There is evidently quite a disagreement as to dates and provenience of the European windmill. Can this be clarified? Perhaps the difficulty arises over just which type of windmill—vertical or horizontal axle—was introduced where.

For the rest of the article, I may say, as other readers possibly have said already to themselves, that the opening thesis seems virtually self-contradictory. I don't know how it would be possible, for instance, for ancient architects to use mathematics for aesthetic effect without mathematics' playing a part in their engineering. In brief, the implied dichotomy between applied and theoretical science is much too great for any period of technological history in the West.

FREDERIC AMORY

Berkeley, Calif.

Sirs:

The pictures on pages 93 and 98 of your August issue, and every spinning wheel that I have seen in a museum or junk shop, illustrate an interesting point on which I hope you will be able to get Professor Lynn White, Jr., to comment. The crank has its radial member shaped like a *C*. Obviously the shape of this rigid connecting piece is immaterial and later devices such as the bicycle pedal were made straight. But initially mechanics seem to have felt that the torque from a shaft, as in the waterwheels you illustrate, or the torque transmitted to a shaft, as in a spinning wheel, had to be instructed. The *C*-shaped connecting piece seems to satisfy an emotional need that is felt by the mechanic....

N. W. PIRIE

Rothamsted Experimental Station
Harpenden, Herts.,
England

Sirs:

In comment on Mr. Amory's letter, latest date of publication need not reflect the best scholarship: it may simply perpetuate old error. In 1968 Rockenbach revived the date 1105 for the first appearance of the windmill in Europe. One hundred seventeen years earlier, in 1851, the immensely learned Léopold Delisle in his *Études sur la classe agricole en Normandie au moyen âge* noted that the charter of 1105 which mentions *molendina ad ventum* is a forgery: it purports to record gifts to the abbey of Savigni, which was not founded until 1112. The earliest unambiguous record of a European windmill that I have been able to find places it at Weedley in Yorkshire in 1185. See *Records of the Templars in England in the Twelfth Century: The Inquest of 1185*, edited by B. A. Lees (London, 1935).

Marc Bloch was one of the greatest historical minds of our century; I have dedicated a book to his memory, although I never knew him. If he were alive today, I suspect that he would modify his very guarded statement that the European windmill "was probably borrowed from the Arab world." We have much to learn about medieval Islamic engineering, but the failure of the windmill to spread in Islam seems clear. Writing in 1205–1206 at Edessa, al-Jazarī, the most interesting Muslim technologist of his time, said that the wind was simply too fickle to operate mills, this despite the fact that vertical-axle windmills had been twirling for nearly three centuries in Afghanistan, and horizontal-axle windmills for about 14 years in the Crusader states of the Syrian coast.

As for the use of mathematics by medieval architects, who were normally engineers and artists as well, all I can say is that their extant notebooks from Villard de Honnecourt's (*ca.* 1235) onward show intense interest in achieving beauty in a building, a statue or a painting by geometrical and proportional relationships, but no mathematical approach to purely structural problems. These were handled empirically—and often magnificently.

I wish that I could answer Dr. Pirie's very discerning question that gets us into the subliminal minds of engineers. Curved key seats appear in cranks even in the 19th century. Yet as early as Giuseppe Ceredi's *Tre discorsi sopra il modo d'alzar acque da' luoghi bassi* (Parma, 1567) experts have pointed out that these curves lack function. In my *Medieval Technology and Social Change* I suggested that they may have been an effort to get some flywheel action into the crank motion. But I cannot prove it.

LYNN WHITE, JR.

University of California at Los Angeles
Los Angeles, Calif.

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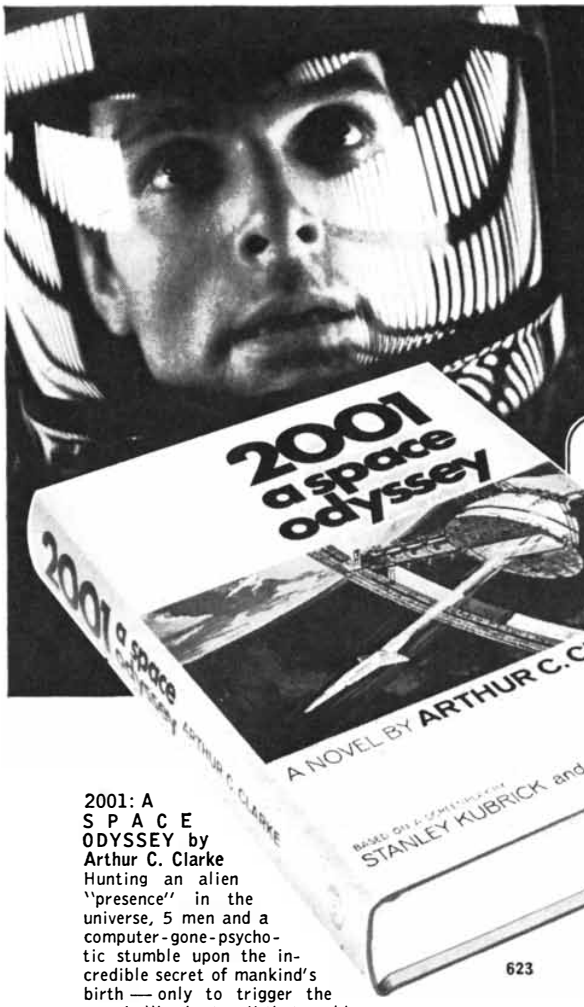


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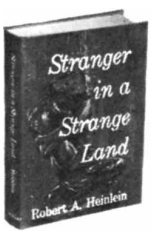


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## SCIENTIFIC AMERICAN

OCTOBER, 1920: "We celebrate with this issue the 75th anniversary of the founding of SCIENTIFIC AMERICAN, which took place in 1845."

"Herr Colsmann, the director-general of the Zeppelin interests, recently returned from the U.S. after negotiating with certain firms regarding transatlantic air traffic. Negotiations have also been carried on with Holland, Sweden and the U.S. for the construction of airships on an international basis. It is rumored that a new type of Zeppelin airship, with a load capacity of 60 tons, accommodation for 500 passengers and a fuel capacity for a voyage three times the length of the Atlantic crossing, is to be evolved."

"The authorized English translation of Einstein's own book (*Relativity: The Special and the General Theory*), which is intended to explain his theories to the general public, is now available from the SCIENTIFIC AMERICAN Publishing Co. Dr. Einstein has scored a conspicuous success in this volume, steering a skillful course between the twin dangers of too much mathematics and too little explanation. Also, he makes clearer than has yet been made just wherein lies the dividing line between his special theory and his general theory, and just where the two join. In literary style as well as in clarity of exposition this book bids fair to take rank as a classic; and in any event, it is by far the most satisfactory treatment of the subject to be had at the present date in English."

"The Sixth Gordon Bennett Aviation Cup race was held near Étampes, France, on September 28th. It was won by Sadi Lecointe on a French Nieuport biplane equipped with a 300-horsepower Hispano-Suiza engine. The contest was held over a 50-kilometer course extending from the aerodrome of Villesauvage to La Marmogne. Three rounds of this course had to be covered, making a total of 300 kilometers (186.45 miles). Lecointe rose to 3,000 feet to pick out the most direct line to the other end of the course. He then descended to about 40 feet, crossed the starting line and in a few seconds disappeared over the horizon. Lecointe's piloting on the turns aroused great enthusiasm. His system was to bank the machine several hundred yards before the line. Just before reaching it he would kick the rudder hard over, centrifugal force carrying him beyond the line in a turn approximating the vertical. The finish line was crossed at a bare 10 feet above the ground, the 300 kilometers being covered in only one hour six minutes 17⅕ seconds, thereby creating a new world's record."

## SCIENTIFIC AMERICAN

OCTOBER, 1870: "The art and science of photography has only existed 25 years, yet it is safe to say that in no other department of investigation has there been greater progress than in this. At first it was confined to taking portraits and was looked upon as a trade rather than as a science; now its applications extend to every branch of human knowledge. It gives to the naturalist true pictures of animals, plants and minerals, and to the geographer plans for charts; by it the engineer in a few minutes can make true copies of the most difficult drawings, for the preparation of which the most skillful draftsman would require many weeks. In lithography and porcelain painting there is now extensive application of photography. The finest productions of artists are copied and easily multiplied, so as to be accessible to the poorest man, and in this way photography serves to cultivate the tastes of the people for art, just as printing disseminates a knowledge of science. There are few branches of science into which photography has not penetrated, and where its services have not been of the most signal importance."

"There have been of late several brilliant displays of the Aurora Borealis, or Northern Lights, and the indications are that the present fall and coming winter will witness a succession of magnificent auroral demonstrations. These are accompanied by the usual magnetic disturbance and interruption of telegraphic working. The true character of the phenomena is still undetermined, but there would seem to be little room for doubt

that they are electrical, and are mainly induced by the magnetic action or disturbances of the sun. The photosphere of the sun is in a state of great perturbation, and has been for some time past. At times the spots have been so extensive as to be almost visible to the unaided eye. Cyclones and storms, of an extent and violence almost inconceivable to us, are taking place on the surface of our great luminary, and the auroras which render our nights brilliant and magnificent are in some undiscovered way the result of these terrible manifestations."

"It appears that the bill revising the patent and copyright law, enacted July 8, 1870, by a singular blunder repeals the acts of March 3, 1849, that provide for the establishment of the Department of the Interior. According to this state of things Secretary Cox is not now a member of the Cabinet. Although a blunder appears to have been committed, the act is now treated as a dead letter."

"According to the Paris correspondent of the New York *Tribune*, the roar of cannons is now continuous in Paris, as the contending armies are constantly at work, harassing and destroying each other. One shudders at the probable condition of this beautiful city and its inhabitants at the present moment. The Palace of the Tuileries, the Palace of the Luxembourg, the Grand Hotel and other public buildings are turned into hospitals and lazar houses, as shown by the yellow flags displayed upon them, and the city is crowded with probably a million and a half non-combatants. The long list of disasters to the French arms has been crowned with news of the fall of Strasbourg, which must strike to the hearts of the Parisians like the final death-blow to all hope of success for their cause. Their parks are dismantled, their beautiful groves destroyed, and their rich bronzes melted down as material for artillery. They are cut off from external intercourse with the world, and can only get such news of external affairs as the Prussians permit to pass their lines. They are consequently well posted as to their disasters, but anything calculated to raise hope could only, if it existed, reach them by devious and doubtful means. To crown it all, it is reported that riots rage in the streets, and that firing can be both seen and heard from a distance between unknown factions, which must, whatever their character, add to the confusion of the populace."

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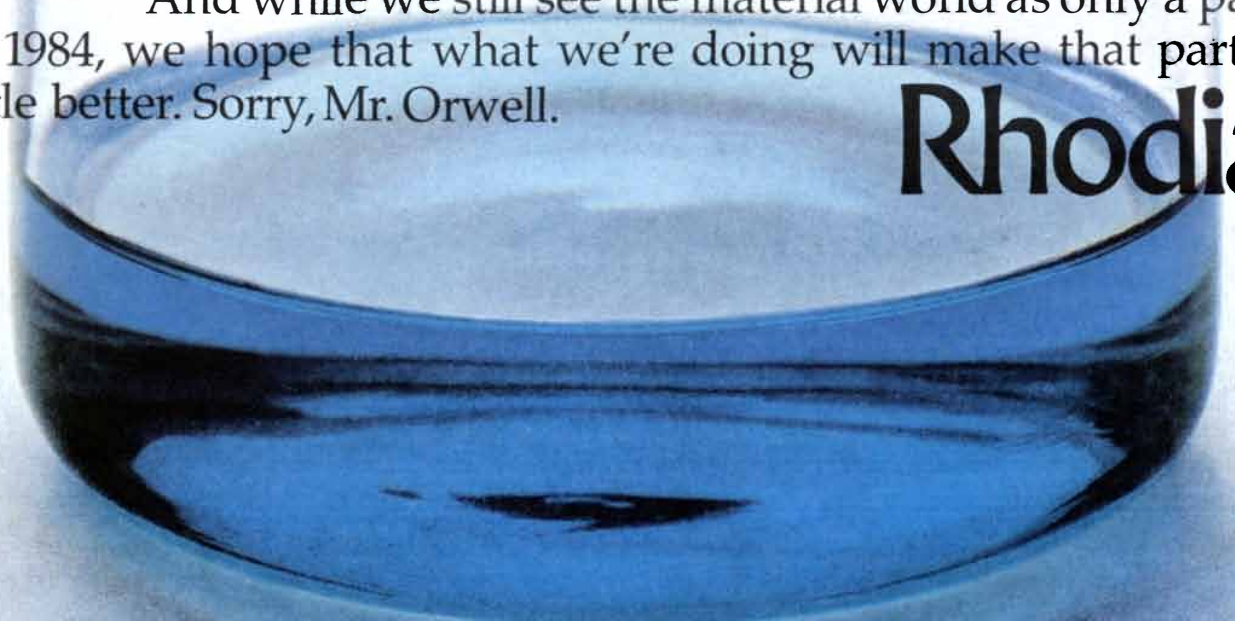

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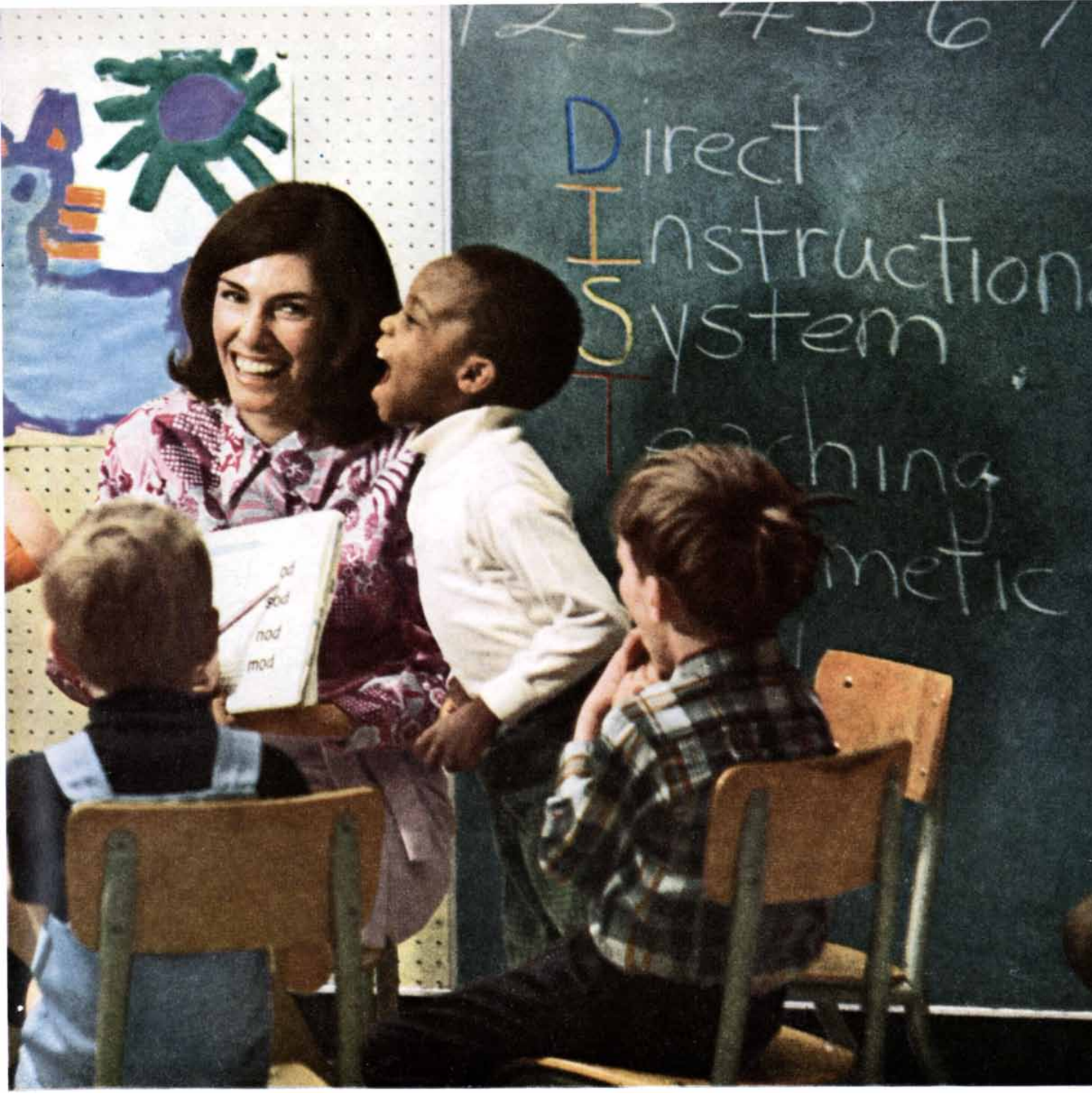



*A kindergarten class in Brooklyn, N.Y. Schools in 45 states already use the Distar™ Systems, published by SRA, a subsidiary of IBM.*

Ruth Simmons teaches kindergarten at P.S. 321 K, in Brooklyn, New York. Dr. Harry Weintraub is the Principal. Between them, they've taught and observed all kinds of youngsters—bright, slow, and the educationally disadvantaged.

"Usually, we don't teach formal reading to children before the first grade," says Dr. Weintraub. "But last year we experimented with a new system called Distar that starts them off in kindergarten.

"This system provides teachers with a technique designed to reward even the slowest child with a sense of success. You have no idea how important this is for such youngsters."

The Distar System evolved from five years of research by Siegfried Engelmann and colleagues at the University of Illinois. The program includes material for teachers, workbooks and take-home sheets for children.

Miss Simmons explains some of the classwork. "We teach the *sounds* letters of the alphabet represent. If a child finds it hard to grasp, we don't point out his troubles. We merely reprogram the lessons a little to give his problem special attention without anyone becoming aware of it.

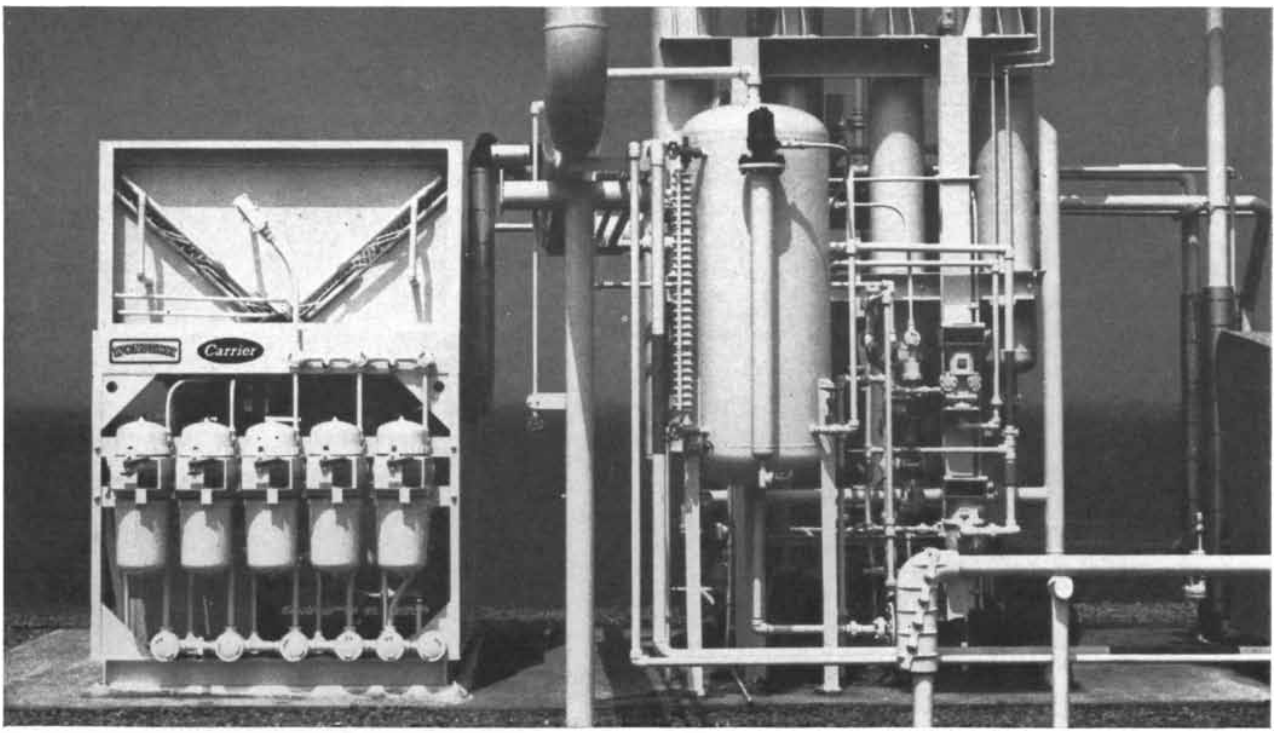
"When the children learn these sounds, we teach them how to put several of them together. All of a sudden, they're reading words. And do they feel great!

"Our District Superintendent, Dr. Anthony Ferrerio, introduced Distar to two schools in our district last year after hearing how successful it was in schools around the country.

"I'm very enthusiastic about it. I know my kids will be reading *stories* before they get to the first grade. And that's really something."

IBM

# How The Group helps get the gas that got away.

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This year, vapor recovery systems are out to plug up this costly leak.

One of these systems has been developed by Wonderly Construction Company. And major oil companies are using it in the Los Angeles area, right now. A vapor condensing cycle that collects gasoline vapor at the tank truck filling vent. Condenses it to a liquid. Pumps it back to the storage tank.

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# THE AUTHORS

WALTER F. BODMER and LUIGI LUCA CAVALLI-SFORZA ("Intelligence and Race") are respectively professor of genetics at the University of Oxford and professor of genetics and chairman of the department of genetics at the University of Pavia. Until recently they were together at the Stanford University School of Medicine, where Bodmer had been a member of the faculty since 1962 and Cavalli-Sforza was a visiting professor. Bodmer writes: "I was born in Germany but came to England at a very young age when my parents emigrated to escape from Hitler. I went to school in Manchester to the Manchester Grammar School, which is well known mainly for its ability to get its students scholarships at Oxford and Cambridge." Bodmer was graduated from the University of Cambridge in 1956 and obtained his Ph.D. there in 1959. Cavalli-Sforza received a degree in medicine at the University of Pavia in 1944 and a master's degree at Cambridge in 1950.

ROBERT S. DIETZ and JOHN C. HOLDEN ("The Breakup of Pangaea") are marine geologists with the Environmental Science Services Administration, working at the Atlantic Oceanographic and Meteorological Laboratories in Miami. Dietz, who obtained his Ph.D. from the University of Illinois in 1941, has written extensively on geotectonics, geosynclines, continental drift (with the late Harry H. Hess of Princeton he was originator of the sea-floor-spreading concept that is now widely accepted as the underlying mechanism of continental drift), the morphology and structure of the ocean floor, the history of ocean basins, the evolution of continental shelves and slopes, marine mineral resources and astroblemes. Holden is completing work on his doctorate in micropaleontology at the University of California at Berkeley. "As a switch from the megathinking world of plate tectonics and continental drift," he writes, "I find solace in investigating the microcosmic world revealed by the microscope."

HOWARD RASMUSSEN and MAURICE M. PECHET ("Calcitonin") are respectively Benjamin Rush Professor of Biochemistry at the University of Pennsylvania School of Medicine and head of the Research Institute for Medicine and Chemistry in Cambridge, Mass. Rasmussen was graduated from Gettysburg College in 1948, obtained his M.D. at Harvard University in 1952 and took his Ph.D. at the Rockefeller Institute in 1959. He was at the University of Wisconsin for four years before going to Pennsylvania in 1965. This year, while on a sabbatical leave, he is working at the University of Cambridge. Pechet, who is also scientific director of the Research Institute for Medicine and Chemistry, received his Ph.D. in chemistry from Harvard in 1945 and then entered the Harvard Medical School, obtaining his M.D. in 1948.

BARRY N. TAYLOR, DONALD N. LANGENBERG and WILLIAM H. PARKER ("The Fundamental Physical Constants") began their collaboration at the University of Pennsylvania, where Langenberg is now professor of physics. Taylor recently joined the National Bureau of Standards as head of the Absolute Electrical Measurements Section, and Parker is vice-chairman of the physics department and assistant professor of physics at the University of California at Irvine. Taylor was graduated from Temple University and took his master's and doctor's degrees at the University of Pennsylvania in 1960 and 1963 respectively, remaining there as a member of the faculty until 1966, when he joined the RCA Laboratories. Langenberg was graduated from Iowa State University in 1953 and obtained his master's degree at the University of California at Los Angeles in 1955 and his doctorate from the University of California at Berkeley in 1959. He has been a member of the Pennsylvania faculty since 1960. Parker was graduated from Allegheny College in 1963 and received his master's and doctor's degrees from Pennsylvania in 1964 and 1967 respectively.

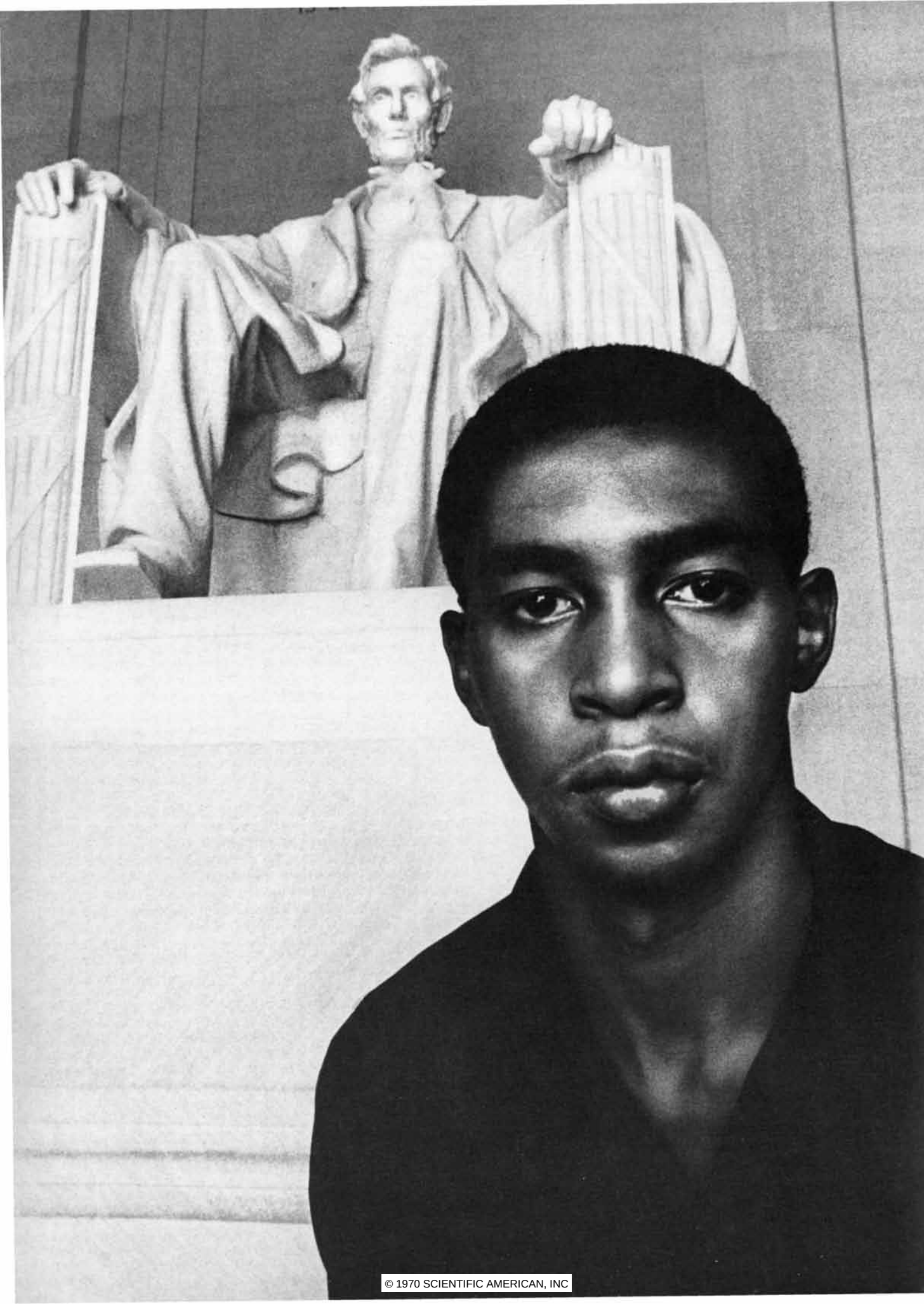
RICHARD W. YOUNG ("Visual Cells") is professor of anatomy at the School of Medicine of the University of California at Los Angeles, where he teaches microscopic anatomy. He was graduated from Antioch College in 1956 with a degree in biology and obtained his Ph.D. in anatomy from Columbia University in 1959. He has been at U.C.L.A. since 1960, although in the academic year 1966–1967 he was visiting investigator in the department of biology at the Nuclear Research Center at Saclay in France. His research has involved the study of cell systems by means of autoradiography.

F. HERBERT BORMANN and GENE E. LIKENS ("The Nutrient Cycles of an Ecosystem") are respectively Oastler Professor of Forest Ecology at Yale University and associate professor of zoology at Cornell University. Bormann, who obtained his Ph.D. in plant ecology from Duke University, taught at Emory University from 1952 to 1956 and at Dartmouth College from 1956 until he went to Yale in 1966. He is president-elect (for 1970–1971) of the Ecological Society of America. Likens, who received his bachelor's degree at Manchester College and his master's and doctor's degrees from the University of Wisconsin, was on the faculty at Dartmouth before going to Cornell last year.

IVAN BERENYI ("Computers in Eastern Europe") is a free-lance journalist based in London. "I was born in Hungary," he writes, "and educated there at Sarospatak English College and Budapest University (degree in agricultural economics, 1956). In 1956 I came to England and read economics at Oxford and Bristol universities until 1961; B.A. degree. Traveled widely, earning a living as a free-lance journalist, in Europe, Africa, the Middle East, the Far East and Australia for four years; worked as a computer systems analyst for two years in London; married a Japanese girl in 1966 (met her during a year's stay in Japan in 1964–1965); reverted to journalism in 1967, joining the staff of a London trade journal, *Computer Weekly*. Last October I returned to free-lancing; I contribute to a number of publications, mainly on subjects related to automation and the computer industry."

OTTO MAYR ("The Origins of Feedback Control") is curator of mechanical engineering at the National Museum of History and Technology of the Smithsonian Institution. "I came to history by a detour," he writes. "Born in Germany, I was trained as a mechanical engineer (I have degrees from Munich and Rochester). This profession I have both practiced (designing steam power plants and automatic control systems) and taught (at the Rochester Institute of Technology). The switch to the history of technology came when I recognized that I could not give one good reason for teaching anyone engineering. I went back to Munich and, working at the Deutsches Museum, took a Ph.D. in the history of science and technology."

ALFRED E. MIRSKY, who in this issue reviews *Biology and the Future of Man*, edited by Philip Handler, is professor and librarian at Rockefeller University.



# MAN CANNOT LIVE BY FREEDOM ALONE.

Twenty million free Americans are locked in slums.

Living in misery.

Idling away their lives on front stoops.

Because they don't have the training to get and hold decent jobs.

But for some of them there is hope. Because something is being done.

Government and industry are working together to train the unskilled.

Back in January '68 Shell introduced an automotive tune-up course in a New York high school where there was a dropout problem.

The course exposed the students to sophisticated electronic equipment, and to scientific thinking with a practical end.

It was a big success.

For the first time in their lives many of these boys took an interest in school and showed a desire to learn. And continue learning.

Of those who graduated from the course, many went on to college.

In a low-income area of Trenton, New Jersey, Shell has opened a modern packaging plant.

The objective is to make it a business that is owned-and-operated by people of different minority groups.

Business is solicited on a competitive basis, not as a "give-us-the-work-and-you'll-be-helping-the-underdog" plea.

The company began with a contract to package Shell products, and has bright prospects of more business to come.

In cities throughout the country, Shell has made special deposits of nearly one million dollars in banks mostly owned and operated by businessmen of different minorities. These deposits increase the banks' loanable funds to minority businesses.

Shell feels that money for all these programs is well spent. Our goal is to help provide the increased capability America needs. And, of greater importance, to help more Americans share in the tangible rewards of living in this country.

Because without these rewards, freedom has a hollow ring.

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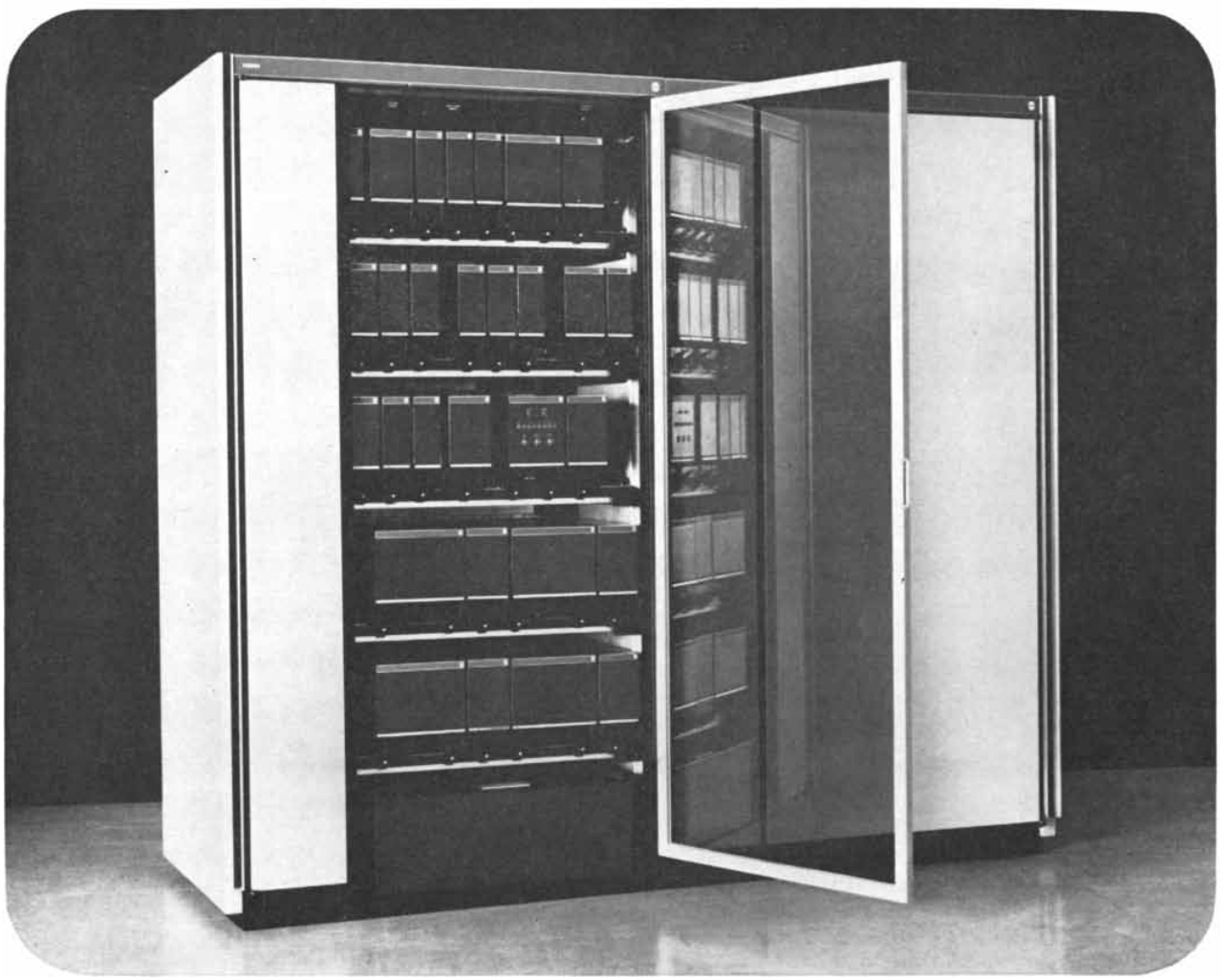

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# Intelligence and Race

*Do the differences in I.Q. scores between blacks and whites have a genetic basis? Two geneticists, reviewing the evidence, suggest that the question cannot be answered in present circumstances*

by Walter F. Bodmer and Luigi Luca Cavalli-Sforza

To what extent might behavioral differences between social classes and between races be genetically determined? This question is often discussed, although generally not at a scientific level. Recently attention has been focused on the average differences in intelligence, as measured by I.Q., between black and white Americans by the educational psychologist Arthur R. Jensen and the physicist William Shockley. We are geneticists who are interested in the study of the interaction between heredity and environment. Our aim in this article is to review, mainly for the nongeneticist, the meaning of race and I.Q. and the approaches to determining the extent to which I.Q. is inherited. Such a review can act as a basis for the objective assessment of the evidence for a genetic component in race and class I.Q. differences.

We should first define what we mean by terms such as "heredity," "intelligence" and "race." Heredity refers to those characteristics of an individual that are inherited from past generations. The primary functional unit of heredity is the gene. The human genome—the complete set of genes in an individual—consists of perhaps as many as 10 million genes. Some of these genes and their expression can now be analyzed at the biochemical level. Complex behavioral traits such as intelligence, however, are most probably influenced by the combined action of many genes. The inheritance of differences known to be determined by one gene or a few genes can be reliably predicted, but the tools for dealing with the inheritance of more complex characteristics are still relatively ineffective.

What is intelligence? A rigorous, objective definition of such a complicated characteristic is not easy to give, but for the purposes of this discussion one can focus on qualities that can actually be observed and measured. One instrument of measurement for intelligence is a test such as the Stanford-Binet procedure. Such a test is devised to measure a capacity to learn or, more generally, the capacity to benefit from experience.

Intelligence tests are based on the solution of brief problems of various kinds and on the response to simple questions. The total score is standardized for a given age by comparing it with the values of a large sample of a given reference population (such as native-born American whites). The final standardized score, which is called the intelligence quotient, is usually computed so that it is given on a scale for which the average of the reference population is 100, and for which the spread is such that about 70 percent of the individuals have I.Q.'s in the range of 85 to 115 and 5 percent have I.Q.'s either below 70 or above 130 (corresponding to a standard deviation of about 15 points).

The Stanford-Binet test and other procedures yield results that correspond reasonably well to one another. More ambitious attempts have been made to measure the "general intelligence factor." There is a tendency among the more optimistic psychologists to consider such tests as measuring an "innate" or potential ability. Any given test, however, depends on the ability acquired at a given age, which is inevitably the result of the combination of innate ability and the experience of the subject. Intelligence tests are therefore at most tests of achieved ability.

This limitation is confirmed by the dependence of all intelligence tests on the particular culture of the people they are designed to test. The transfer of tests to cultures different from the one for which they were designed is usually difficult, and sometimes it is impossible. Attempts to design tests that are genuinely "culture-free" have so far failed.

A check on the usefulness of I.Q. measurements is provided by examining their reliability (equivalent to short-term consistency), their stability (equivalent to long-term consistency) and their validity. For the Stanford-Binet test the average difference between repeat tests after a short time interval ranges from 5.9 points at an I.Q. of 130 to 2.5 for I.Q.'s below 70, indicating a fairly high reproducibility. The long-term consistency of the test is less impressive, particularly if the age at the first test is lower than five or six. Repetitions of testing after a period of years may show large discrepancies (up to 20 to 30 I.Q. points), and

these differences increase with the number of years between tests.

There is at present no definition of intelligence that is precise enough to answer questions of validity in general terms. The validity of a particular test must therefore be related to its predictive aims. If the aim is to predict future school performance, then the validity is measured by how well I.Q. predicts that performance. The prediction will be on a probability basis, meaning that a higher I.Q. will usually but not always be associated with better school performance. There is, in fact, fairly general agreement that there is a high correlation between intelligence tests and success in school. The same is true for success in jobs and, in general, in society. I.Q. tests do have some predictive value on a probability basis, although this is limited to performance in contemporary American and European society. In this sense I.Q. tests do have some validity.

Races are subgroups that emerge within the same species. Like other species, the human species is made up of individuals whose genetic composition is so similar that in principle any male can mate with any female and give rise to fertile progeny. In the course of evolution this highly mobile species has spread over the entire surface of the earth. Even today, however, most individuals live out their lives within a small area. This pattern, together with geographic and other barriers, leads to considerable reproductive isolation of groups living in different regions.

Ecological factors, such as geology, climate and flora and fauna, may differ widely in the different habitats of a species. Natural selection, that is, the preferential survival and reproduction of individuals better fitted to their local environment, inevitably creates differences among these somewhat localized groups. In addition the isolation of one group from another allows differences to arise by the random sampling to which genes are subject from generation to generation; this process results in what is called random genetic drift.

Isolated subgroups of the same species therefore tend to differentiate. The process is a slow one: hundreds—more probably thousands—of generations may be necessary for biological differences to become easily noticeable. When sufficient time has elapsed for the differences to become obvious, we call the subgroups races.

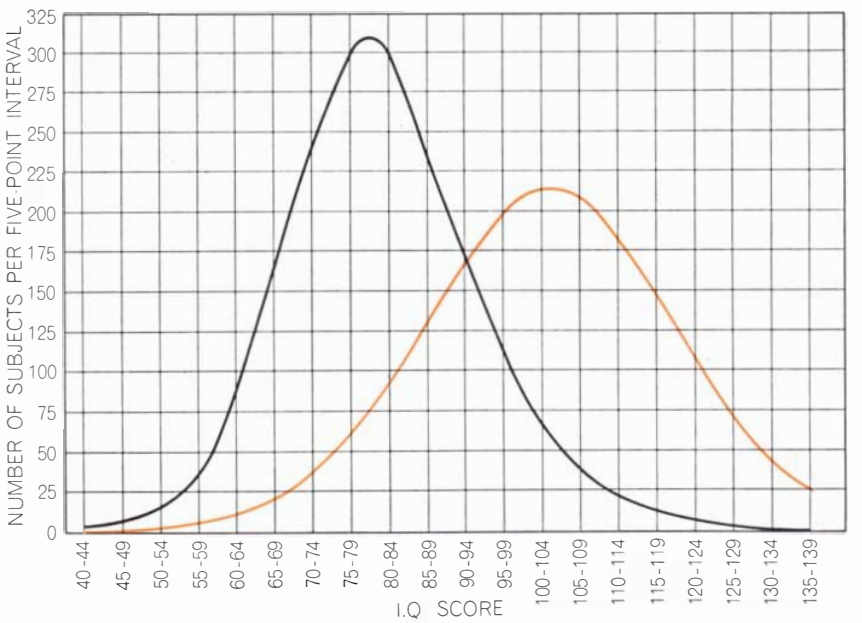
In man biological differentiation is usually accompanied or preceded by cultural differentiation, which is a much faster process than biological evolution. The two kinds of differentiation inevitably interact. Cultural differences may contribute to perpetuation of the geographic barriers that lead to reproductive isolation. For example, religious differences may promote reproductive isolation. In the U.S. differences in skin color, which reflect biological differentiation, usually reduce the chances of marriage between groups. This effect, however, is probably a direct psychological consequence not of the difference in skin color but of the parallel cultural divergence.

The relative contributions of biological and cultural factors to complex characteristics such as behavioral differences, including those that distinguish one race from another, are exceedingly difficult to identify. In this connection it is instructive to consider characteristics in which differences can easily be attributed to biological factors. It is clear, for example, that differences in skin color are mostly biological. There is a predominantly nongenetic factor—tanning—that operates during the life of an individual; it is a short-term physiological adaptation and is generally reversible. Apart from this adaptation, most of the differences in skin color both within and among races are genetic.

There are many differences among individuals that are totally under genetic control, that is, they are not subject to even the small physiological adaptation mentioned for skin color. These genetic differences are called genetic polymorphisms when the alternative versions of the genes determining them each occur within a population with a substantial frequency. Such genetic traits are generally detected by chemical or immunological tests, as in the case of the "blood groups." (There are three genes, A, B and O, that determine the ABO blood type.)

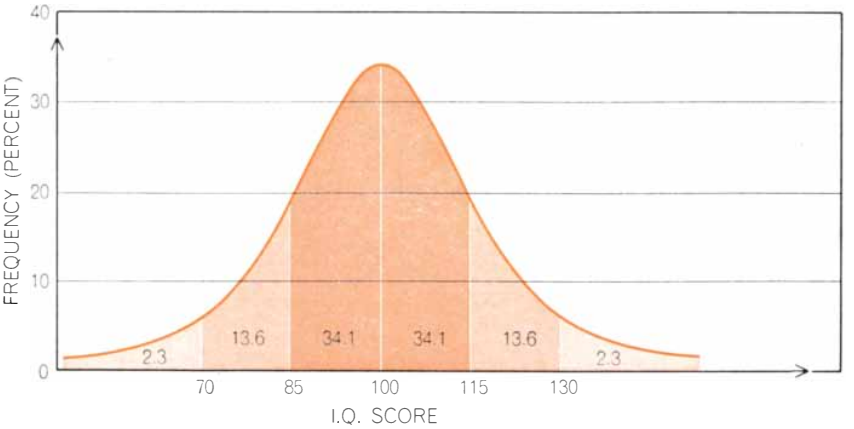
The frequencies of polymorphic genes vary widely among races. For example, in Oriental populations the frequencies of the A, B and O genes are respectively 49 percent, 18 percent and 65 percent; in Caucasian populations they are 29 percent, 4 percent and 68 percent. Such polymorphisms are a valuable aid in understanding the nature and magnitude of the biological similarities and differences among races, since they show what kinds of factor can be due solely to heredity. The inheritance of the more conspicuous face and body traits, however, is complex and not well understood, which decreases their value for the biological study of races.

The analysis of genetic polymorphisms demonstrates three very important features of the nature and extent of genetic variation within and among races. First, the extent of variation with-




**I.Q. DIFFERENCE BETWEEN U.S. BLACKS AND WHITES** emerges from a comparison of the I.Q. distribution in a representative sample of whites (*colored curve*) with the I.Q. distribution among 1,800 black children in the schools of Alabama, Florida, Georgia, Tennessee and South Carolina (*black curve*). Wallace A. Kennedy of Florida State University, who surveyed the students' I.Q., found that the mean I.Q. of this group was 80.7. The mean I.Q. of the white sample is 101.8, a difference of 21.1 points. The two samples overlap distinctly, but there is also a sizable difference between the two means. Other studies show a difference of 10 to 20 points, making Kennedy's result one of the most extreme reported.

in any population generally far exceeds the average differences between populations. Second, the differences between populations and races are mostly measured by differences in the relative frequencies of a given set of genes rather than by qualitative differences as to which gene is present in any particular population. Thus any given genetic combination may be found in almost any race, but the frequency with which it is found will vary from one race to another. Third, the variation from race to race is mostly not sharp but may be almost continuous at the boundaries between races. This is the consequence of hybridization's occurring continuously at these boundaries in spite of isolation, or of the formation of hybrid groups by recent migration followed by the more complete mixing of formerly isolated groups.




**NORMAL DISTRIBUTION OF I.Q. for a population whose mean is 100 is shown by curve. The standard deviation, that is, the usual measure of variation, is about 15 points and the distance in either direction from this mean is measured in multiples of the standard deviation. Thus about 34 percent have an I.Q. with a value that lies between 85 and 100, another 34 percent of the population have an I.Q. score of 100 to 115 points (*dark color*). Those with very high or low scores are a smaller part of population: about 2 percent have an I.Q. below 70, whereas another 2 percent have an I.Q. above 130 (*light color*).**

As we have noted, intelligence must be a complex characteristic under the control of many genes. Extreme deviations from normal levels, as in cases of severe mental retardation, can, however, be attributed to single gene differences. Such deviations can serve to illustrate important ways in which genetic factors can affect behavior. Consider the disease phenylketonuria. Individuals with this disease receive from both of their parents a mutated version of the gene controlling the enzyme that converts one amino acid, phenylalanine, into another, tyrosine. That gene allows phenylalanine to accumulate in the blood and in the brain, causing mental retardation. The accumulation can be checked early in life by a diet deficient in phenylalanine.

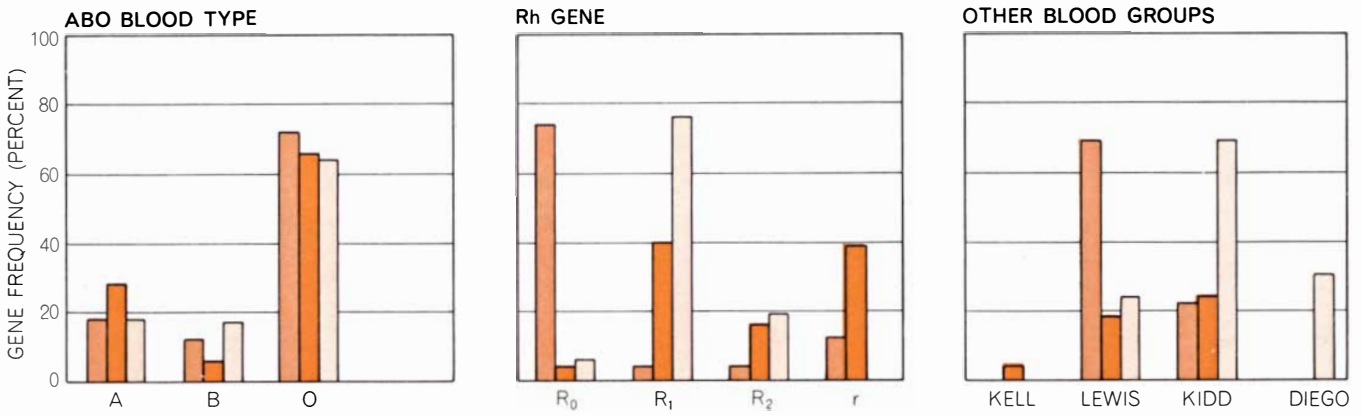
The difference between the amounts of phenylalanine in the blood of people with phenylketonuria and that in the blood of normal people, which is closely related to the primary activity of the gene causing phenylketonuria, clearly creates two genetic classes of individuals [*see bottom illustration on next page*]. When such differences are compared with differences in I.Q., there is a slight overlap, but individuals afflicted with phenylketonuria can be distinguished clearly from normal individuals. This simply reflects the fact that the phenylketonuric genotype, that is, the genetic constitution that leads to phenylketonuria, is associated with extreme mental retardation. If differences in head size and hair color in phenylketonuric individuals and normal individuals are compared, however, they show a considerable overlap. Although it can be said that the phenylketonuric genotype has on the average a significant effect on both head size and hair color, measurements of these characteristics cannot be used to distinguish the phenylketonuric genotype from the normal one. The reason is that the variation of head size and hair color is large compared with the average difference. Thus the genetic difference between phenylketonuric and normal individuals contributes in a major way to the variation in blood phenylalanine levels but has only a minor, although significant, effect on head size and hair color.

The phenylketonuric genotype is very rare, occurring with a frequency of only about one individual in 10,000. It therefore has little effect on the overall distribution of I.Q. in the population. It is now known, however, that a large fraction of all genes are polymorphic. Among the polymorphic genes must be included many whose effect on I.Q. is comparable to the effect of the phenylketonuric genotype on head size or hair color. These genotype differences cannot be individually identified, but their total effect on the variation of I.Q. may be considerable.

The nature of phenylketonuria demonstrates another important point: The expression of a gene is profoundly influenced by environment. Phenylketonuric individuals show appreciable variation. This indicates that the genetic difference involved in phenylketonuria is by no means the only factor, or even the major factor, affecting the level of phenylalanine in the blood. It is obvious that dietary differences have a large effect, since a phenylalanine-deficient diet brings the level of this amino acid in the blood of a phenylketonuric individual almost down to normal. If an individual receives the phenylketonuric gene from only one parent, his mental development is not likely to be clinically affected. Nevertheless, he will tend to have higher than normal levels of phenylalanine in his blood. The overall variation in phenylalanine level is therefore the result of a combination of genetic factors and environmental factors. Measuring the relative contribution of genetic factors to the overall variation is thus equivalent to measuring the relative importance of genetic differences in determining this type of quantitative variation.

When we turn to the analysis of a complex characteristic such as I.Q., which is influenced by many genes each contributing on the average a small effect, we can expect the characteristic to be even more strongly affected by the previous history of the individual and by a host of other external, nongenetic or in any case unrelated factors, which can together be called the "environment." It is necessary to resort to statistical analysis in order to separate the effects of these various factors. Consider an experiment of nature that allows the separation, at least roughly, of environmental factors from genetic factors. This is the occurrence of two types of twins: twins that are "identical," or monozygous (derived from only a single zygote, or fertilized egg, and therefore genetically identical), and twins that are "fraternal," or dizygous (derived from two separate zygotes and therefore genetically different).

Clearly the difference between the



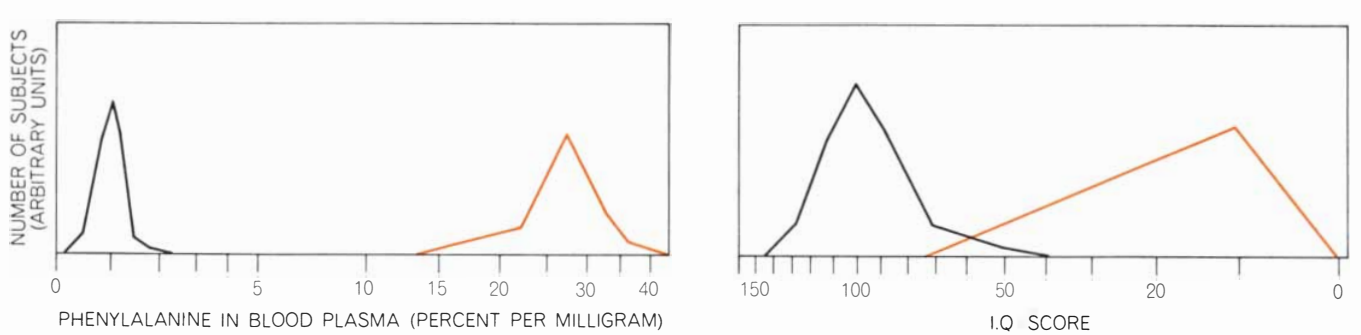

**FREQUENCIES OF POLYMORPHIC GENES among Africans, Caucasians and Orientals provide a means of differentiating these three races. (A polymorphic gene is one of a group that accounts for variability in a particular characteristic.) About half of the**

two members of a monozygous pair is determined only by environmental factors. It would seem that the distribution of such differences among a number of pairs might tell us how much two individuals can differ because of environmental factors alone. The members of monozygous pairs do not generally have identical I.Q.'s. The members of a given twin pair can differ by as much as 20 I.Q. points, although in the majority of cases they differ by less than 10. Hence environmental differences can have an effect on I.Q. whose average magnitude is comparable to, or slightly larger than, the difference between the I.Q. scores of the same individual who has been tested more than once over a period of time.

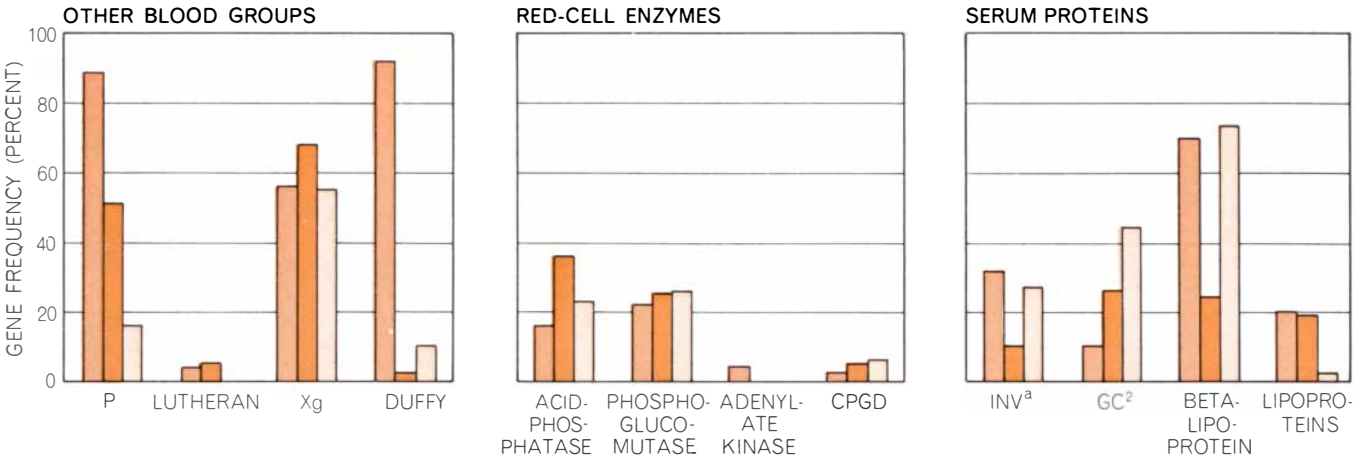
To see whether or not, and if so to what extent, genetic differences are found, we turn to dizygous twins. Here we know that in addition to the environment genetic factors also play a role in differentiating the members of a pair. The differences in I.Q. among dizygous pairs show a greater spread than those among monozygous pairs, indicating that the addition of genetic diversity to the purely environmental factors increases, on the average, the overall difference between members of a pair. Hence genetic factors that can contribute to the differentiation of I.Q.'s also exist among normal individuals.

It might seem that the twin data could easily provide a measure of the relative importance of genetic variation and environmental variation. A comparison of the average difference between the members of a monozygous pair and the average difference between the members of a dizygous pair should be a good index of the comparative importance of genetic factors and environmental ones. (A minor technical point should be mentioned here. As is customary in all modern statistical analysis, it is better to consider not the mean of the differences but the mean of their squares. This is comparable to, and can easily be transformed into, a "variance," which is a well-known measure of variation.)

There are two major contrasting reasons why such a simple measure is not entirely satisfactory. First, the difference between members of a dizygous pair represents only a fraction of the genetic differences that can exist between two individuals. Dizygous twins are related to each other as two siblings are; therefore they are more closely related than two individuals taken at random from a population. This implies a substantial reduction (roughly by a factor of two) in the average genetic difference between dizygous twins compared with that between two randomly chosen individuals. Second, the environmental difference between members of a pair of twins encompasses only a fraction of the total environmental difference that can exist between two individuals, namely the difference between individuals belonging to the same family. This does not take into account differences among families, which are likely to be large. Within the family the environmental differences between twins are limited. For instance, the effect of birth order is not taken into account. Differences between ordinary siblings might therefore tend to be slightly greater than those between dizygous twins. It also seems possible




**PHENYLALANINE LEVELS in blood plasma shown in first set of curves at left distinguish those who carry a double dose of the defective gene that causes high phenylalanine levels (*colored curve*), a condition called phenylketonuria, from those with normal phenylalanine levels (*dark curve*). Second set of curves shows that this genotype has a direct effect on intelligence: phenylketonurics (*colored curve*) have low I.Q.'s because accumulation of phenylalanine and its by-products in blood and nerve tissue damages the brain. Individuals with functioning gene (*dark curve*) have normal I.Q.'s. In the third set phenylalanine levels are related**



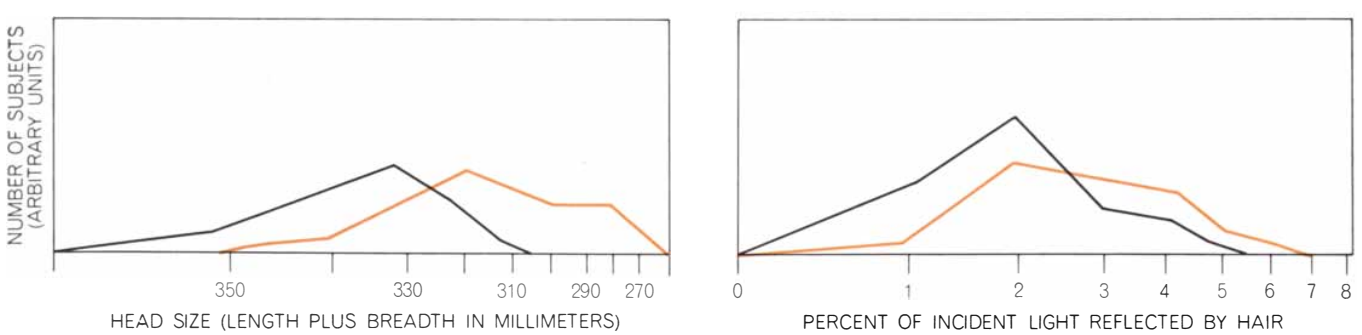

**polymorphic systems in man are shown. Average differences in frequencies between Africans (*color*) and Caucasians (*dark color*) are 22 percent, those between Africans and Orientals (*light color*) are 30 percent, those between Caucasians and Orientals are 22 percent.**

that the environmental differences between monozygous twins, who tend to establish special relations with each other, are not exactly comparable to those between dizygous twins. In short, whereas the contrast between monozygous and dizygous twin pairs minimizes genetic differences, it also tends to maximize environmental differences.

In order to take account of such difficulties one must try to use all available comparisons between relatives of various types and degrees, of which twin data are only a selected case. For technical reasons one often measures similarities rather than differences between two sets of values such as parent I.Q.'s and offspring I.Q.'s. Such a measure of similarity is called the correlation coefficient. It is equal to 1 when the pairs of values in the two sets are identical or, more generally, when one value is expressible as a linear function of the other. The correlation coefficient is 0 when the pairs of measurements are completely independent, and it is intermediate if there is a relation between the two sets such that one tends to increase when the other does.

The mean observed values of the correlation coefficient between parent and child I.Q.'s, and between the I.Q.'s of pairs of siblings, are very nearly .5. This is the value one would expect on the basis of the simplest genetic model, in which the effects of any number of genes determine I.Q. and there are no environmental influences or complications of any kind. It seems probable, however, that the observed correlation of .5 is coincidental. Complicating factors such as different modes of gene action, tendencies for like to mate with like and environmental correlations among members of the same family must just happen to balance one another almost exactly to give a result that agrees with the simplest theoretical expectation. If we ignored these complications, we might conclude naïvely (and in contradiction to other evidence, such as the observation of twins) that biological inheritance of the simplest kind entirely determines I.Q.

Instead it is necessary to seek a means of determining the relative importance of environmental factors and genetic factors even taking account of several of the complications. In theory this measurement can be made by computing the quotients known as heritability estimates. To understand what such quotients are intended to measure, consider a simplified situation. Imagine that the genotype of each individual with respect to genes affecting I.Q. can be identified. Individuals with the same genotype can then be grouped together. The differences among them would be the result of environmental factors, and the spread of the distribution of such differences could then be measured. Assume for the sake of simplicity that the spread of I.Q. due to environmental differences is the same for each genotype. If we take the I.Q.'s of all the individuals in the population, we obtain a distribution that yields the total variation of I.Q. The variation within each genotype is the environmental component. The difference between the total variation and the environmental component of variation leaves a component of the total variation




**to head size (displayed as the sum of head length and breadth), and in the fourth set phenylalanine levels are related to hair color (displayed as the percentage of light with a wavelength of 700 millimicrons reflected by the hair). In both cases it is obvious that the phenylketonuric genotype has a significant effect on each of these characteristics: the reflectance is greater and the head size is smaller (*colored curves*) among phenylketonurics than they are among normal individuals (*dark curves*). Yet the distribution of these characteristics is such that they cannot be used to distinguish those afflicted with phenylketonuria from those who are not.**

that may be accounted for by genetic differences. This component, when expressed as a fraction of the total variance, is one possible measure of heritability.

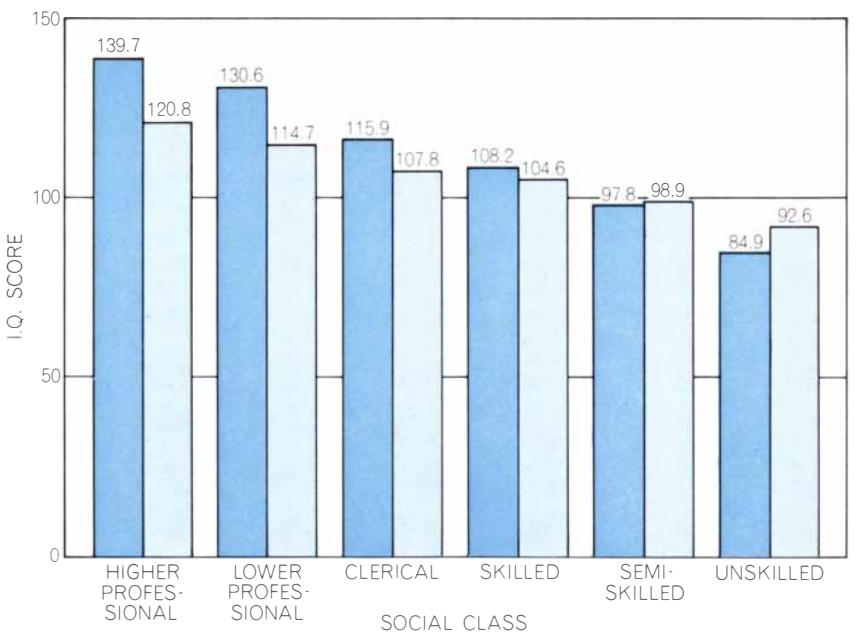
In practice, however, the estimation of the component of the total variation that can be accounted for by genetic differences (from data on correlations between relatives) always depends on the construction of specific genetic models, and is therefore subject to the limitations of the models. One problem lies in the fact that there are a number of alternative definitions of heritability depending on the genetic model chosen, because the genetic variation may have many components that can have quite different meanings. A definition that includes only those parts of the genetic variation generally considered to be most relevant in animal and plant breeding is often used. This is called heritability in the narrow sense. If all genetic sources of variation are included, then the heritability estimate increases and is referred to as heritability in the broad sense.

The differences between these estimates of heritability can be defined quite precisely in terms of specific genetic models. The resulting estimates of heritability, however, can vary considerably. Typical heritability estimates for I.Q. (derived from the London population in the early 1950's, with data obtained by Sir Cyril Burt) give values of 45 to 60 percent for heritability in the narrow sense and 80 to 85 percent for heritability in the broad sense.

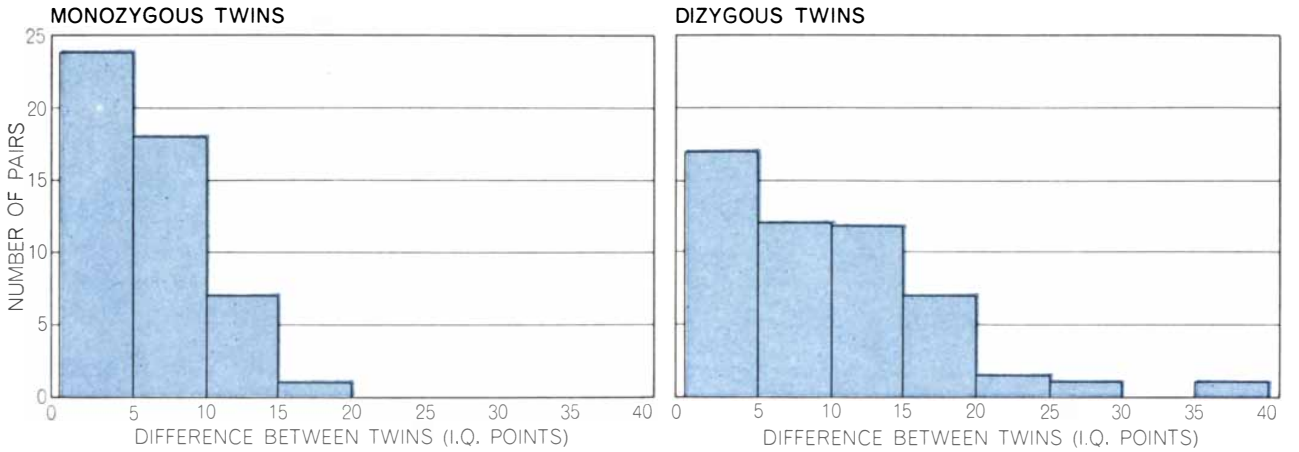
A further major complication for such heritability estimates has the technical name "genotype-environment interaction." The difficulty is that the realized I.Q. of given genotypes in different environments cannot be predicted in a simple way. A given genotype may develop better in one environment than in another, but this is not necessarily true for any other genotype. Even if it is true, the extent of the difference may not be the same. Ideally one would like to know the reaction of every genotype in every environment. Given the practically infinite variety of both environments and genotypes, this is clearly impossible. Moreover, in man there is no way of controlling the environment. Even if all environmental influences relevant to behavioral development were known, their statistical control by appropriate measurements and subsequent statistical analysis of the data would still be extremely difficult. It should therefore be emphasized that because estimates of heritability depend on the extent of environmental and genetic variation that prevails in the population examined at the time of analysis, they are not valid for other populations or for the same population at a different time.

In animals and plants the experimental control of the environment is easier, and it is possible to explore "genotype-environment" interactions. An interesting experiment was conducted by R. Cooper and John P. Zubek of the University of Manitoba with two lines of rats in which genetic differences in the rats' capacity to find their way through a maze had been accumulated by artificial selection. The two lines of rats had been selected to be either "bright" or "dull" at finding their way through the maze. When rats from these lines were raised for one generation in a "restricted" environment that differed from the "normal" laboratory conditions, no difference between the lines could be found. Both bright and dull animals performed at the same low level. When they were raised in a stimulating environment, both did almost equally well [*see illustration on page 29*]. Since the difference between the lines is genetic, the effect of environmental conditions should be reversible in future generations. This experiment is particularly relevant to differences in I.Q. because of the structure of human societies. If "ghetto" children tend to have I.Q. scores lower, and the children of parents of high social and economic status to have scores higher, than the level one would expect if both groups of children were reared in the same environment, then heritability estimates may be biased upward.

The only potential safeguard against such bias is provided by the investigation of the same genotype or similar genotypes in different environments. In man this can be done only through the study of adopted children. A particularly interesting type of "adoption" is that in which monozygous twins are separated and reared in different families from birth or soon afterward. The outcome is in general a relatively minor average decrease in similarity. Following the same line of reasoning, the similarity between foster parents and adopted children can be measured and contrasted with that between biological parents and their




**SOCIAL CLASS AND INTELLIGENCE** are closely related, a study by Sir Cyril Burt of the University of London indicates. Set of bars at left shows the mean I.Q. for higher professionals (*dark bar*) is 139.7, children of higher professionals have a mean I.Q. of 120.8 (*light bar*). Second set of bars shows that lower professionals have a mean I.Q. of 130.6, children of lower professionals have a mean I.Q. of 114.7. Third set shows that clerical workers have a mean I.Q. of 115.9, their children have a mean I.Q. of 107.8. Fourth set shows that skilled workers have a mean I.Q. of 108.2, their children have a mean I.Q. of 104.6. Fifth set shows that semiskilled workers have a mean I.Q. of 97.8, their children have a mean I.Q. of 98.9. Sixth set shows that unskilled workers have a mean I.Q. of 84.9, their children have a mean I.Q. of 92.6. Mean I.Q.'s of wives (*not shown*) correlate well with husbands'. Above the mean children's I.Q. tends to be lower than that of parents. Below it children's I.Q. tends to be higher. Social mobility maintains distribution because those individuals with high I.Q.'s tend to rise whereas those with low I.Q.'s tend to fall.




**EXPERIMENT OF NATURE based on I.Q. data collected by Horatio H. Newman of the University of Chicago gives a rough measurement of the relative influence of heredity and environment on intelligence. Chart at left shows I.Q. differences between the members of 50 pairs of monozygous twins, that is, twins who developed from the same egg and have identical genotypes. I.Q. differences between members of these pairs tend to be low: 24 pairs (or almost half of the sample) show a difference of from zero to five points. Only one pair shows a difference of between 15 and 20 points. The mean difference between the members of each pair is 5.9 points. Since the genotypes in each pair are identical it appears that the environmental effect tends to be small. Second chart shows I.Q. differences between 45 pairs of dizygous twins, that is, twins with different genotypes who developed from separate eggs. In this case the mean difference in I.Q. between the members of these pairs is about 10 points. Thus a fairly large difference appears to be attributable to heredity. Such a comparison does not separate the effects of heredity and environment precisely. Members of monozygous pairs have very similar environments, whereas genotypes of dizygous twins are less different on the average by a factor of two than those of unrelated individuals. Comparison thus underestimates effect of heredity but also minimizes environmental influence.**

children. A few such studies have been conducted. They show that the change of family environment does indeed have an effect, although it is not as great as that of biological inheritance. The correlation between foster parents and their adopted children is greater than 0, but it is undoubtedly less than that between biological parents and their offspring.

A complete analysis of such data is almost impossible because environmental variation among families and genotype-environment interactions of various kinds must be responsible for the observed effects in ways that make it difficult to disentangle their relative importance. Adoption and rearing apart take place in conditions far from those of ideal experiments, and so any conclusions are bound to be only semiquantitative. On the basis of all the available data, with allowance for these limitations, the heritability of intelligence, as measured by I.Q., is still fairly high. It must be kept in mind, however, that the environmental effects in such studies are generally limited to the differences among and within families of a fairly homogeneous section of the British or American population. They cannot be extrapolated to prediction of the effects of greater differences in environment, or of other types of difference.

There are significant differences in mean I.Q. among the various social classes. One of the most comprehensive and widely quoted studies of such differences and the reasons for their apparent stability over the years was published by Burt in 1961 [*see illustration on opposite page*]. His data come from schoolchildren and their parents in a typical London borough. Socioeconomic level was classified, on the basis of type of occupation, into six classes. These range from Class 1, including "university teachers, those of similar standing in law, medicine, education or the church and the top people in commerce, industry or civil service," to Class 6, including "unskilled laborers, casual laborers and those employed in coarse manual work." There are four main features of these data:

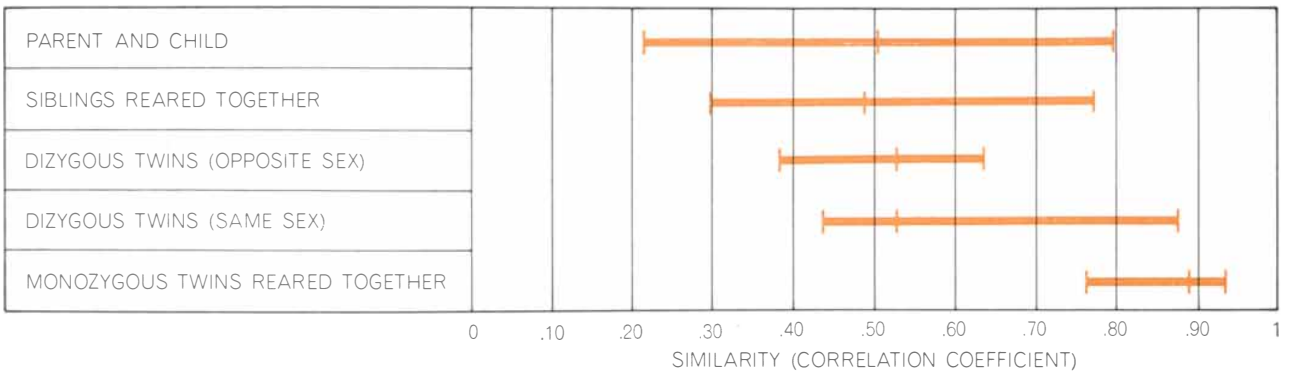
1. Parental mean I.Q. and occupational class are closely related. The mean difference between the highest and the lowest class is over 50. Although occupational class is determined mostly by the father, the relatively high correlation between the I.Q.'s of husband and wife (about .4) contributes to the differentiation among the classes with respect to I.Q.

2. In spite of the significant variation between the parental mean I.Q.'s, the residual variation in I.Q. among parents within each class is still remarkably large. The mean standard deviation of the parental I.Q.'s for the different classes is 8.6, almost three-fifths of the standard deviation for the entire group. That standard deviation is about 15, and it is usual for the spread of I.Q.'s in any group.

3. The mean I.Q. of the offspring for each class lies almost exactly between the parental mean I.Q.'s and the overall population mean I.Q. of 100. This is expected because it is only another way of looking at the correlation for I.Q. between parent and child, which as we have already seen tends to be about .5 in any given population.

4. The last important feature of the data is that the standard deviations of the I.Q. of the offspring, which average 13.2, are almost the same as the standard deviation of the general population, namely 15. This is another indication of the existence of considerable variability of I.Q. within social classes. Such variability is almost as much as that in the entire population.

The most straightforward interpretation of these data is that I.Q. is itself a major determinant of occupational class and that it is to an appreciable extent inherited (although the data cannot be used to distinguish cultural inheritance from biological). Burt pointed out that, because of the wide distribution of I.Q. within each class among the offspring and the regression of the offspring to the population mean, appreciable mobility among classes is needed in each generation to maintain the class differences with respect to I.Q. He estimated that to maintain a stable distribution of I.Q. differences among classes, at least 22 percent of the offspring would have to change class, mainly as a function of I.Q., in each generation. This figure is




**CORRELATION COEFFICIENTS** are calculations of similarity, for example, between the I.Q.'s of two sets of relatives such as parents and children. A coefficient of 1 indicates identity, 0 indicates independence of one value from the other. These data were collected from published literature by L. Erlenmeyer-Kimling and Lissy F. Jarvik of the New York State Psychiatric Institute to derive measurements of comparative effects of heredity and environment, taking into account all possible effects of relatedness between individuals. The horizontal line at top indicates that the coefficients of samples of parents and children from different studies range from about .20 to .80. Second horizontal line indicates that coefficients for siblings reared together range from .30 to about .78. Range for dizygous (fraternal) twins of opposite sex is .38 to .65; for dizygous twins of same sex it is .43 to .88. The mean (*vertical line intersecting each horizontal line*) for each of these four sets of relatives is about .50. Monozygous (identical) twins, however, have a range of .77 to .92 with a mean of .89. Mean coefficient of .50 is that which would be expected if there were no environmental effects in I.Q. Since other evidence indicates that environment exerts a significant effect, these calculations must be further refined.

well below the observed intergenerational social mobility in Britain, which is about 30 percent.

Fears that there may be a gradual decline in I.Q. because of an apparent negative correlation between I.Q. and fertility have been expressed ever since Francis Galton pointed out this correlation for the British ruling class in the second half of the 19th century. If there were such a persistent association, if I.Q. were at least in part genetically determined and if there were no counteracting environmental effects, such a decline in I.Q. could be expected. The fact is that no significant decline has been detected so far. The existing data, although they are admittedly limited, do not support the idea of a persistent negative correlation between I.Q. and overall reproductivity.

The existence of culturally, and often racially, reproductively isolated subgroups within a human population almost inevitably leads to social tensions, which are the seeds of racism. This has been true throughout the history of mankind, and is by no means unique to the present tensions among different racial groups such as those between blacks and whites in the U.S. Conflicts between religious groups, such as Protestants and Catholics in Northern Ireland, are examples of the same type of social tension. Cultural divergence is often accompanied by relative economic deprivation in one group or the other, which aggravates the tensions between them.

The striking outward differences between blacks and whites, mainly of course the color of their skin, must be a major extra factor contributing to the racial tensions between them. If the cultural differences between the Protestants and Catholics of Ireland disappeared, there would be no way of telling the two groups apart. The same is not true for black and white Americans. Many generations of completely random mating would be needed to even out their difference in skin color.

Such mating has not taken place in the U.S. The average frequency of marriages between blacks and whites throughout the U.S. is still only about 2 percent of the frequency that would be expected if marriages occurred at random with respect to race. This reflects the persistent high level of reproductive isolation between the races, in spite of the movement in recent years toward a strong legal stand in favor of desegregation. Hawaii is a notable exception to this separation of the races, although even there the observed frequency of mixed marriages is still only 45 to 50 percent of what would be expected if matings occurred at random.

The socioeconomic deprivation of one racial group with respect to another inevitably raises the question of whether or not the difference has a significant genetic component. In the case of U.S. blacks and whites the question has recently been focused on the average difference in I.Q. Many studies have shown the existence of substantial differences in the distribution of I.Q. in U.S. blacks and whites. Such data were obtained in an extensive study published by Wallace A. Kennedy of Florida State University and his co-workers in 1963, based on I.Q. tests given to 1,800 black children in elementary school in five Southeastern states (Florida, Georgia, Alabama, Tennessee and South Carolina). When the distribution these workers found is compared with a 1960 sample of the U.S. white population, striking differences emerge. The mean difference in I.Q. between blacks and whites is 21.1, whereas the standard deviation of the distribution among blacks is some 25 percent less than that of the distribution among whites (12.4 v. 16.4). As one would expect, there is considerable overlap between the two distributions, because the variability for I.Q., like the variability for most characteristics, within any population is substantially greater than the variability between any two populations. Nevertheless, 95.5 percent of the blacks have an I.Q. below the white mean of 101.8 and 18.4 percent have an I.Q. of less than 70. Only 2 percent of the whites have I.Q.'s in the latter range.

Reported differences between the mean I.Q.'s of blacks and whites generally lie between 10 and 20, so that the value found by Kennedy and his colleagues is one of the most extreme reported. The difference is usually less for blacks from the Northern states than it is for those from the Southern states, and clearly it depends heavily on the particular populations tested. One well-known study of Army "Alpha" intelligence-test results, for example, showed that blacks from some Northern states achieved higher average scores than whites from some Southern states, although whites always scored higher than blacks from

the same state. There are many uncertainties and variables that influence the outcome of I.Q. tests, but the observed mean differences between U.S. blacks and whites are undoubtedly more or less reproducible and are quite striking.

There are two main features that clearly distinguish I.Q. differences among social classes described above from those between blacks and whites. First, the I.Q. differences among social classes relate to the environmental variation within the relatively homogeneous British population. It cannot be assumed that this range of environmental variation is comparable with the average environmental difference between black and white Americans. Second, and more important, these differences are maintained by the mobility among occupational classes that is based to a significant extent on selection for higher I.Q. in the higher occupational classes. There is clearly no counterpart of this mobility with respect to the differences between U.S. blacks and whites; skin color effectively bars mobility between the races.

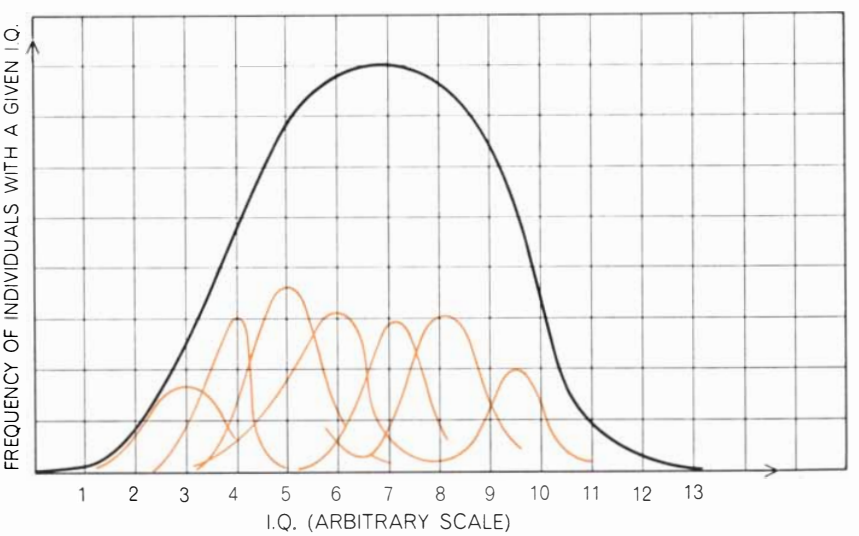
The arguments for a substantial genetic component in the I.Q. difference between the races assume that existing heritability estimates for I.Q. can reasonably be applied to the racial difference. These estimates, however, are based on observations within the white population. We have emphasized that heritability estimates apply only to the population studied and to its particular environment. Thus the extrapolation of existing heritability estimates to the racial differences assumes that the environmental differences between the races are comparable to the environmental variation within them. Since there is no basis for making this assumption, it follows that there is no logical connection between heritabilities determined within either race and the genetic difference between them. Whether or not the variation in I.Q. within either race is entirely genetic or entirely environmental has no bearing on the question of the relative contribution of genetic factors and environmental factors to the differences between the races.

A major argument given by Jensen in favor of a substantial genetic component in the I.Q. difference is that it persists even when comparisons are made between U.S. blacks and whites of the same socioeconomic status. This status is defined in terms of schooling, occupation and income, and so it is necessarily a measure of at least a part of the environmental variation, comparable to the class differences we have discussed here.

Taken at face value—that is, on the assumption that status is truly a measure of the total environment—these data would indicate that the I.Q. difference is genetically determined. It is difficult to see, however, how the status of blacks and whites can be compared. The very existence of a racial stratification correlated with a relative socioeconomic deprivation makes this comparison suspect. Black schools are well known to be generally less adequate than white schools, so that equal numbers of years of schooling certainly do not mean equal educational attainment. Wide variation in the level of occupation must exist within each occupational class. Thus one would certainly expect, even for equivalent occupational classes, that the black level is on the average lower than the white. No amount of money can buy a black person's way into a privileged upper-class white community, or buy off more than 200 years of accumulated racial prejudice on the part of the whites, or reconstitute the disrupted black family, in part culturally inherited from the days of slavery. It is impossible to accept the idea that matching for status provides an adequate, or even a substantial, control over the most important environmental differences between blacks and whites.

Jensen has suggested other arguments in defense of his thesis that the average I.Q. difference between blacks and whites is entirely genetic or mostly so, and he has challenged readers of his paper in the *Harvard Educational Review* to consider them. One is a set of data on blacks that is quite similar to those we have cited for whites; it shows the filial regression of I.Q. or related measurements as a function of the social class of the parents. The only conclusion one can draw is that among blacks the inheritance of I.Q. must also be fairly high. No conclusion can be drawn from these data concerning environmental differences between blacks and whites that affect I.Q., and it is this that is the real issue.

Jensen also discusses differences between the races in rates of early motor development, and in other developmental rates, which are believed to be correlated with I.Q. The argument must, by implication, be that developmental rates are determined mostly by genetic factors. Environmental influences on such rates are widely recognized, so that this information does not help to clarify the situation concerning I.Q. Moreover, Jensen makes the statement, based on the well-known "Coleman report," that American Indians, in spite of poor schooling, do not show the same I.Q. gap as blacks. According to the Coleman report, however, American Indians typically go to schools where whites are in the majority, which is not the case for most of the schools attended by black children. (The actual difference between whites and Indians may be greater, be-




**HERITABILITY is a measure of the relative effects of heredity and environment on characteristics such as I.Q. The heritability estimate is based on the assumption that a population consists of several groups each distinguished by a different genotype and I.Q. distribution (*colored curves*). The total of these I.Q. distributions equals the I.Q. spread for the population (*black curve*). By definition those in each group have the same genotype, thus any variation in a group is environmental. Heredity's effect on the total I.Q. distribution can be calculated by averaging together the I.Q. spread of each group and subtracting the result from the total I.Q. spread. The remainder is the total variation due to genetic factors.**

cause the sample may not have adequately represented the 70 to 80 percent of American Indians who live on reservations.) The differences between Indians and blacks or whites are clearly no easier to assess than those between blacks and whites.

Jensen states that because the gene pools of whites and blacks are known to differ and "these genetic differences are manifested in virtually every anatomical, physiological and biochemical comparison one can make between representative samples of identifiable racial groups ... there is no reason to suppose that the brain should be exempt from this generalization." As geneticists we can state with certainty that there is no a priori reason why genes affecting I.Q., which differ in the gene pools of blacks and whites, should be such that on the average whites have significantly more genes increasing I.Q. than blacks do. On the contrary, one should expect, assuming no tendency for high-I.Q. genes to accumulate by selection in one race or the other, that the more polymorphic genes there are that affect I.Q. and that differ in frequency in blacks and whites, the less likely it is that there is an average genetic difference in I.Q. between the races. The same argument applies to the differences between any two racial groups.

Since natural selection is the principal agent of genetic change, is it possible that this force has produced a significant I.Q. difference between American blacks and whites? Using the simple theory with which plant and animal breeders predict responses to artificial selection, one can make a rough guess at the amount of selection that would have been needed to result in a difference of about 15 I.Q. points, such as exists between blacks and whites. The calculation is based on three assumptions: that there was no initial difference in I.Q. between Africans and Caucasians, that the heritability of I.Q. in the narrow sense is about 50 percent and that the divergence of black Americans from Africans started with slavery about 200 years, or seven generations, ago. This implies a mean change in I.Q. of about two points per generation. The predictions of the theory are that this rate of change could be achieved by the complete elimination from reproduction of about 15 percent of the most intelligent individuals in each generation. There is certainly no good basis for assuming such a level of selection against I.Q. during the period of slavery.

It seems to us that none of the above arguments gives any support to Jensen's conclusion. The only observation that could prove his thesis would be to compare an adequate sample of black and white children brought up in strictly comparable environments. This seems practically impossible to achieve today.

What can be said concerning environmental differences that are known or suspected to affect I.Q.? First it should be mentioned that, in spite of high I.Q. heritability estimates, the mean intrapair I.Q. difference found by Horatio H. Newman and his co-workers at the University of Chicago between monozygotic twins reared apart was 8 and the range was from 1 to 24. Therefore even within the white population there is substantial environmental variation in I.Q.

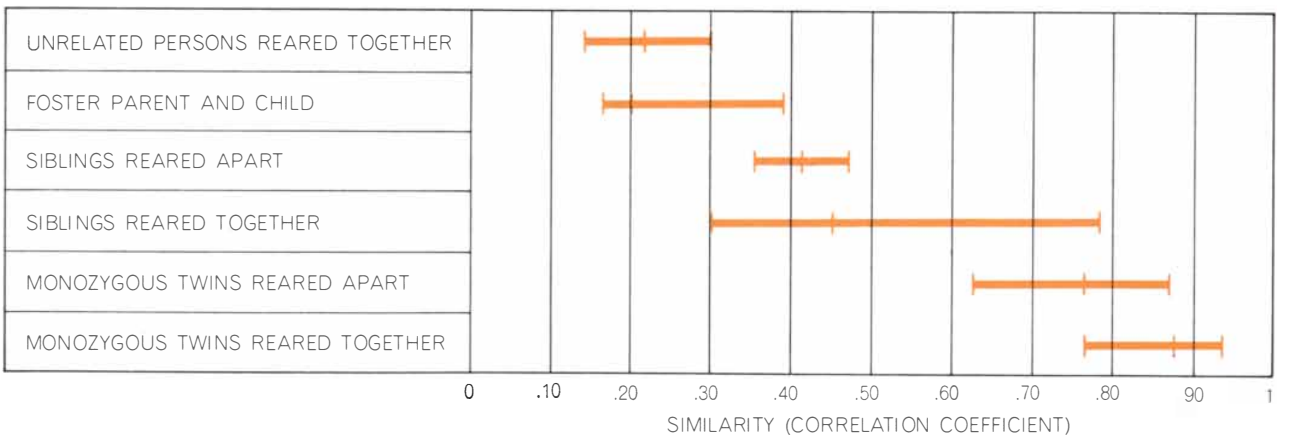
The following known environmental effects are also worth mentioning:

1. There is a systematic difference of as much as five I.Q. points between twins and nontwins, irrespective of socioeconomic and other variables. This reduction in the I.Q. of twins could be due either to the effects of the maternal environment *in utero* or to the reduced attention parents are able to give each of two very young children born at the same time.

2. It has been reported that the I.Q. of blacks tested by blacks was two to three points higher than when they were tested by whites.

3. Studies of the effects of protein-deficient diets administered to female rats before and during pregnancy (conducted by Stephen Zamenhof and his coworkers at the University of California School of Medicine in Los Angeles) have shown a substantial reduction in total brain DNA content of the offspring and hence presumably a reduction in the number of brain cells. The reductions were correlated with behavioral deficiencies and in man could be the basis for substantial I.Q. differences. There can be no doubt that in many areas the poor socioeconomic conditions of blacks are correlated with dietary deficiency. Dietary deficiencies in early childhood are likely to have similar consequences.

4. The very early home environment has long been thought to be of substantial importance for intellectual development. There are clear-cut data that demonstrate the detrimental effects of severe early sensory deprivation. There can be little doubt that both the lower socio-




**EFFECTS OF ENVIRONMENT** can be measured by comparing correlation coefficients of individuals with similar genetic backgrounds reared in different environments and those with different backgrounds reared in the same environment. Published data collected by Erlenmeyer-Kimling and Jarvik show that unrelated persons reared together have coefficients that range from about .15 to slightly over .30. Coefficients for foster-parents and children range from .16 to almost .40. Siblings reared apart have coefficients that range from more than .30 to more than .40. Siblings reared together have coefficients that range from .30 to almost .80. Monozygous twins reared apart have coefficients that range from more than .60 to above .80, and monozygous twins reared together have coefficients of more than .70 to more than .90. It appears that environment affects intelligence but not as strongly as heredity does.

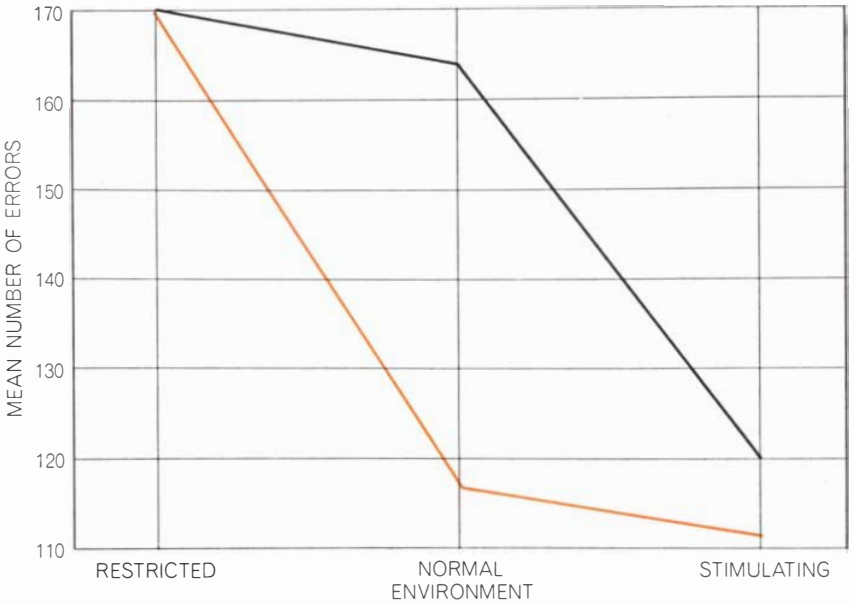
economic status of U.S. blacks and a cultural inheritance dating back to slavery must on the average result in a less satisfactory home environment; this may be particularly important during the preschool years. Here again animal experiments support the importance of early experience on brain development.

5. Expectancy of failure usually leads to failure.

In his *Harvard Educational Review* article Jensen chooses to minimize environmental effects such as these. We believe, however, that there is no evidence against the notion that such influences, among other environmental factors, many of which doubtless remain to be discovered, could explain essentially all the differences in I.Q. between blacks and whites.

We do not by any means exclude the possibility that there could be a genetic component in the mean difference in I.Q. between races. We simply maintain that currently available data are inadequate to resolve this question in either direction. The only approach applicable to the study of the I.Q. difference between the races is that of working with black children adopted into white homes and vice versa. The adoptions would, of course, have to be at an early age to be sure of taking into account any possible effects of the early home environment. The I.Q.'s of black children adopted into white homes would also have to be compared with those of white children adopted into comparable white homes. To our knowledge no scientifically adequate studies of this nature have ever been undertaken. It is questionable whether or not such studies could be done in a reasonably controlled way at the present time. Even if they could, they would not remove the effects of prejudice directed against black people in most white communities. We therefore suggest that the question of a possible genetic basis for the race I.Q. difference will be almost impossible to answer satisfactorily before the environmental differences between U.S. blacks and whites have been substantially reduced.

Apart from the intrinsic difficulties in answering this question, it seems to us that there is no good case for encouraging the support of studies of this kind on either theoretical or practical grounds. From a theoretical point of view it seems unlikely that such studies would throw much light on the general problem of the genetic control of I.Q., because any racial difference would be a small fraction of the total variation in I.Q. The mere fact that even the relatively crude studies on the inheritance of I.Q. conducted so far have not taken advantage of racial differences suggests that these are not the most convenient differences to investigate. Much basic work on the biology and biochemistry of mental development under controlled conditions, making use of known genetic differences, is needed before a fuller understanding of the inheritance of I.Q. can be achieved.




**GENOTYPE-ENVIRONMENT INTERACTION is measured in these results from an experiment carried out by R. Cooper and John P. Zubek of the University of Manitoba. The experiment involved two strains of rats: those that were bred to be "bright," that is, clever at finding their way through a maze, and those that were "dull." In a normal environment bright rats (*colored curve*) made only 120 errors, whereas dull rats made about 168 errors. When both strains were raised in a restricted environment, however, both made about 170 errors. When raised in a stimulating environment, both kinds of rats did equally well.**

Perhaps the only practical argument in favor of research on the race I.Q. difference is that, since the question that the difference is genetic has been raised, an attempt should be made to answer it. Otherwise those who now believe—we think on quite inadequate evidence—that the difference is genetic will be left to continue their campaigns for an adjustment of our educational and economic systems to take account of "innate" racial differences.

A demonstration that the difference is not primarily genetic could counter such campaigns. On the other hand, an answer in the opposite direction should not, in a genuinely democratic society free of race prejudice, make any difference. Our society professes to believe there should be no discrimination against an individual on the basis of race, religion or other a priori categorizations, including sex. Our accepted ethic holds that each individual should be given equal and maximum opportunity, according to his or her needs, to develop to his or her fullest potential. Surely innate differences in ability and other individual variations should be taken into account by our educational system. These differences must, however, be judged on the basis of the individual and not on the basis of race. To maintain otherwise indicates an inability to distinguish differences among individuals from differences among populations.

We are not unaware of the dangers of either overt or implicit control of scientific inquiry. The suppression of Galileo and the success of T. D. Lysenko are two notorious examples of the evils of such control. Most investigators, however, do accept certain limitations on research on human beings, for example in the right of an individual not to be experimented on and in the confidentiality of the information collected by organizations such as the Bureau of the Census. In the present racial climate of the U.S. studies on racial differences in I.Q., however well intentioned, could easily be misinterpreted as a form of racism and lead to an unnecessary accentuation of racial tensions. Since we believe that, for the present at least, no good case can be made for such studies on either scientific or practical grounds, we do not see any point in particularly encouraging the use of public funds for their support. There are many more useful biological problems for the scientist to attack.

# THE BREAKUP OF PANGAEA

## Pangaea is the single land mass that is believed to have given rise to the present continents. Its outline has now been plotted and its further disruption has been projected into the future

by Robert S. Dietz and John C. Holden

The history of science is replete with outrageous hypotheses. They are mostly forgotten, as best they should be, but from time to time one of them turns out to be true. So it was with the concept that the earth is a sphere spinning in space, supported by nothing at all. Now it also seems to be with the theory of continental drift, which in its extreme form holds that all the continents were once joined in a single great land mass. Named Pangaea, this universal continent was somehow disrupted, and its fragments—the continents of today—eventually drifted to their present locations.

Over the past three years geologists and geophysicists have been forced to abandon the old dogma that the crust of the earth is essentially fixed and to accept the new heresy that it is quite mobile. The notion that continents can drift thousands of kilometers in a few hundred million years is now generally accepted. Geology therefore finds itself in much the same position that astronomy was in at the time of Copernicus and Galileo. Textbooks are being rewritten to embrace the new mobilistic viewpoint.

Although the theory of continental drift has triumphed, many of its details remain uncertain. Advocates of drift are challenged to say exactly how the present continents fitted together to form Pangaea, or alternatively to reconstruct the two later supercontinents Laurasia and Gondwana, which some theorists prefer to a single all-embracing land mass. The original concept of Pangaea ("all lands") was proposed in the 1920's by Alfred Wegener. Most attempts to improve on his reconstruction have been rather generalized sketches showing how the continents might have been joined. A few workers have made jigsaw fits with considerable care but without taking advantage of the latest concepts in geotectonics. Recently British theorists have presented detailed reconstructions showing how land masses were juxtaposed before the opening of either the Atlantic or the Indian Ocean, but their solutions show only the relative motions of the masses involved.

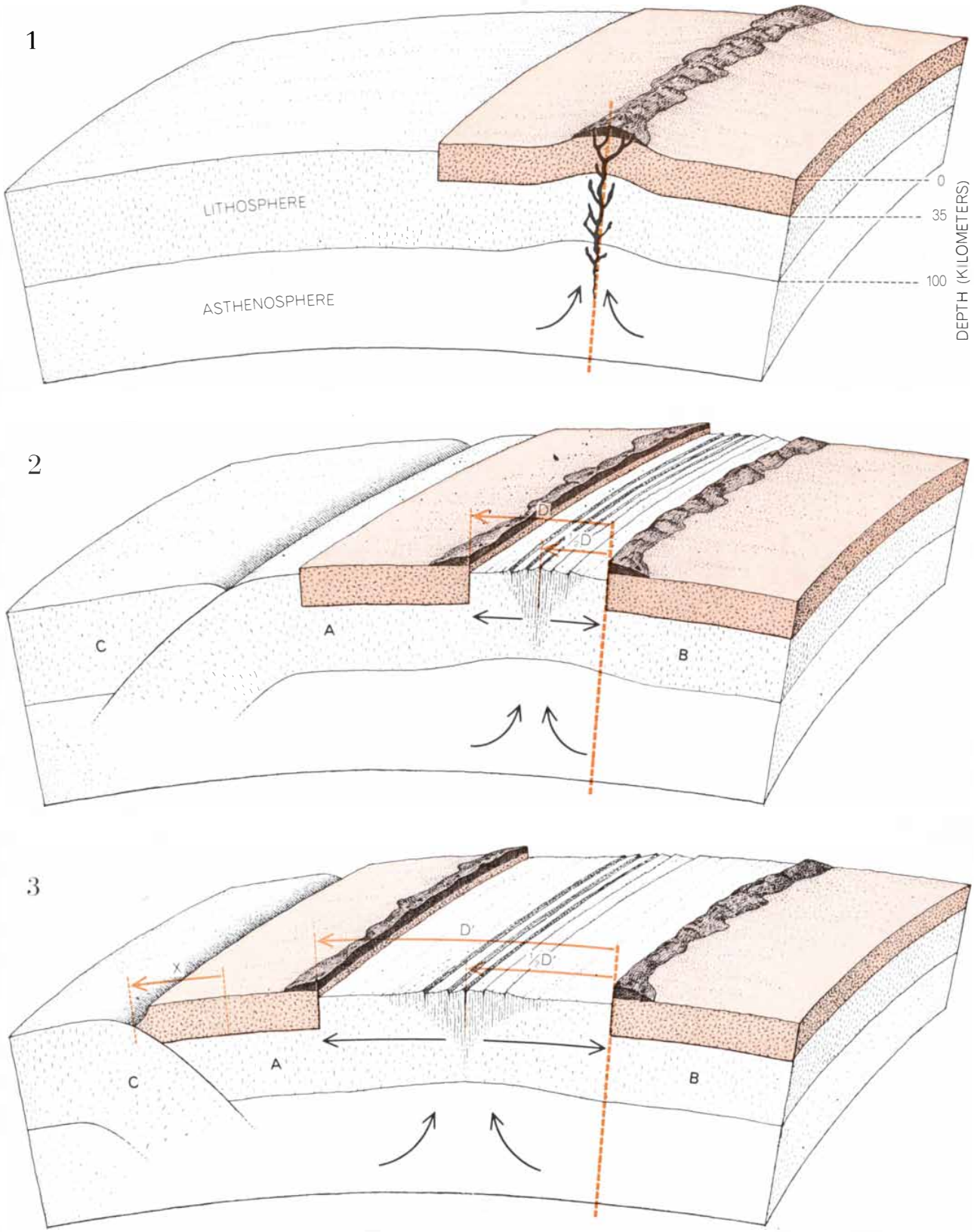
In this article we present a reconstruction of Pangaea in which the continents are assembled with cartographic precision. For the first time Pangaea is positioned on the globe in absolute coordinates. This reconstruction is accompanied by four maps that show the breakup and subsequent dispersion of the continents by the end of the four major geologic periods covering the past 180 million years: the Triassic, the Jurassic, the Cretaceous and the Cenozoic.

The guiding rationale for our reconstruction is the drift mechanism associated with plate tectonics and seafloor spreading [*see illustration on page 32*]. According to this concept the earth has a strong lithosphere, or outer shell of rock, about 100 kilometers thick. Presumably in response to forces generated in the asthenosphere, the weak upper mantle of rock underlying the lithosphere, the shell was broken up into a number of separate plates. There are now some 10 major plates, plus numerous additional subplates. The continents resting on these plates were rafted across the surface of the globe.

The mechanism of plate movement is not yet clear. The plates may be pushed, carried by convection cells in the mantle, driven by gravitational forces or pulled. We prefer a model based on pulling; we suspect that plates are colder and heavier at one boundary than elsewhere and thus dive down into the earth's mantle along "subduction" zones. These zones usually show themselves as deep trenches, which are disposed principally around the periphery of the Pacific. As a result a tear, or rift, widens along the opposite boundary of the plate; this rift is filled by a solid flow of viscous mantle rock and by dikes of molten tholeiitic basalt (a differentiated partial melt of the mantle). Because the mantle rock and its basaltic derivative are both heavier than the granitoid rock of the continents they assume a level about four kilometers below sea level. Consequently such a pulled-apart region always becomes new ocean floor. As two adjacent plates continue to pull apart, basaltic dikes continue to pour into the suboceanic rift, which remains midway between the two plates. This highly symmetrical process, which creates new ocean basins or continuously repaves old ocean floors, is termed seafloor spreading. The rate of spreading, measured from the mid-ocean rift to either plate, is from one centimeter per year (10 kilometers per million years) to several times that figure. This is remarkably rapid by geological standards, being many times faster than mountains are elevated by tectonism or leveled by erosion. For example, the North American plate is moving westward the length of one's body in a lifetime.

The discovery of a mid-ocean ridge system some 40,000 kilometers long, winding through all the ocean basins, was an important prelude to the seafloor-spreading hypothesis. It was soon recognized that the ridge has a fossa, or axial depression, into which dikes of basalt are continuously being injected. This linear depression in the ridge marks the location of the rift. The term "mid-ocean," although appropriate for the part of the ridge system in the Atlantic

**SUBCONTINENT OF INDIA, originally attached to what is now Antarctica, made the longest migration of all the drifting land masses: approximately 9,000 kilometers in 200 million years. This picture, taken at an altitude of 650 kilometers from *Gemini XI* in September, 1966, shows all of India and Ceylon. The Himalayan mountains, 3,700 kilometers away, are just visible on the horizon.**



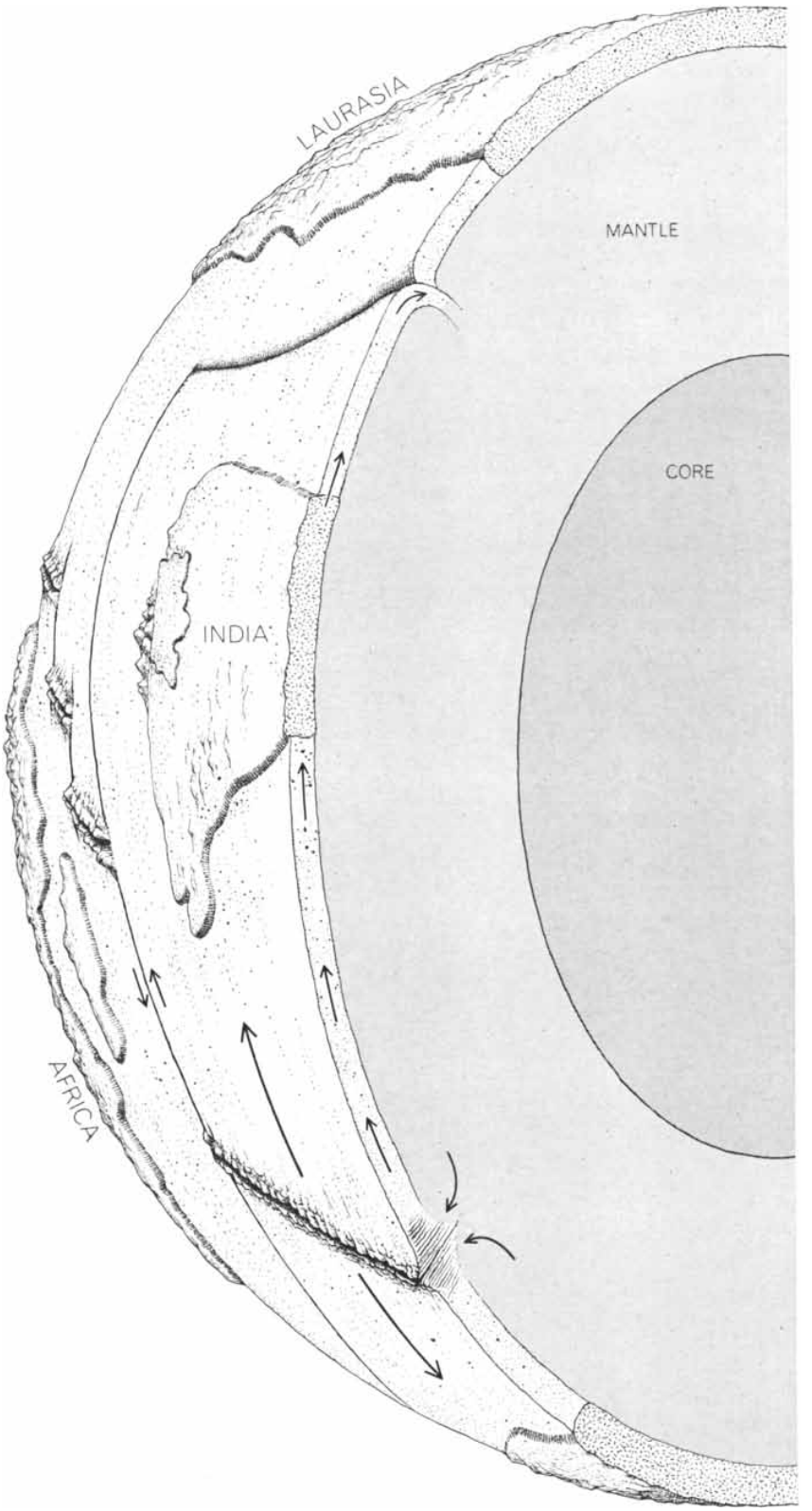

**THEORY OF PLATE TECTONICS** provides a mechanism for continental drift. The process begins (*1*) when a spreading rift develops under a continent (*color*) that is resting on a single crustal plate. Molten basalt from the asthenosphere spills out. The second simultaneous requirement for continental drift is the formation of a zone of subduction, or trench, into which oceanic crust of the new moving plate (*A*) is pulled and "consumed" (*2*). As the new continent carried by plate *A* is rafted to the left, a new ocean basin is created between the two land masses. In the third stage (*3*) the continent on plate *A* encounters and overrides the trench for some distance (*X*) and eventually reverses, or flips, its direction from west-dipping to east-dipping. Because the continent on plate *B* is here arbitrarily fixed, the mid-ocean rift migrates to the left, remaining in the center of the new ocean basin, whose width is *D'*.

and the Indian Ocean, is a misnomer for the ridge in the Pacific. The Atlantic and the Indian Ocean are rift oceans, formed where continents were once split apart; therefore it is natural for the axis of spreading, marked by the ridge system, to remain in the center of these two oceans. The Pacific, on the other hand, is not a rift ocean; it is clearly the ancestral ocean, and it is becoming smaller as new ocean basins grow. Although the Pacific also has a ridge, it runs north-south well to the east of the ocean's center.

In reality the crustal motions are considerably more complex than the ones we have just outlined. The trenches and rifts apparently migrate, and the opposing plates are also subject to displacements produced by internal shears. The "megashears," the large zones of slippage along plate boundaries, also seem able to accommodate minor amounts of crustal extension or compression. Few of the plates are "ideal" in the sense of being rectilinear, of having a rift matched by an opposing trench and of having these two antithetical zones connected by a megashear. The Antarctic plate, for example, has no trench at all. Perhaps this anomaly is partly explained by the fact that a sphere cannot be covered with rectangles.

We can visualize the continents as being passively rafted over the surface of the globe as embedded plateaus of sialic (granite-like) rock resting on the even larger and thicker crustal plates. The continents have generally maintained their size and shape since the breakup of Pangaea. There have been some accretions with the formation of mountain belts, but these have been mostly confined to the sides of continents facing the Pacific. The sides of continents facing rift oceans (the Atlantic and the Indian Ocean) show little change; hence they can be fitted together almost as neatly as pieces of a jigsaw puzzle.

In contrast, the crustal plates can change in size or shape either by the addition of new ocean floor along the rifts or by the resorption of oceanic crust in trenches. Thus it has been possible for the North American and South American plates moving toward the Pacific to grow larger at first and then smaller as they passed over the great circle of the earth and now converge toward the central Pacific. An even more tortured history is reflected in the complex evolution of the Caribbean Sea region, caught as a "gore" between the North American and South Ameri-




**NORTHWARD DRIFT OF INDIA** exemplifies how far a land mass can be carried when tectonic conditions are favorable. The plate carrying the Indian land mass is nearly a perfect rectangle, which was sliced away from Antarctica within the primitive universal continent of Pangaea. The plate that rafted India then migrated northward toward and subducted into the Tethyan trench, which ran east-west near the Equator. The plate evidently glided freely along parallel "megashears" on its eastern and western boundaries without interacting with the other crustal plates of the world. India finally collided with and underthrust the southeast margin of Asia, creating the Himalayas, which are thus two plates thick.

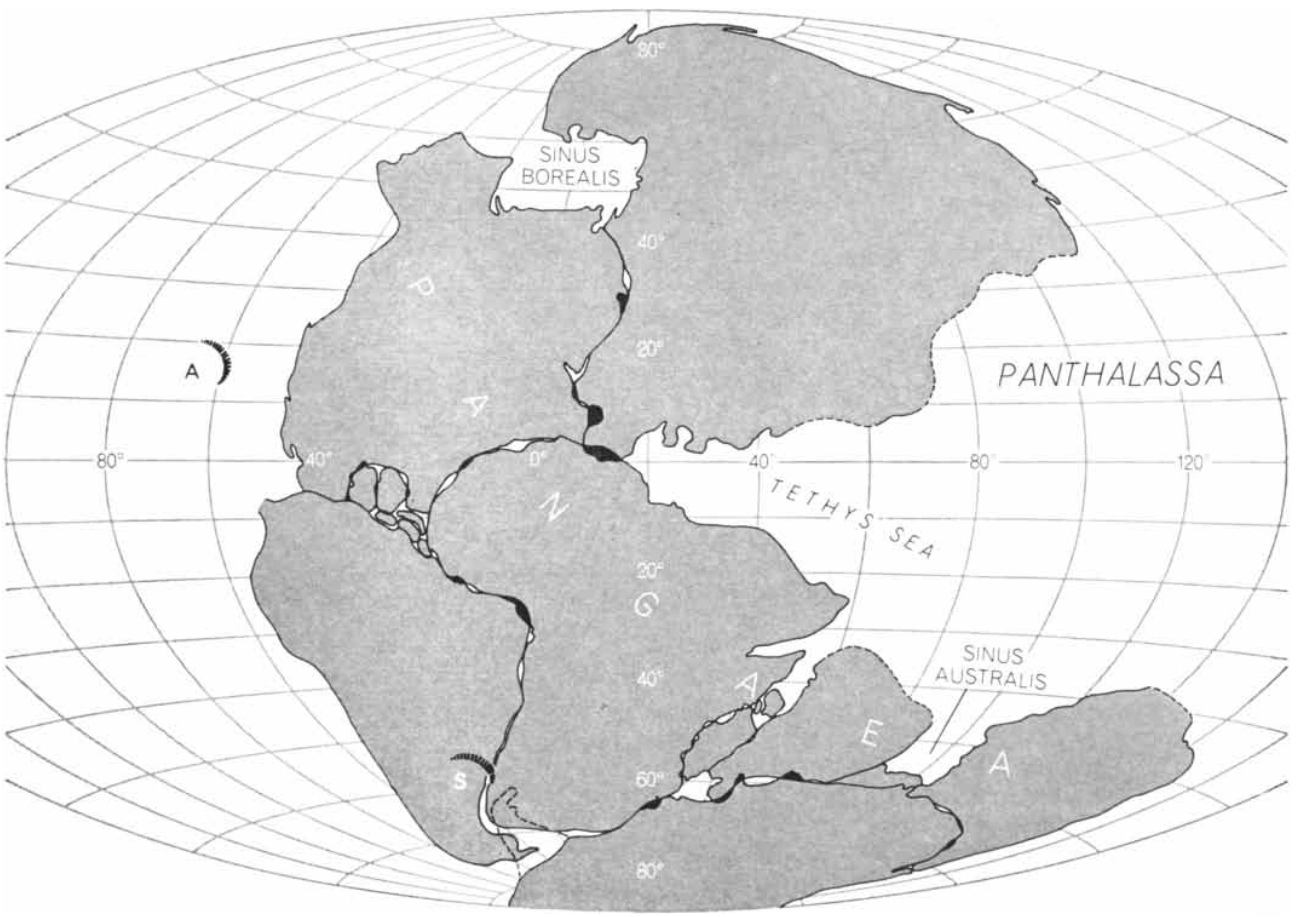
can plates, and the Scotia Sea region, similarly trapped between the South American and Antarctica plates. As we shall see, in at least one case two plates evidently collided, producing a mid-continent mountain range: the Himalayas.

In making our reconstruction of Pangaea we selected for fitting not the present coastlines of continents but the contour lines where the continental slope reaches a depth of 1,000 fathoms, or about 2,000 meters [*see illustration below*]. This isobath was selected because it is approximately halfway down the continental slope and thus marks roughly half the height of the vertical walls created when the continents first rifted. On the assumption that these walls subsequently slumped to a condition of stable repose, the 1,000-fathom isobath closely delineates the location of the original break.

For joining the two sides of the Atlantic we have followed, with some modification, the reconstruction proposed by Sir Edward Bullard, J. E. Everett and A. G. Smith of the University of Cambridge. For closing the Indian Ocean we have used the best-fit computer solutions of Walter P. Sproll, a colleague of ours in the Marine Geology and Geophysics Laboratory of the Environmental Science Services Administration. His studies provide precise fits between Australia and Antarctica and between Antarctica and Africa. The three continents together constitute most of Gondwana. Presumably India was also part of the Gondwana complex, but where it was attached remains unclear. Fortunately the pattern of fracture zones in the ocean floor provides crude but useful dead-reckoning tracks showing how the continents drifted. Using such tracks, we have placed the west coast of India against Antarctica rather than against western Australia, the fit that is often proposed.

Another difficult fit is presented by the bulge of Africa and the bight of North America. The areas of mismatch, particularly that caused by the Florida-Bahamas platform, are sufficiently large for one to reasonably argue that Africa and North America were never joined. On this assumption instead of Pangaea one obtains two unconnected supercontinents as the antecedent land masses: Laurasia in the Northern Hemisphere and Gondwana in the Southern. This version of the continental-drift theory has important adherents.

We nevertheless prefer the Pangaea reconstruction; in our view the areas of mismatch can reasonably be regarded as modifications that arose after Africa and North America began drifting apart. We regard the Florida-Bahamas platform as a sedimentary infilling of a small ocean basin that appeared when Africa




**UNIVERSAL LAND MASS PANGAEA** may have looked like this 200 million years ago. Panthalassa was the ancestral Pacific Ocean. The Tethys Sea (the ancestral Mediterranean) formed a large bay separating Africa and Eurasia. The relative positions of the continents, except for India, are based on best fits made by computer, using the 1,000-fathom isobath to define continental boundaries. When the continents are arranged as shown, the relative locations of the magnetic poles in Permian times are displaced to the positions marked by circles. Ideally these positions should cluster near the geographic poles. The hatched crescents (*A and S*) serve as modern geographic reference points; they represent the Antilles arc in the West Indies and Scotia arc in the extreme South Atlantic.

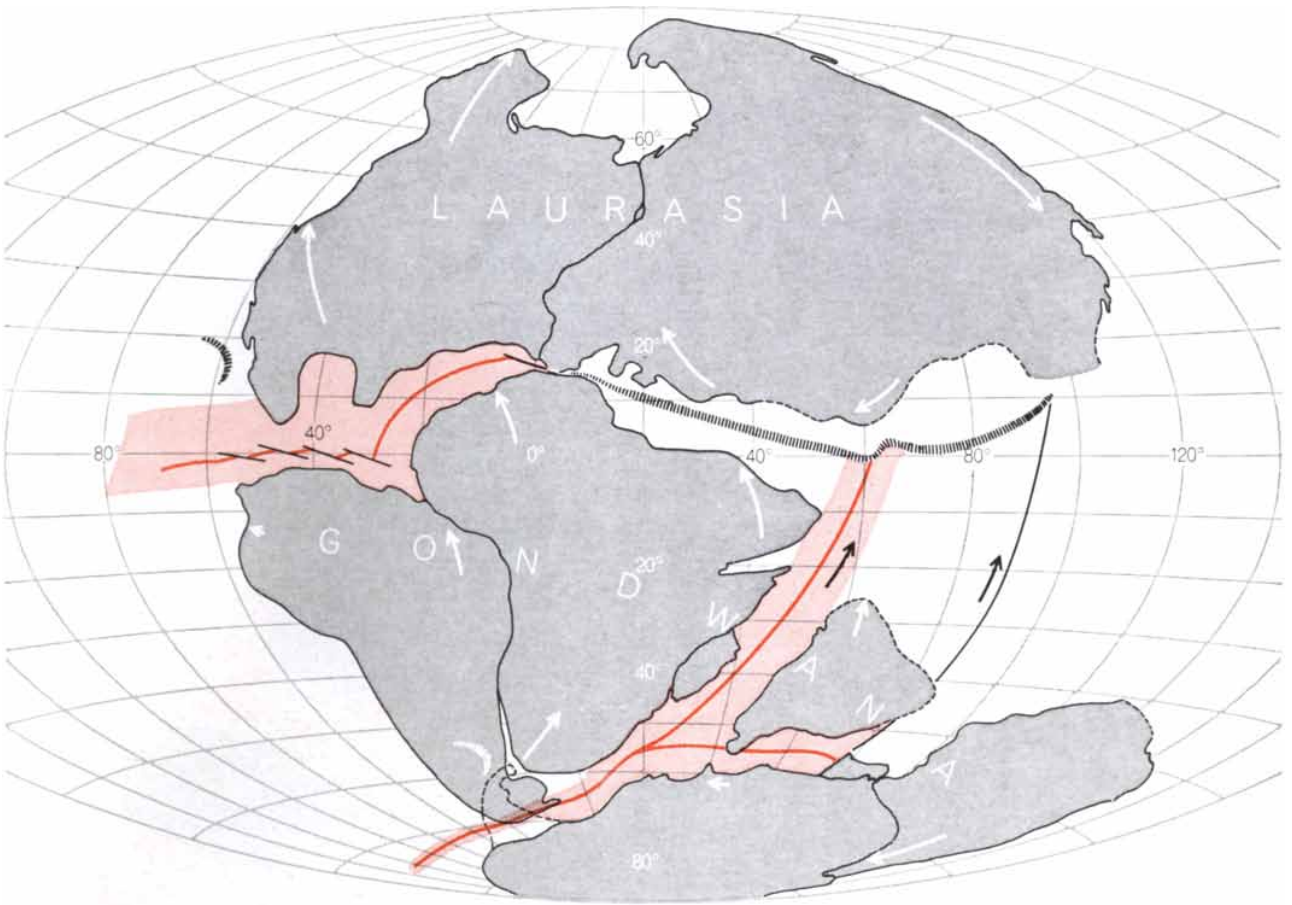
and North America first began to pull apart. Without this assumption the platform unaccountably overlaps a large portion of the bulge of Africa [*see illustration on page 40*].

According to our reconstruction, Pangaea was a land mass of irregular outline surrounded by the universal ocean of Panthalassa: the ancestral Pacific. The fit between North America and Africa provides the principal connection between the future block of northern continents and the future group of southern ones. On the east the Tethys Sea, a large triangular bight, separated Eurasia from Africa; the present Mediterranean Sea is a remnant of the Tethys. Other major indentations in the outline of Pangaea (adapting terminology from the moon) can be named Sinus Borealis, the ancestral Arctic Ocean, and Sinus Australis, a southern bay off the Tethys separating India from Australia. Our fully closed reconstruction of the Central American region is problematical. An alternate possibility is that the Gulf of Mexico is the remnant of an oceanic arm extending into the Americas from Panthalassa—a Sinus Occidentalis.

When measured down to the 1,000-fathom isobath, the total area of Pangaea was 200,000 square kilometers, or 40 percent of the earth's surface—equal to the area of the present continents measured to the same isobath. When the future continents were still part of Pangaea, they were generally to the south and east of their present location, so that the amount of land in the two hemispheres was almost equally balanced. (Today two-thirds of all the land lies north of the Equator.) The *Y*-shaped junction connecting North America, South America and Africa was located in the South Atlantic not far from the present position of Ascension Island. If New York had been in existence at the time, it would have been on the Equator and at longitude 10 degrees east (rather than 74 degrees west). Spain would also have been on the Equator, but it would have been near its present longitude. Japan would have been in the Arctic, well north of its position today. India and Australia would have bordered the Antarctic, far to the south of where they are now.

The great event that broke up Pangaea and set its fragments adrift evidently began no more than 200 million years ago, or in the last few percent of geologic time. There may have been—indeed, there probably was—"predrift drift" that assembled Pangaea from two or more smaller land masses. The evidence is still scanty, however, and does not bear directly on this discussion.

We take the immediate prelude to the breakup of Pangaea to be the first large outpourings of basaltic rock along the continental margins being es-



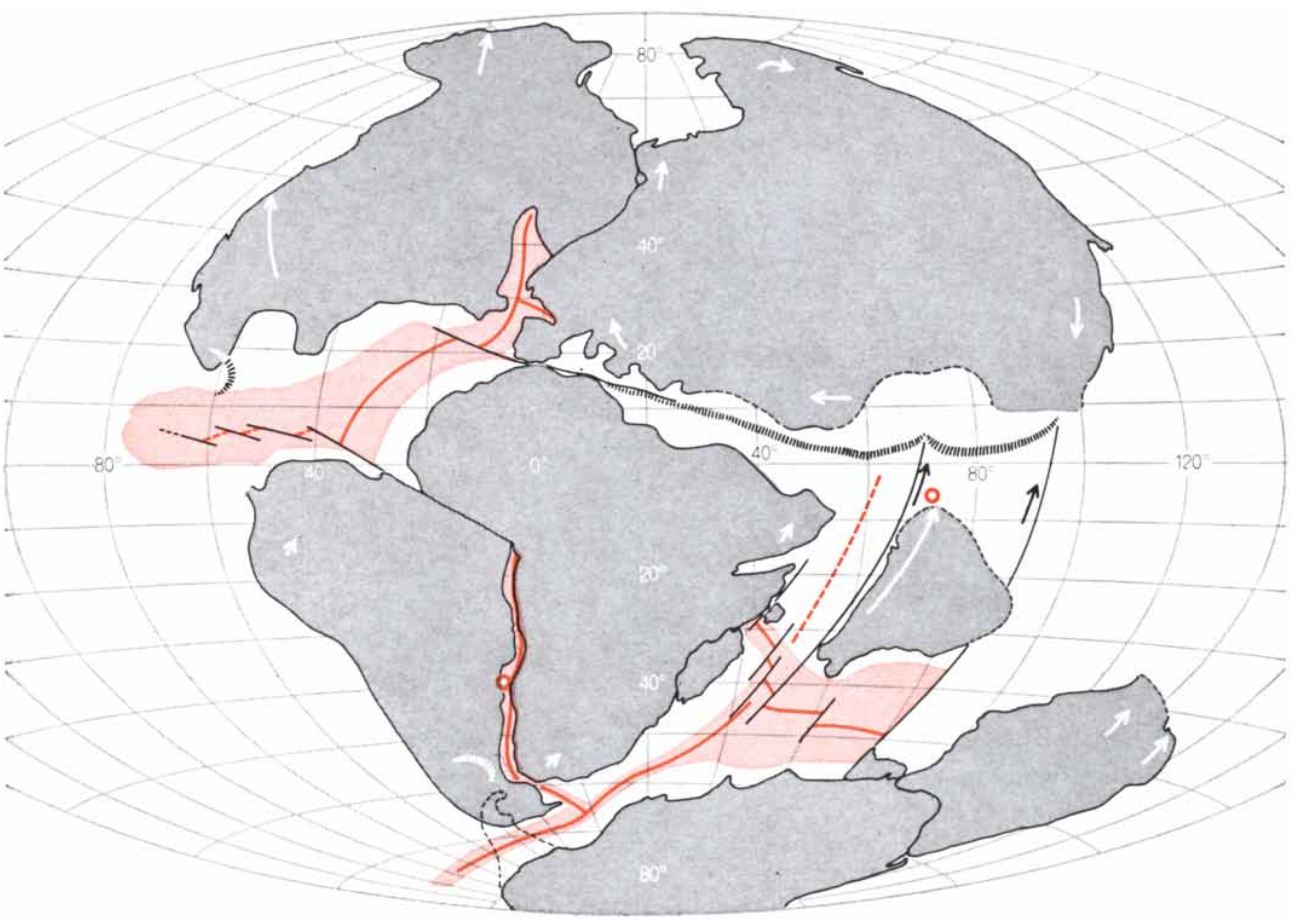

AFTER 20 MILLION YEARS OF DRIFT, at the end of the Triassic period 180 million years ago, the northern group of continents, known as Laurasia, has split away from the southern group, known as Gondwana. The latter has started to break up: India has been set free by a *Y*-shaped rift (*heavy line in color*), which has also begun to isolate the Africa–South America land mass from Antarctica-Australia. The Tethyan trench (*hatched lines in black*), a zone of crustal uptake, runs from Gibralter to the general area of Borneo. Black lines and black arrows denote megashears, zones of slippage along plate boundaries. The white arrows indicate the vector motions of the continents since drift began. Oceanic areas tinted in color represent new ocean floor created by sea-floor spreading.

tablished by rifting. The Triassic Newark series of basaltic flows along the east coast of the U.S. is a good example. Measurements of radioactivity indicate that the most ancient of these rocks are about 200 million years old, yielding a date that coincides with the middle of the Triassic period. As we interpret the evidence, two extensive rifts were initiated in Pangaea about 200 million years ago, which resulted in the opening of the Atlantic and the Indian Ocean by the end of the Triassic period 180 million years ago [*see illustration on preceding page*]. The northern rift split Pangaea from east to west along a line slightly to the north of the Equator and created Laurasia, composed of North America and Eurasia. The Laurasian land mass evidently rotated clockwise as a single plate around a pole of rotation that is now in Spain, creating a western "Mediterranean" that ultimately became part of the Gulf of Mexico and the Caribbean Sea. The southern rift split South America and Africa as a single land mass away from the remainder of Gondwana, consisting of Antarctica, Australia and India. Soon afterward (if not simultaneously) India was severed from Antarctica by a smaller rift to begin its rapid drift northward.

During the Jurassic period, from 180 to 135 million years ago, the direction of drift established by the Triassic rifts continued, further opening up the Atlantic and the Indian Ocean [*see illustration below*]. As North America drifted to the northwest, the Atlantic became more than 1,000 kilometers wide and probably remained fully connected to the Pacific. The east coast of the present U.S. ran almost east and west at a latitude of about 25 degrees north, so that coral reefs were able to grow all along the edge of the Atlantic continental shelf to the present Grand Banks, off Nova Scotia.

During the 45-million-year Jurassic period the Atlantic rift extended northward, blocking out the Labrador coastline and possibly initiating the opening up of the Labrador Sea between North America and Greenland. The interaction between the African and Eurasian plates forced the region of Spain to rotate counterclockwise 35 degrees, opening up the Bay of Biscay. The Tethys Sea, forerunner of the Mediterranean, continued to close at its eastern end. The Tethys was not only a zone of crustal subduction, or trench, but also a zone of shear along which Eurasia slid westward with respect to Africa. The compression associated with the Tethys trench raised bordering mountains composed of deep-water sediments.

At the close of the Jurassic an incipient rift began splitting South America away from Africa, entering from the south and working only as far north as where Nigeria is today. The tectonic situation first resembled the one now found in the rift zone along the backbone of high Africa (the region from Ethiopia to Tanzania) and then gradually opened farther to form a body of water resembling the Red Sea of today.




**AFTER 65 MILLION YEARS OF DRIFT, at the end of the Jurassic period 135 million years ago, the North Atlantic and the Indian Ocean have opened considerably. The birth of the South Atlantic has been initiated by a rift. The rotation of the Eurasian land mass has begun to close the eastern end of the Tethys Sea. The Indian plate is about to pass over a thermal center (*colored dot*) that will soon pour out basalt to form the Deccan plateau. Later the hot spot will create the Chagos-Laccadive ridge in the Indian Ocean. Similarly, in the South Atlantic the Walvis thermal center (*colored dot*) will create the Walvis and Rio Grande "thread ridges."**

At first freshwater sediments created thick deposits in pockets opened by faults; these sediments were overlain by deposits of salt.

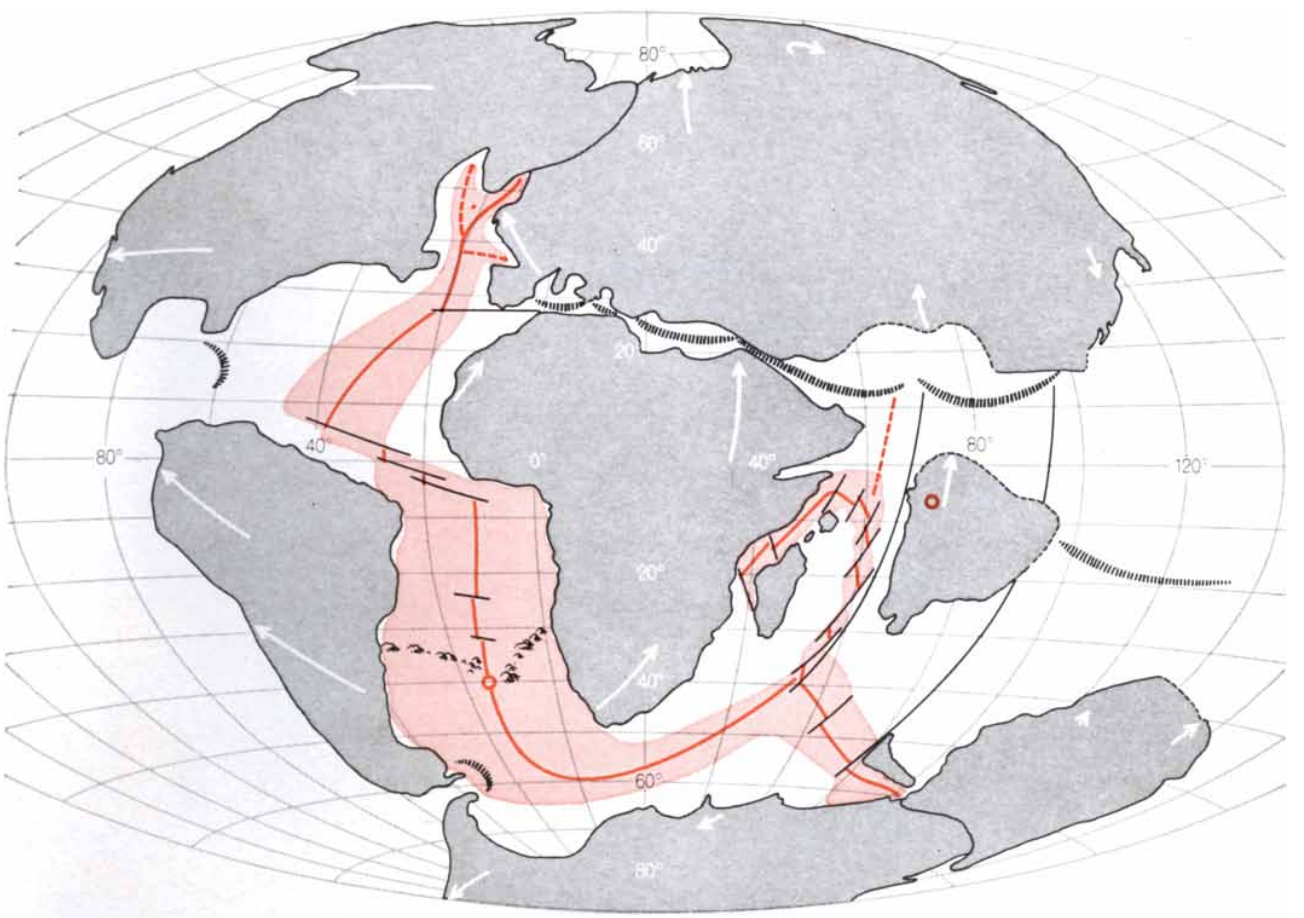
By the end of the Cretaceous period, some 70 million years later (and 65 million years ago), the rupture of South America and Africa was complete, and the South Atlantic had widened rapidly to at least 3,000 kilometers [*see illustration below*]. Meanwhile the rift in the North Atlantic had switched from the west side of Greenland to the east side, blocking out its eastern margin (without, however, penetrating to the Arctic Ocean). Africa had drifted northward about 10 degrees and continued its counterclockwise rotation as the Eurasian plate rotated slowly clockwise. These two opposed motions nearly closed the eastern end of the Tethys Sea. The slow westward rotation of Antarctica continued. All the continents were now blocked out except for the remaining connection between Greenland and northern Europe and between Australia and Antarctica.

Although it is not shown on our maps, an extensive north-south trench system must have existed in the ancient Pacific to consume by subduction the rapid westward drift of the two plates carrying North and South America. North America presumably encountered this trench in the late Jurassic and early Cretaceous, with the result that the Franciscan fold belt, the predecessor of the California Coast Ranges, was accreted to the western margin of the continent. It appears that the trench was eventually overridden and "stifled" by North America's continued westward drift. Such trenches have the capacity to resorb ocean crust but not the lighter granitic crust of continents.

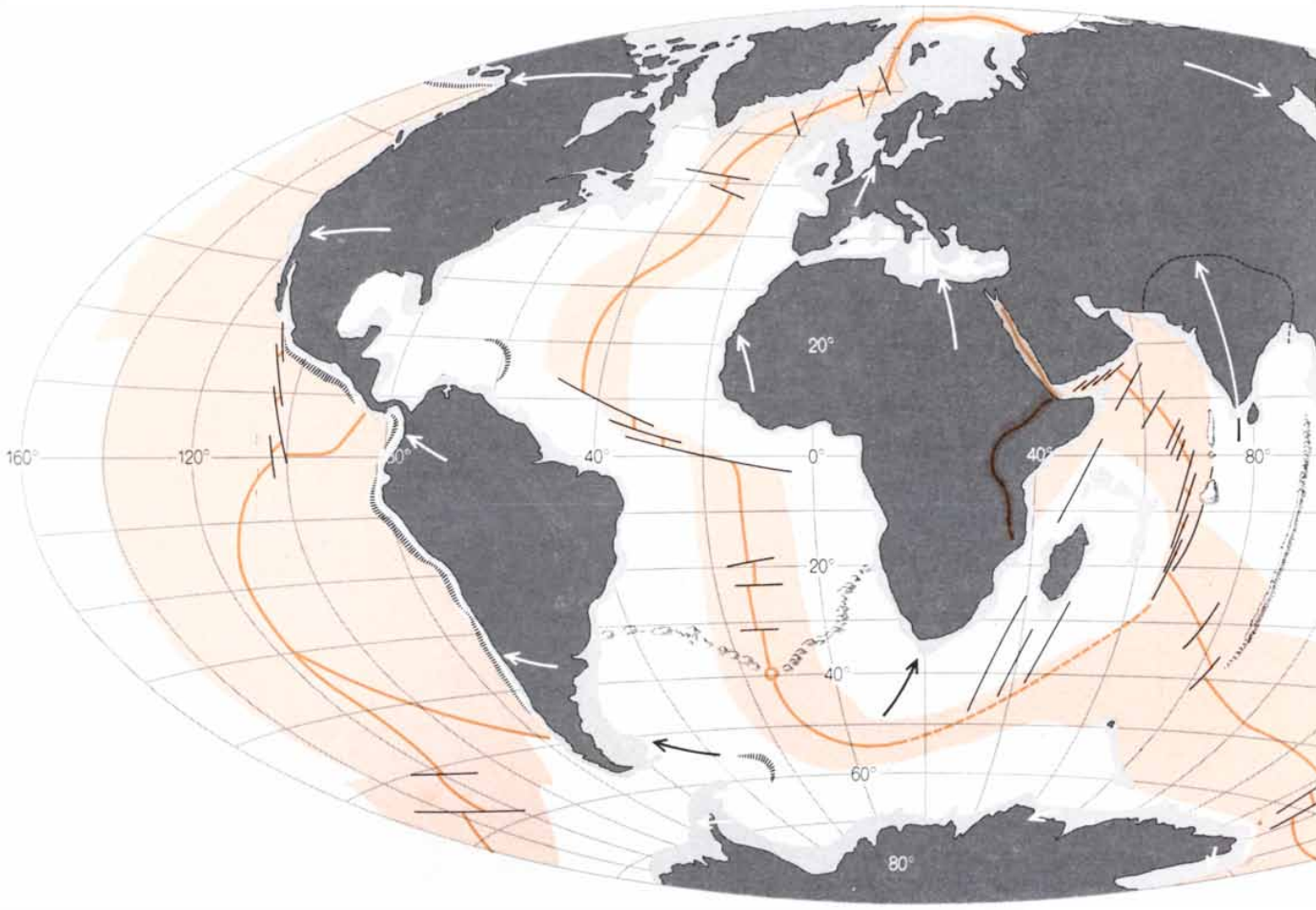
At about the same time, or soon afterward, South America first encountered the Andean trench and began to displace the trench westward, without ever overriding it. The early Andean fold belt resulted from this encounter. It seems likely that the trench originally dipped toward the west but was flipped over to its present eastward dip.

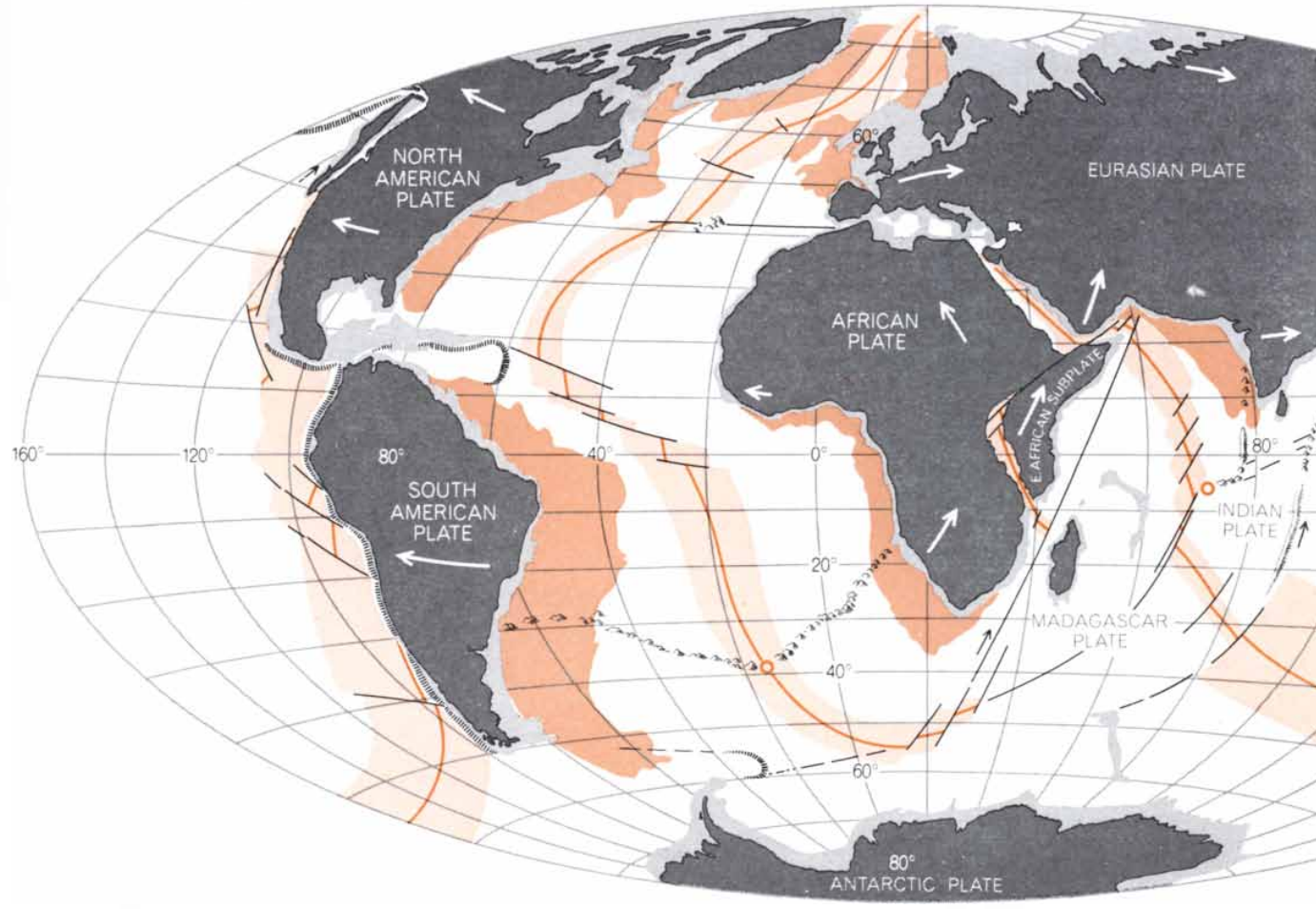
In the Cenozoic period (from 65 million years ago to the present) the continents drifted to the positions we observe today. The mid-Atlantic rift propagated into the Arctic basin, finally detaching Greenland from Europe [*see top illustration on next two pages*]. There were three other major developments during the Cretaceous: (1) the two Americas were rejoined by the Isthmus of Panama, created by volcanism and the arching upward of the earth's mantle, (2) the Indian land mass completed its remarkable journey northward by colliding with the underbelly of Asia and (3) Australia was rifted away from Antarctica and drifted northward to its present position.

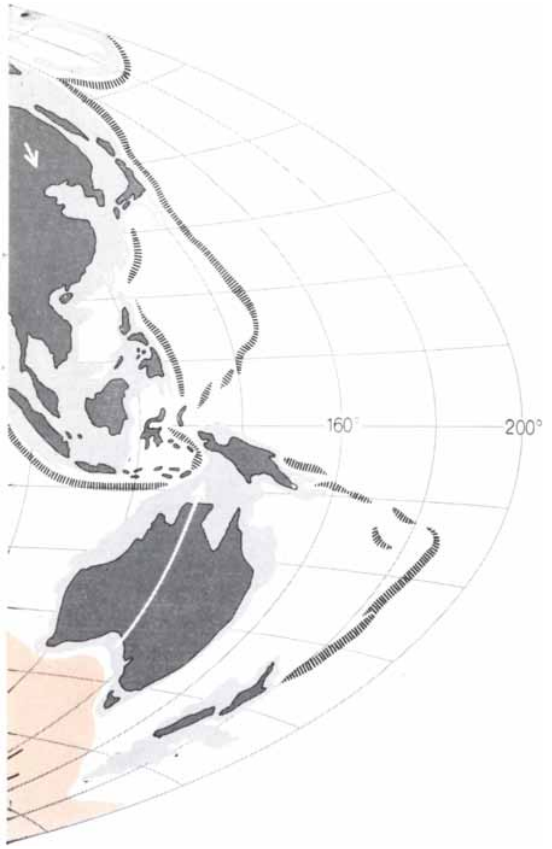
In the collision of India with Asia the northern margin of the Indian plate was subducted below the Asiatic plate, creating the Himalayas. On India's passage to the north early in the Cenozoic its western margin crossed a fixed source of

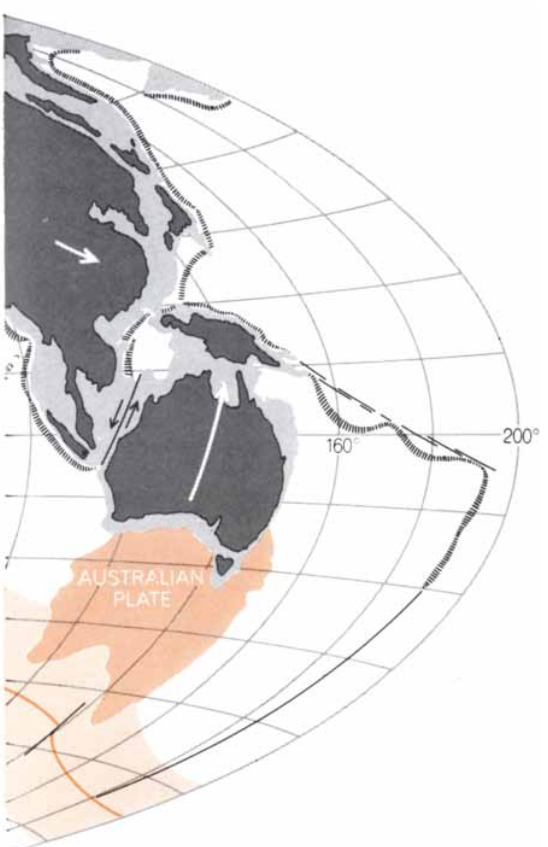



**AFTER 135 MILLION YEARS OF DRIFT, 65 million years ago at the end of the Cretaceous period, the South Atlantic has widened into a major ocean. A new rift has carved Madagascar away from Africa. The rift in the North Atlantic has switched from the west side to the east side of Greenland. The Mediterranean Sea is clearly recognizable. Australia still remains attached to Antarctica. An extensive north-south trench (*not shown*) must also have existed in the Pacific to absorb the westward drift of the North American and South American plates. Note that the central meridian in all these reconstructions is 20 degrees east of the Greenwich meredian.**






**WORLD AS IT LOOKS TODAY was produced in the past 65 million years in the Cenozoic period. Nearly half of the ocean floor was created in this geologically brief period, as shown by the areas stippled in color. India completed its flight northward by colliding with Asia and a rift has separated Australia from Antarctica. The North Atlantic rift finally entered the Arctic Ocean, fissioning Laurasia. The widening gap between South America and Africa is closely traced by the thread ridges produced by the Walvis thermal center. The Antilles and Scotia arcs now occupy their proper positions with respect to neighboring land masses.**

basaltic magma rising from the earth's upper mantle near the Equator. Molten rock erupted through the crust and poured onto the Indian subcontinent, laying down the basalts of the Deccan plateau. Even after India had left the hot spot behind, magma continued to stream out on the ocean floor, producing the Chagos-Laccadive ridge, which became covered with coral as it subsided into the Indian Ocean. Finally, a branch of the Indian Ocean rift split Arabia away from Africa, creating the Gulf of Aden and the Red Sea, and a spur of this rift meandered west and south into Africa.

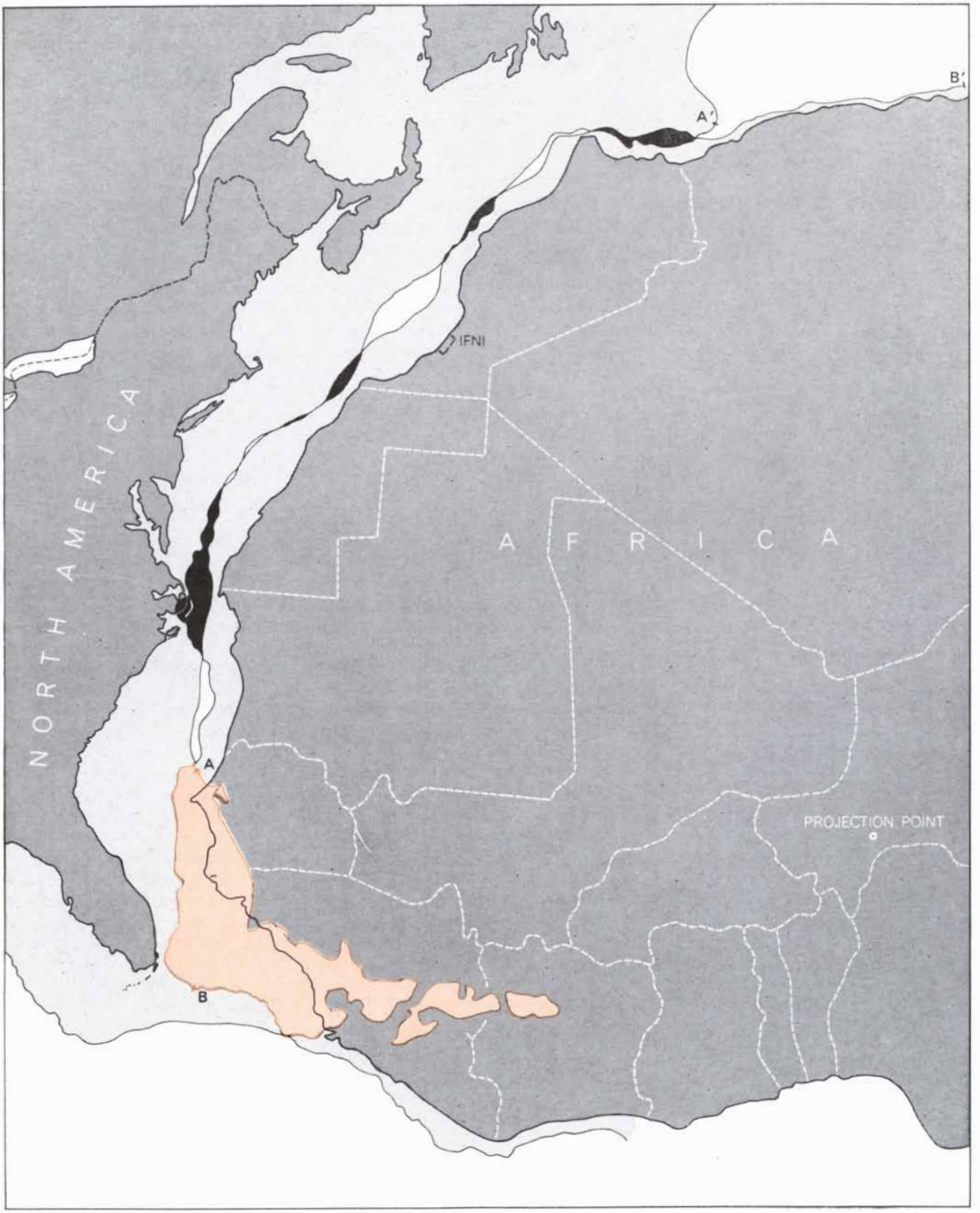
Less pronounced changes during the Cenozoic period included the partial closing of the Caribbean region and the continued widening of the South Atlantic as new ocean crust was emplaced by sea-floor spreading. As the Atlantic continued to open in the far north the northwestward movement of the Eurasian land mass was halted and reversed, simultaneously reversing its sense of slippage with respect to Africa. The new direction of shear has been strongly impressed on the tectonic character of the Mediterranean and the Near East. The major north-south rift in the Indian Ocean largely ceased spreading and became instead a megashear that accommodated the counterclockwise and northward rotation of the African plate.

The reader will have observed that our maps of continental drift show more than relative positions and motions; the land masses, beginning with Pangaea itself, are assigned absolute geographic coordinates. Since this has not been attempted before we shall briefly describe how we arrived at our results. In the mobile world of plate tectonics one must assume that all parts of the crust are capable of moving and almost surely have moved.

After an extensive search for some absolute reference point, we finally concluded that the Walvis thermal center, or hot spot, might provide what we sought. In reaching this conclusion we accepted a hypothesis put forward by J. Tuzo Wilson of the University of Toronto. He had suggested that the Walvis ridge and the Rio Grande ridge in the South Atlantic are nemataths, or "thread ridges" of basalt, that had been poured onto the spreading ocean floor from a fixed lava orifice rising from a deep, stagnant region of the mantle. As new floor was carried past the orifice, lava would periodically pour out and form a small volcanic cone. By observing the location of succeeding cones as they merged into a ridge one can establish the absolute direction taken by the crust in that region. A study of the Walvis and Rio Grande ridges enabled us to establish not only the drift of the South American plate with respect to the African plate but also any motion the two plates may have had in some other direction [*see illustration on page 41*].

Unfortunately the Walvis hot spot did not exist earlier than about 140 million years ago, so that its usefulness as a fixed point does not go back earlier than the end of the Jurassic period. To trace crustal motions during the first 60 million years after the breakup of Pangaea one has to rely on dead reckoning. We have made the assumption that Antarctica has moved very little from its original location when it was part of Pan-

**WORLD 50 MILLION YEARS FROM NOW may look something like this. The authors have extrapolated present-day plate movements to indicate how the continents will have drifted by the end of what they propose to call the Psychozoic era (the age of awareness). The Antarctic remains essentially fixed but may rotate slightly clockwise. The Atlantic (particularly the South Atlantic) and the Indian Ocean continue to grow at the expense of the Pacific. Australia drifts northward and begins rubbing against the Eurasian plate. The eastern portion of Africa is split off, while its northward drift closes the Bay of Biscay and virtually collapses the Mediterranean. New land area is created in the Caribbean by compressional uplift. Baja California and a sliver of California west of the San Andreas fault are severed from North America and begin drifting to the northwest. In about 10 million years Los Angeles will be abreast of San Francisco, still fixed to the mainland. In about 60 million years Los Angeles will start sliding into the Aleutian trench.**



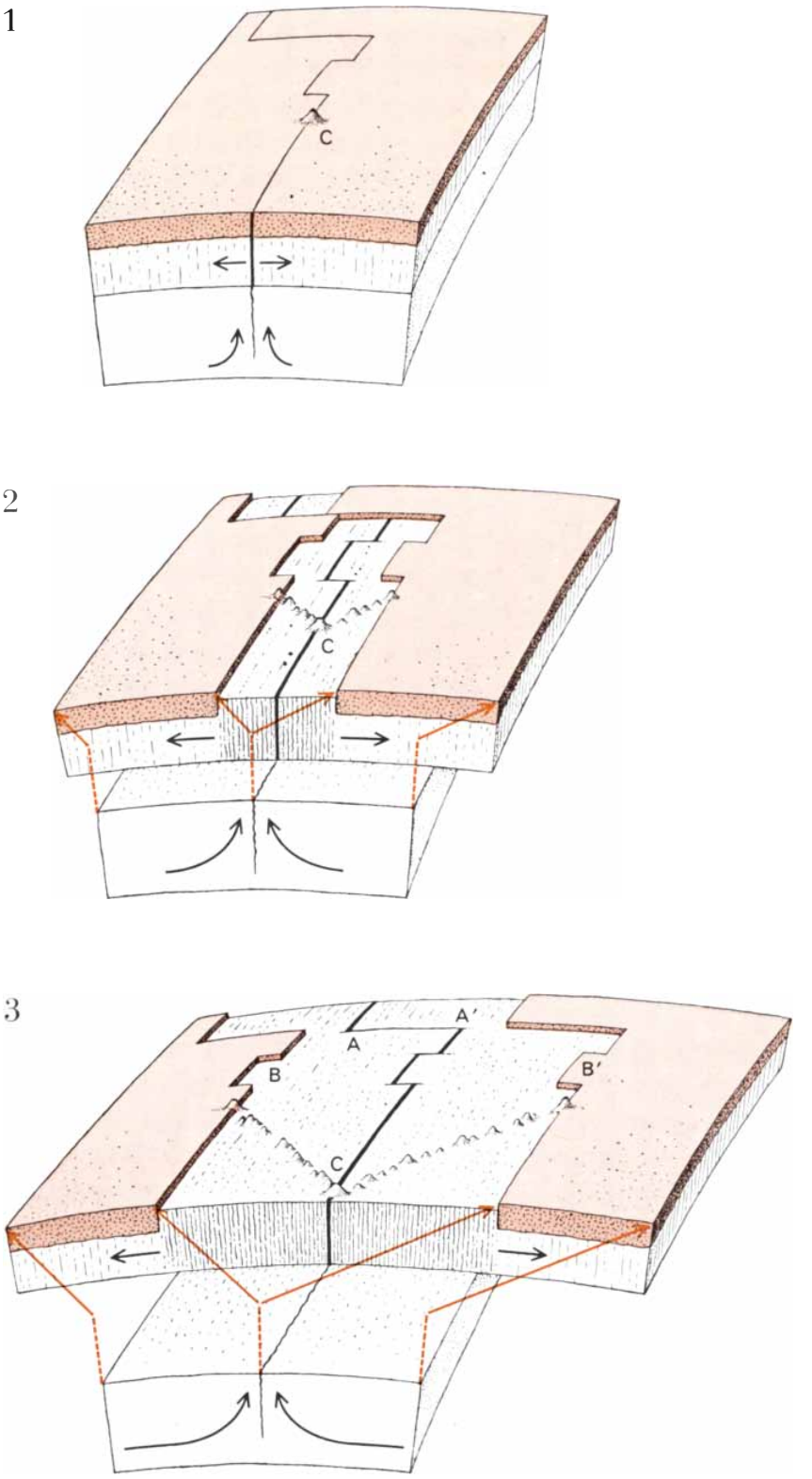

FIT OF AFRICA AGAINST NORTH AMERICA was made by the authors' colleague Walter P. Sproll with the aid of a computer. As in the reconstruction of Pangaea, it is assumed that each continent actually extends out into the ocean and halfway down the continental slope, where the ocean reaches a depth of 1,000 fathoms. The North American "coast" between *A* and *A′* was matched for best fit to the African "coast" between *B* and *B′*. White areas are gaps in the fit; black areas are overlaps. The overlap produced by the Bahamas platform, an enormous area half the size of Texas, is specially depicted in dark color. The authors propose that the platform represents an accumulation of sediments followed by coral growth after the two continents became separated. The largest gap in the proposed fit between the two continents is found off the Spanish enclave of Ifni. The Ifni gap may have been created when a small section of Africa split off and was translated 190 kilometers to the southwest, forming the eastern group of the Canary Islands.

gaea. This seems reasonable because the Antarctica plate is entirely surrounded by a system of rifts and megashears; there is no associated trench toward which the plate would tend to move away from its polar position.

Independent support for this assumption is obtained by plotting the position of the North and South poles before the dispersal of Pangaea. These positions are obtained by studying the direction of magnetization in rocks of the Permian period, as obtained by E. Irving of the Dominion Observatory in Canada and by other workers. We plotted the Permian pole positions with respect to each continent as it exists today and then rotated these pole positions as needed to assemble the continents into our version of Pangaea. By this method the pole positions should ideally cluster at one of the geographic poles. Actually there is some scatter, as can be seen in our reconstruction of Pangaea [*see illustration on page 34*], but all the positions do fall within either the Arctic Circle or the Antarctic Circle.

We can now summarize how the continents have moved in time and space. The two Americas have drifted a long way, generally westward. North America has drifted more than 8,000 kilometers west northwest; the tip of Florida once lay in the South Atlantic near the present position of Ascension Island. Moving toward the Tethyan trench system, India and Australia were carried far to the north. Africa rotated counterclockwise perhaps 20 degrees as the Eurasian land mass, similarly moving toward the Tethyan trench, rotated clockwise a roughly equal amount. India's remarkable flight is probably attributable to its being rafted on an "ideal" plate. Approximately rectangular, the Indian plate was sliced away from Pangaea by a rift along what is now India's east coast and then was free to move northward toward a major trench. This northward movement was facilitated by two parallel megashears.

Decades ago Wegener proposed that the drift of the continents was vectored by forces he termed *Westwanderung* (westward drift) and *Polarfluchtkraft* (flight from the poles). Although real, these forces are minuscule and not likely to be the underlying cause of drift. Our solution, however, does support Wegener's hypothesis of a westward flight, which, like the slip of the atmosphere, directly opposes the earth's rotation. We have also inferred a latitudinal drift, but from the South Pole only, or, paraphrasing Wegener's terminology, a *Sudpolarfluchtkraft*.




**SEPARATION OF SOUTH AMERICAN AND AFRICAN PLATES** can be traced in absolute geographic coordinates by observing the orientation of the thread ridges, a *V*-shaped stream of volcanoes, produced by the Walvis thermal center (*C*). The hot spot has evidently been pouring out magma from a source deep in the mantle for the past 140 million years. The three-part diagram illustrates a hypothesis first proposed by J. Tuzo Wilson of the University of Toronto. The thread ridges show that the South American and African plates have been not only drifting rapidly apart but also migrating northward. Features such as the strike of the ridge-ridge transform faults (*A*–*A′*) and matching indentations on opposing continents (*B*–*B′*) can do more than indicate the relative motion of two plates.

# CALCITONIN

## This recently discovered thyroid hormone plays an important role in metabolism: it inhibits the breakdown of bone and thus keeps the calcium in the blood from reaching an excessively high level

by Howard Rasmussen and Maurice M. Pechet

The endocrinology of mammals has been investigated so intensively and with such a wealth of discoveries over three-quarters of a century that one might suppose the subject by this time would have lost some of its novelty and excitement. In actuality, however, the story of the endocrine glands and their hormones retains an unending fascination. New mammalian hormones are currently being discovered at a high rate, as in the early rush of exploration during the first quarter of this century. The new hormone we shall discuss in this article turns out to be of great importance in the regulation of a crucial phase of human metabolism. Ironically, this hormone escaped attention for nearly 80 years although it was more or less constantly on stage throughout that time. It is a product of the thyroid gland, which over the years has been studied more intensively than any other endocrine organ. Discovered less than a decade ago, the long overlooked hormone, calcitonin, has evoked such interest among physiologists, biochemists and physicians that it has already been isolated in pure form, synthesized completely in the laboratory, investigated in detail as to its functions and used therapeutically in human disease.

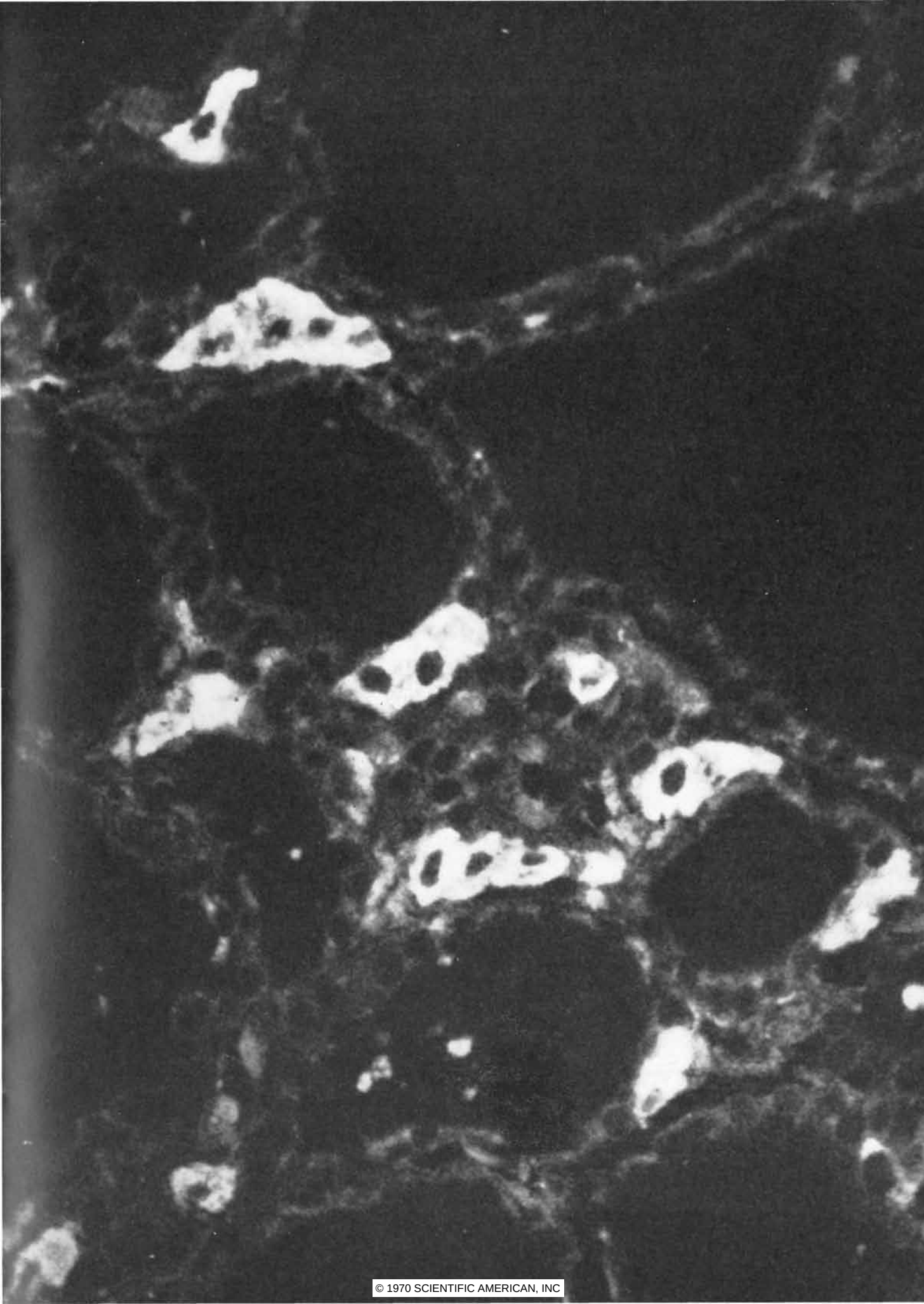
The discovery of calcitonin grew out of a puzzling question regarding the regulation of the calcium level in the blood. A constant supply of calcium (and phosphate as well) is required in the circulating blood for the building of bone and the control of certain functions of cells. If the concentration of calcium ions in the blood plasma falls below normal, the nerve and muscle cells, for instance, begin to discharge spontaneously and the voluntary muscles go into continuous contraction—the condition known as tetany. It was known that two agents, vitamin D and a hormone of the parathyroid gland, were active in maintaining the plasma's calcium supply: vitamin D by assisting the uptake of calcium from food by the intestinal cells, the parathyroid hormone by causing the release of calcium to the blood from bone and by inducing the kidney tubules to capture, for return to the circulating blood, calcium that would otherwise be lost in the urine.

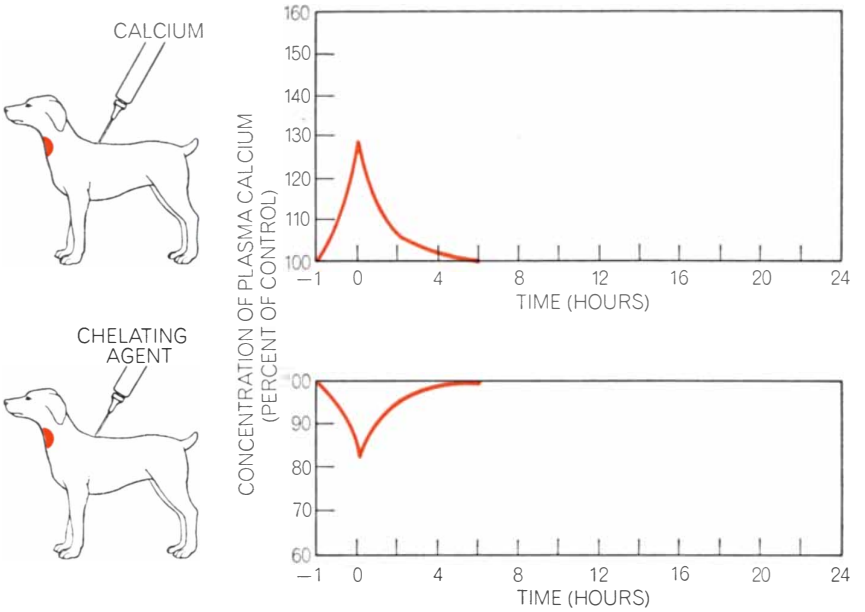
Experiments had established that the activity of the parathyroid was governed by a feedback system. When the calcium in the plasma dropped below the normal level, the gland increased its secretion of the hormone; when the calcium rose above normal, secretion of the hormone stopped. The question arose: Was this strictly negative control—the shutoff of the parathyroid hormone—sufficient to protect the animal against a dangerous rise in the blood's calcium concentration? Peter Sanderson and his associates at the Peter Bent Brigham Hospital in Boston and D. Harold Copp at the University of British Columbia began to look into the possibility that there was also some mechanism that exerted a positive control on the accumulation of calcium in the blood. They soon found evidence that such a mechanism was indeed at work.

Sanderson's group performed an elegant series of experiments involving both the thyroid and the parathyroid glands. They first tested the reactions of dogs, with the glands intact, to abrupt experimental changes in the plasma calcium level; they raised the level by injecting calcium salts or lowered it by injecting a chelating agent that bound and inactivated the calcium ions in the plasma. They found that in either case the animals' plasma calcium quickly returned to the normal level after the infusions were stopped. They then removed the thyroid and parathyroid glands surgically from the same animals and retested them with the injection treatments. This time there was no rapid return to normal; the calcium content of the plasma remained elevated or subpar for as long as 36 hours after the injection.

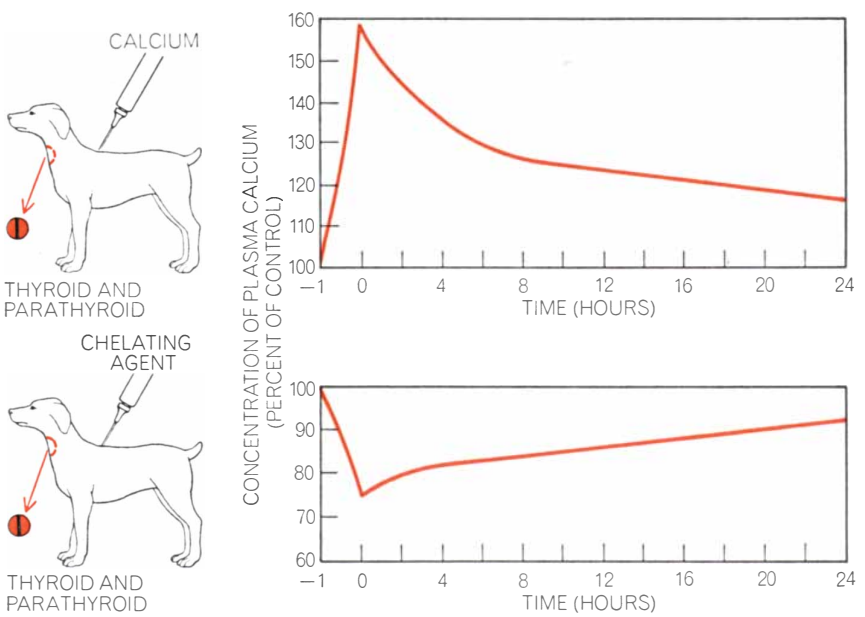
The failure of calcium to rise rapidly to normal in the cases where the level had been depressed could be explained by the absence of the stimulating parathyroid hormone (the source of the hormone having been removed). Obviously, however, lack of the hormone could not account for the fact that the calcium level remained high in the cases where the level had been elevated. It was clear that some other corrective agent must be missing in the animals with the thyroid and parathyroid glands removed—some positive agent that could cut back the delivery of calcium to the blood or speed up its removal. Copp, on the basis of experiments similar to Sanderson's, concluded that the agent must be a hormone that he named calcitonin, signifying that it participated in regulating the tone, or concentration, of calcium in the blood. Two groups of investigators, Philip F. Hirsch and Paul L. Munson at the Harvard Dental School and Iain MacIntyre

**"*C*" CELLS that produce calcitonin are visible as luminous bodies in the micrograph on the opposite page. The tissue is from the thyroid gland of a dog. The *C* cells were made luminous by the injection of a fluorescent antibody that combines with calcitonin. The large dark areas are follicles that contain the principal thyroid hormone, thyroxin. Thyroxin is produced by cells forming grayish perimeter of each follicle. Small dark areas in some of the *C* cells are nuclei. Micrograph was made by A. G. E. Pearse of the Postgraduate Medical School of London.**






**FIRST PHASE OF DOG EXPERIMENT conducted by Peter Sanderson and his colleagues at the Peter Bent Brigham Hospital indicates that there is a positive mechanism preventing excessively high levels of calcium in the blood. At top dog is injected with calcium. Graph at right shows that one hour before injection calcium concentration in the blood is normal. At time of injection concentration rises. About six hours later, however, concentration is normal. Therefore some agent is probably reducing the flow of calcium from the bone into the blood. At bottom same dog is injected with a chelating agent that captures calcium in blood and renders it inactive. The graph shows that one hour before the injection the calcium concentration is normal. After the injection it is depressed. About six hours after the injection the concentration is normal again, as is expected because a hormone secreted by the parathyroid gland is known to elevate the calcium concentration in the blood.**



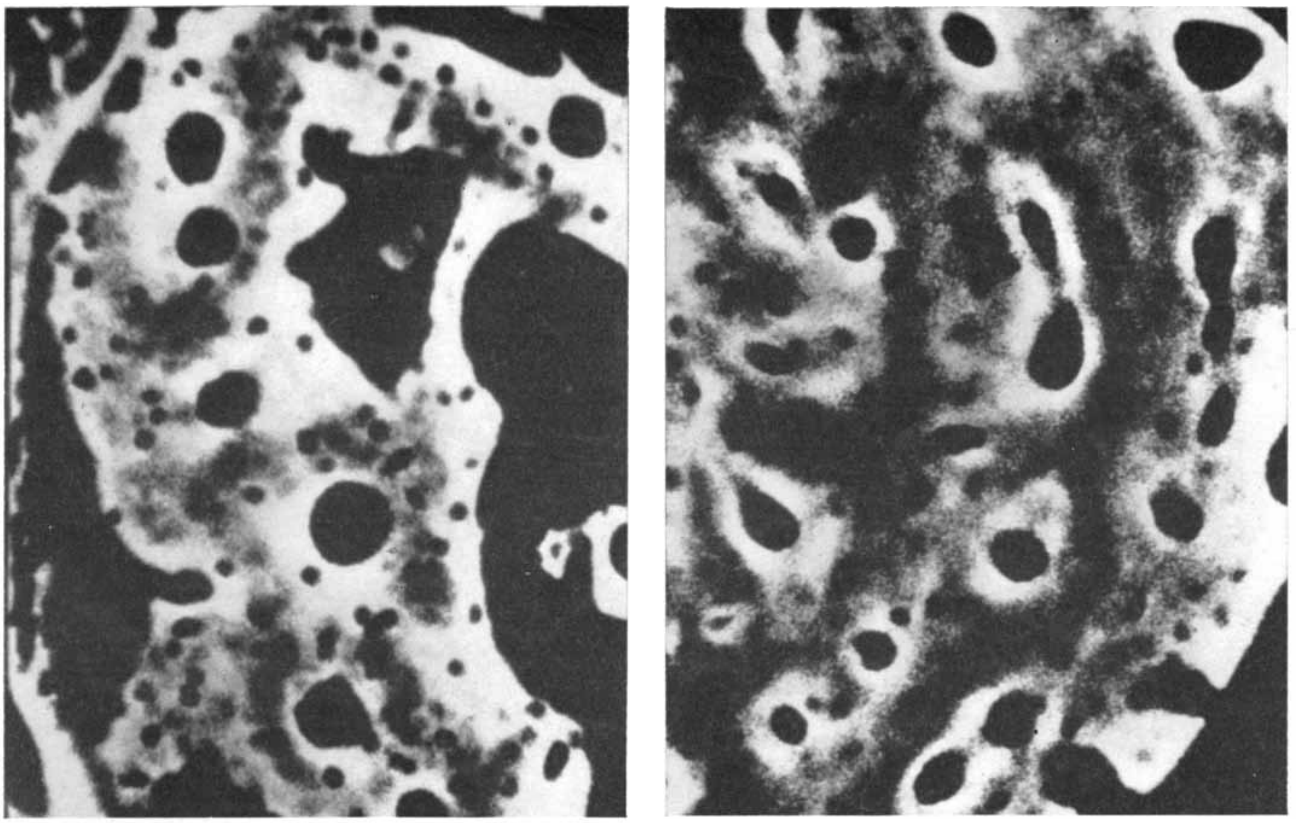

**SECOND PHASE OF DOG EXPERIMENT demonstrates that there definitely is a controlling agent. At top a dog with thyroid and parathyroid glands removed is injected with calcium. The graph indicates that the calcium concentration, which was normal one hour before the injection, quickly rises. More than 24 hours later the concentration is still high, indicating that some agent that normally reduces the concentration is no longer present because the glands are missing. At bottom a chelating agent is administered. The graph at right indicates that the calcium concentration, normal one hour earlier, is depressed. More than 24 hours later the concentration is still low, because the parathyroid hormone, which keeps the concentration high, has been eliminated by removal of the gland. D. Harold Copp of the University of British Columbia demonstrated the significance of these experiments.**

and his colleagues at Hammersmith Hospital in London, soon located the source of the hormone. They found it not in the parathyroid, as Copp had suggested, but in the thyroid gland.

A. G. E. Pearse of the Postgraduate Medical School of London went on to discover the specific site where calcitonin is synthesized. It had been known for many years that the thyroid gland contains two types of cell: the type that produces the gland's classic hormone, thyroxine, and another type called *C* cells, which stain differently. Although the *C* cells were described by Jose F. Nonidez of Cornell University in 1931, their function was unknown until Pearse showed that they produced calcitonin. These cells have had an interesting evolutionary history. In mammals the *C* cells arise in ultimobranchial glands that lose their distinct identity during development and merge with the thyroid. In fishes, amphibians, reptiles and birds, however, the ultimobranchial glands remain separate and persist as distinct organs in the adult. Stuart Tauber of the University of Texas Southwestern Medical School and Copp established that in these animals the ultimobranchial gland contains a high concentration of calcitonin but that the hormone does not show up at all in the thyroid gland.

Thus by 1967 the source of calcitonin in mammals was well established, and investigations of various aspects of its physiological activity were under way. One of the first aspects to be studied was the system that calls forth the secretion of calcitonin and its counterpart, the parathyroid hormone. Sanderson's and Copp's earlier studies had indicated, as we have seen, that the basic controlling factor was the calcium concentration in the blood. Direct measurements of the levels of calcium, calcitonin and the parathyroid hormone in the circulating blood of experimental animals now gave a quantitative picture of the control system. These measurements were made possible by newly developed assay techniques derived from the fundamental work of Solomon A. Berson and Rosalyn S. Yalow of the Veterans Administration Hospital in the Bronx. These investigators, working with John T. Potts, Jr., and Gerald D. Aurbach of the National Institutes of Health, had devised a radioimmunoassay for measuring the concentration of the parathyroid hormone; later Potts, and independently Claude Arnaud of the Mayo Clinic, had worked out a similar assay for calcitonin.

Using these assays, Potts and Arnaud found that in pigs infused with measured



**SECTIONS OF SHEEP BONE shown in these microradiographs demonstrate effects of the parathyroid hormone. The microradiographs were made by interposing a thin section of bone between a source of alpha radiation and a photographic plate. In microradiograph at left bright areas are calcified bone. Large dark holes are channels for blood vessels; small dark holes are occupied by osteocytes. The microradiograph at right was made after parathyroid hormone had caused osteocytes to resorb bone tissue. Resorption of bone tissue produces large blurred areas. The osteocyte spaces are enlarged and some of them have merged with one another.**

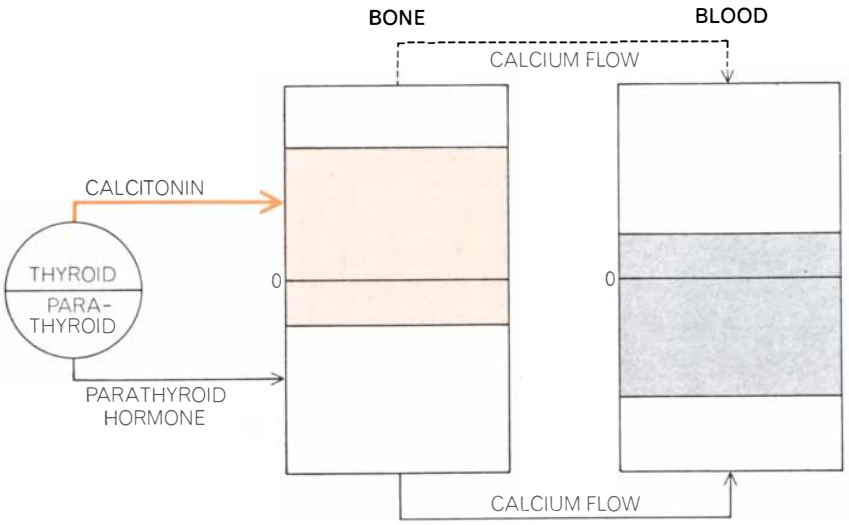
amounts of calcium the secretion of calcitonin increased in direct proportion to the rise in the blood's calcium content, and the secretion of the parathyroid hormone decreased in proportion to the calcium rise. Thus the results showed that the physiological control system responsible for keeping the blood's calcium supply at a stable level consists of two feedback loops: the parathyroid hormone operating to sustain the supply, calcitonin operating to prevent calcium from rising above the required level.

After the discoveries of calcitonin's role and the source that produced the hormone, the next challenge was to decipher its chemical nature, as a preliminary to learning how the hormone brings about its striking effect. A number of investigators set out to isolate the hormone, using various assay methods based on measurements of the potency of their preparations. Six laboratories reported late in 1967 and early in 1968 that they had extracted the hormone in pure form from pig thyroid glands. It turned out to be a polypeptide consisting of a single chain of 32 amino acids. Three laboratories soon determined the sequence of the amino acids in the molecule's structure, and shortly thereafter the Lederle Laboratories in Pearl River, N.Y., and the Ciba and Sandoz laboratories in Switzerland announced the synthesis of the hormone from its amino acids. The Ciba group, headed by R. Neher, also succeeded in isolating the human version of calcitonin (from tissue obtained from a patient with a carcinoma of the thyroid gland) and analyzed its amino acid sequence. This proved to be somewhat different from the structure of the pig hormone, indicating that the activity of calcitonin in curtailing the calcium content of blood depends on certain critical features of the amino acid sequence (common to both the pig and the human forms of the molecule) rather than on the structure as a whole.

The way was now open to investigate calcitonin's mode of action. How does the hormone function to lower the concentration of calcium in the blood plasma? Experiments with preparations of purified calcitonin in many laboratories in the U.S. and Europe soon showed that the hormone produces its effect by decreasing the release of calcium to the blood from bone. Calcitonin was found to act on the metabolism of bone in a way that inhibits bone resorption.

Bone is by far the most refractory and durable of all biological tissues, as is evident in the survival of fossil bones that have been buried for hundreds of thousands of years. Because of the apparent obdurability of bone it was supposed until very recently that once the skeleton of a vertebrate has been formed it ceases to partake of metabolism or to have any appreciable breakdown. Definitive evidence that this is by no means the case did not come until the availability of radioactive isotopes made it possible to examine the events actually occurring in the bone of living animals.

Tracer experiments with labeled isotopes of the main elements that go into the makeup of this tissue (calcium, phosphorus and the carbon of amino acids) showed that even in fully mature bone there is a constant turnover of these materials. It then became evident that metabolic activity in the skeleton is a vital necessity for at least two reasons. For one thing, such activity allows remodeling of the skeleton to enable it to deal with the developing mechanical



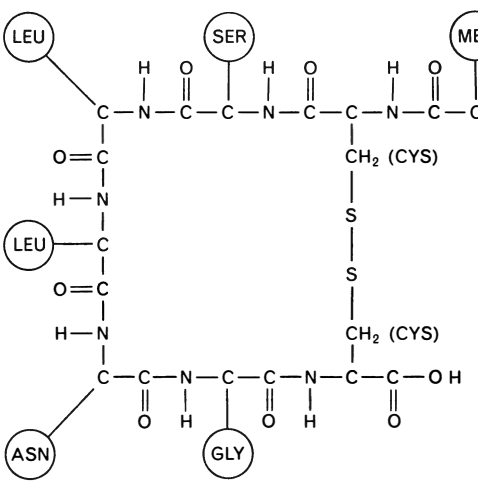

**CONTROL LOOP regulating balance of calcium in bone and blood is established by calcitonin and the parathyroid hormone. Thyroid (*left*) secretes calcitonin (*colored arrow*) when blood calcium is high. Calcitonin prevents resorption, so that bone calcium level (*color in upper part of box in middle*) remains high and flow of calcium into blood is reduced (*broken arrow at top*). Therefore calcium level in the blood (*shading in upper part of box at right*) is low. When calcium level gets too low, parathyroid gland (*left*) increases it by secreting hormone (*black arrow*) so that more calcium enters blood (*solid arrow at bottom*).**

stresses on the body. It is as if each bone were an elaborate Gothic structure in which a resident engineer, in response to changes in stresses, continually directs the replacement of supporting arches with new ones providing a slightly different center of thrust. The other vital function of metabolic activity in bone is that, by allowing an exchange of minerals (calcium and phosphate ions) with the blood, it provides a storehouse of these materials to help meet the body's general requirements. And in fact normally there is an overall balance of supply and demand for the bone minerals, new bone being laid down in some parts of the skeleton and old bone being resorbed elsewhere at the same rate.

To understand the operations of calcitonin and the parathyroid hormone in this system we need to look into the events in the formation and the resorption, or destruction, of bone. We are concerned here with what goes on at the surface of existing bone as new tissue is formed or old bone is dissolved away. The building on of new bone is initiated by a surface layer of osteoblasts, the cells that synthesize and extrude molecules of the fibrous protein collagen. The collagen molecules form thin, insoluble fibrils that pack themselves closely in a definite geometric array constituting a matrix, firmly anchored in the extracellular spaces of the bone. The matrix, which takes several days to form, then acts as a template for the deposit of crystals of mineral in an ordered arrangement. Studies by Melvin J. Glimcher and Stephen M. Krane of the Massachusetts General Hospital indicate that the build-up of the minerals begins with the attachment of phosphate groups on specific sites in the matrix. Once the first mineral crystals form, the depositing of phosphate and calcium proceeds rapidly, and within a few days the new bone contains 70 percent or more of all the mineral it will ever possess. As mineral is deposited, it displaces water and eventually occupies most of the available space in the matrix. It is then locked in so that (in an adult animal) most of the mineral is not free to take part in exchanges of mineral between the bone and the blood. This, of course, is an essential condition, because unrestricted removal of mineral from the bone could deprive it of its rigidity and mechanical strength.

Exactly where in the matrix is the mineral deposited? Is it encrusted around the collagen fibrils? If this were so, one would expect the mineral to play a large role in maintaining the structural form (shape and size) of the bone. Actually experiments have shown that when the mineral is extracted (by artificial means), the bone is not changed in shape or size but merely softens. A more plausible picture of the location of the mineral crystals, suggested by John A. Petruska and Alan J. Hodge of the California Institute of Technology and fitting the known facts, is that they are lodged in spaces between the ends of the fibrils, which are supposedly arranged in an overlapping array. This model implies that the mechanical properties of a bone are determined by the location of mineral in the matrix, and the bone's shape and size are determined by the three-dimensional configuration of the matrix, which is fixed by strong chemical bonds tying the fibrils together.

We come now to the opposite of the bone-building process: the resorption of bone that makes possible the continuous exchange of phosphate and calcium ions between bone and the blood. It turns out that the bone-forming cells play a role in resorption as well. As the osteoblasts complete their function of producing collagen, they become entrapped in these fibrils and are continually overlain by new osteoblasts growing on the surface. The buried osteoblasts are now converted into osteocytes and put out thin extensions, forming an extensive cellular network throughout the bone. When the bone has been fully formed, it is covered by a film of fluid topped by a thin layer of "resting" osteoblasts, which are no longer making collagen. These cells, together with the osteocytes, perform the important function of acting as sentinels that patrol the flow of mineral ions between the blood plasma and the special fluid bathing the bone. Were it not for this guarding network, a small change in the bone's chem-




**CALCITONIN MOLECULE in man consists of a specific sequence of 32 amino acid**

istry might lead to a flood of calcium into or out of the blood, either of which could be lethal.

The involvement of osteocytes in bone resorption was clearly disclosed recently in radiographic studies by Leonard F. Bélanger of the University of Ottawa. It had long been supposed that bone was broken down only by the giant digesting cells called osteoclasts. Examining thin sections of bone by means of radiography (using alpha radiation and X rays), Bélanger produced pictures showing the matrix and indicating where it was calcified and where it was not. He found that in bone that had been treated with the parathyroid hormone both the matrix and the calcium were dissolved away around each osteocyte [*see illustration on page 45*]. Apparently calcium is so tightly trapped in the matrix that it is not readily released unless the matrix structure is broken down.

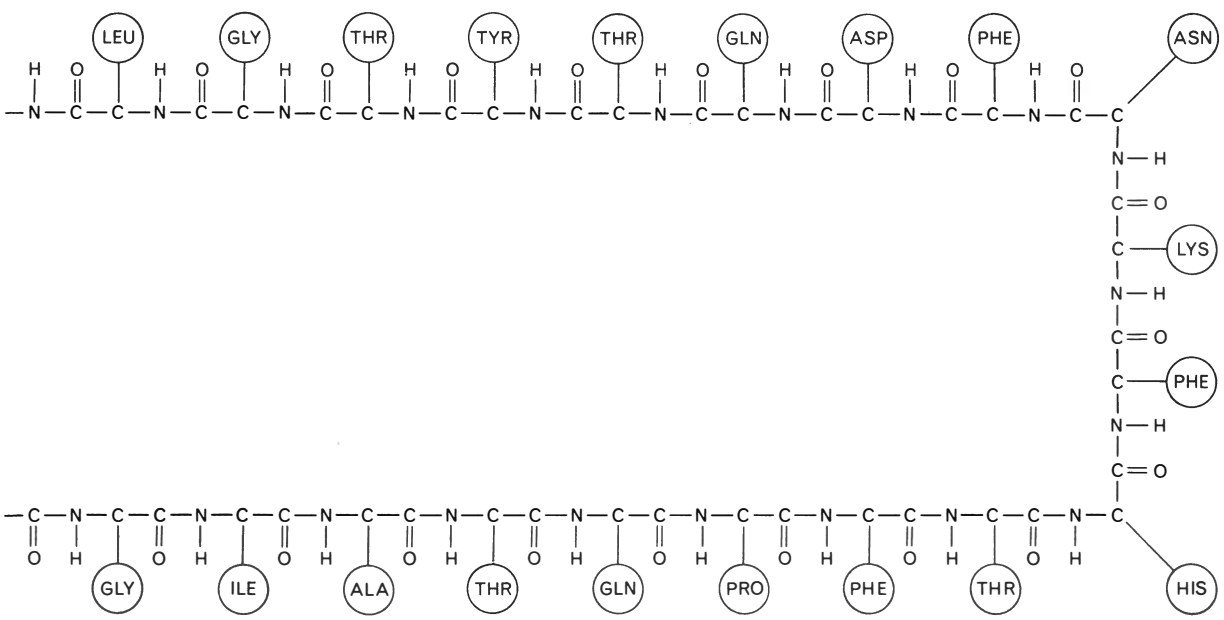
The experiment thus demonstrated that the parathyroid hormone promotes bone resorption by acting on the osteocytes; in some way it incites these cells to engulf and destroy the bone tissue around them, with a consequent release of dissolved calcium into the bloodstream. We undertook a different set of experiments to probe the counteracting behavior of calcitonin. Conceivably this hormone might lower the blood's calcium level by speeding up the laying down of calcium in new bone, but it seemed much more likely that it acted by inhibiting bone resorption.

In looking into the effects of calcitonin we had the benefit not only of the radiographic techniques for examining what went on in bone tissue but also of a newly developed chemical measure of the rate of bone resorption in living animals. The collagen of bone is a protein rich in a peculiar amino acid: hydroxyproline. Darwin J. Prockop of the University of Pennsylvania School of Medicine had learned that hydroxyproline is not incorporated in a protein in the usual way—with the help of transfer RNA. There is no specific transfer RNA for this amino acid. A precursor molecule, protocollagen, is first synthesized and then specific proline units within it are acted on by an enzyme that adds the hydroxyl group to some of the prolines. In this way hydroxyproline is produced at the necessary positions on the collagen molecule. When the collagen molecule is broken down, hydroxyproline shows up in urine. It serves as a distinctive signal; the amount of hydroxyproline in the urine has in fact been found to reflect the rate of bone resorption in an animal. We found it useful in determining whether or not the resorption rate was influenced by calcitonin.

We removed the thyroid and parathyroid glands from rats and then injected the parathyroid hormone, so that the animals had an ample supply of this hormone but no calcitonin. The rats excreted large amounts of calcium and hydroxyproline in their urine, showing a high rate of bone resorption, and radiographic examination of sections from their bones confirmed that the osteocytes had destroyed bone tissue around them and had greatly swelled in size. When we carried out a parallel experiment with another set of rats, this time supplying them with injections of calcitonin as well as the parathyroid hormone after their thyroid and parathyroid glands were removed, the results were strikingly different. The animals' excretion of calcium and hydroxyproline in the urine *decreased*, and radiographic examination of bone sections showed no sign of bone breakdown around the osteocytes. It is also noteworthy that the osteoclasts, the large cells on the surface of bone that are involved in its remodeling, also increase their resorptive activity in response to parathyroid hormone and decrease it in response to calcitonin.

Here, then, was clear evidence that calcitonin performs its role of controlling the calcium content of the blood by inhibiting bone resorption. A simple further experiment demonstrated how

**ALA** ALANINE
**ASN** ASPARAGINE
**ASP** ASPARTIC ACID
**CYS** CYSTINE
**GLN** GLUTAMINE
**GLY** GLYCINE
**HIS** HISTIDINE
**ILE** ISOLEUCINE
**LEU** LEUCINE
**LYS** LYSINE
**MET** METHIONINE
**PHE** PHENYLALANINE
**PRO** PROLINE
**SER** SERINE
**THR** THREONINE
**TYR** TYROSINE
**VAL** VALINE




**subunits. The identity of the individual subunits is indicated by the abbreviations that mark the amino acid side chains. The key at top right gives the full name of each of 17 different amino acid constituents of hormone. The sequence differs in other species.**

vital this control is for the animal. In animals that had both glands removed and were then injected with a continuous infusion of calcium and the parathyroid hormone, the calcium concentration in the blood rose rapidly to a high level, urine excretion began to fail after 16 hours, and shortly afterward the animals died. The cause of death, as postmortem examination showed, was a massive accumulation of insoluble calcium phosphate in the kidneys, destroying their function. When, on the other hand, we removed only the parathyroid gland, leaving the thyroid intact, the animals responded to the same infusion of calcium and parathyroid hormone without apparent ill effects. Clearly in this case the thyroid gland saved the day with an output of calcitonin that prevented a marked rise in the blood's calcium level, and we found no damaging deposits of calcium in the kidneys.

In view of calcitonin's now clearly established function as an inhibitor of bone resorption, it is curious to find that some primitive cartilaginous animals, such as the dogfish shark, produce calcitonin (in an ultimobranchial gland) although they have no bony skeleton. We can only speculate about what function the hormone may serve for them. Apparently calcitonin, like some other hormones, is an ancient biological agent that evolution converted from its original function to a new use in the vertebrates.

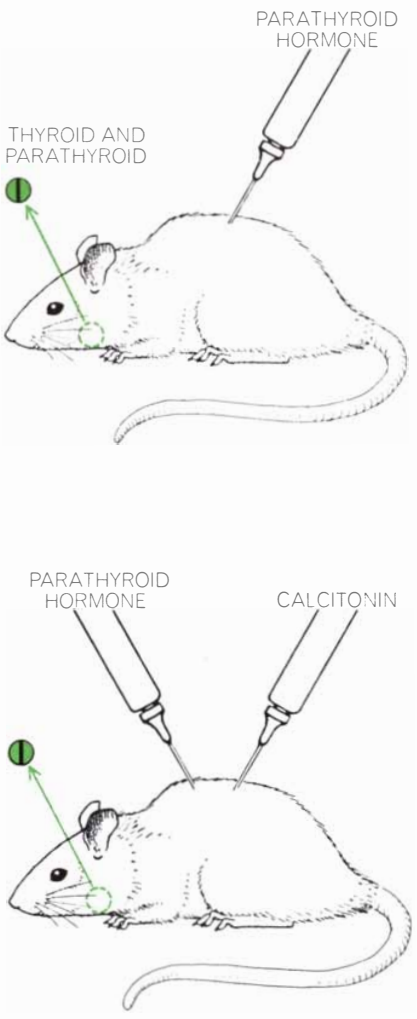
From the physiological study of calcitonin's action we have now gone on to try to learn how the hormone produces its effect in biochemical terms. This is difficult to get at, because bone tissue is structurally so complex and composed of such a diversity of cells that direct exploration by specific chemical experiments is almost out of the question. On the basis, however, of various items of evidence, mostly indirect, we have arrived at a tentative hypothesis about the biochemistry of calcitonin's control of metabolism in bone cells.

A starting point was provided by recent discoveries concerning the biochemical action of the parathyroid hormone. These discoveries have been made in the years since one of us (Rasmussen) wrote an article in *Scientific American* on that hormone ["The Parathyroid Hormone," by Howard Rasmussen; SCIENTIFIC AMERICAN, April, 1961]. In the urine of rats given parathyroid hormone L. R. Chase and Aurbach of the National Institutes of Health noted an increased content of the remarkable compound known as cyclic 3′5′ adenosine monophosphate (cyclic AMP). This substance, first discovered by Earl W. Sutherland, Jr., then at Washington University, had been found to serve as an intermediate in the action of many hormones—the hormone being called the "first messenger" and cyclic AMP the "second messenger."

Sutherland and his co-workers had established that cyclic AMP is produced from adenosine triphosphate (ATP) by an enzyme, adenyl cyclase, located at the surface of cells. From experiments they developed the hypothesis that many hormones interact with specific adenyl cyclases on the surface of specific cells and bring about an increase in the production of cyclic AMP within the cell. For instance, the hormone epinephrine triggers the synthesis of cyclic AMP in liver cells, the parathyroid hormone does so in kidney cells but not in liver cells, and so on. The effect of the second messenger varies according to the special character of the target cell; for example, in the liver it causes an increase in the synthesis and release of glucose; in the adrenal cortex (where cyclic AMP acts as the second messenger for ACTH) it stimulates the synthesis and release of steroid hormones. It is as if cyclic AMP conveyed the messages of the hormones in a generalized form, simply saying to each cell: "Do your thing."

The discovery by Chase and Aurbach that the amount of cyclic AMP in the urine of rats increases following the administration of parathyroid hormone offered an opening for analysis of calcitonin's action. Assume that the parathyroid hormone fosters production of cyclic AMP in bone cells and that the cyclic AMP brings about the resorption of bone. It could be supposed, then, that calcitonin might block the effect of the parathyroid hormone either by preventing the synthesis of cyclic AMP or by inactivating that compound in the cell. (It was known that cyclic AMP could be inactivated by phosphodiesterase, an enzyme in cells that converts it by hydrolysis to 5′ AMP.) Looking into the question experimentally, we first infused rats that had been deprived of their thyroid and parathyroid glands with cyclic AMP, using a dibutyryl form of the compound that had been synthesized by Theo Posternak of Case Western Reserve University and had been found to be invulnerable to hydrolysis by phosphodiesterase.

The urine of these animals showed that the injection of the cyclic AMP increased bone resorption just as injections of the parathyroid hormone did. We then found that injections of calcitonin blocked the bone-resorption effect of cyclic AMP, just as it blocked bone resorption induced by parathyroid hormone. The results of these experiments clearly indicated that neither of the hypotheses about calcitonin's action was correct: obviously it did not block bone resorption simply by preventing the parathyroid hormone from producing cyclic AMP, because it was effective against the action of that compound itself in the absense of the parathyroid hormone, and our use of the unhydrolyzable form of the cyclic AMP showed on the other hand that calcitonin did not inactivate cyclic AMP by causing its hydrolysis. Chase and Aurbach produced support-



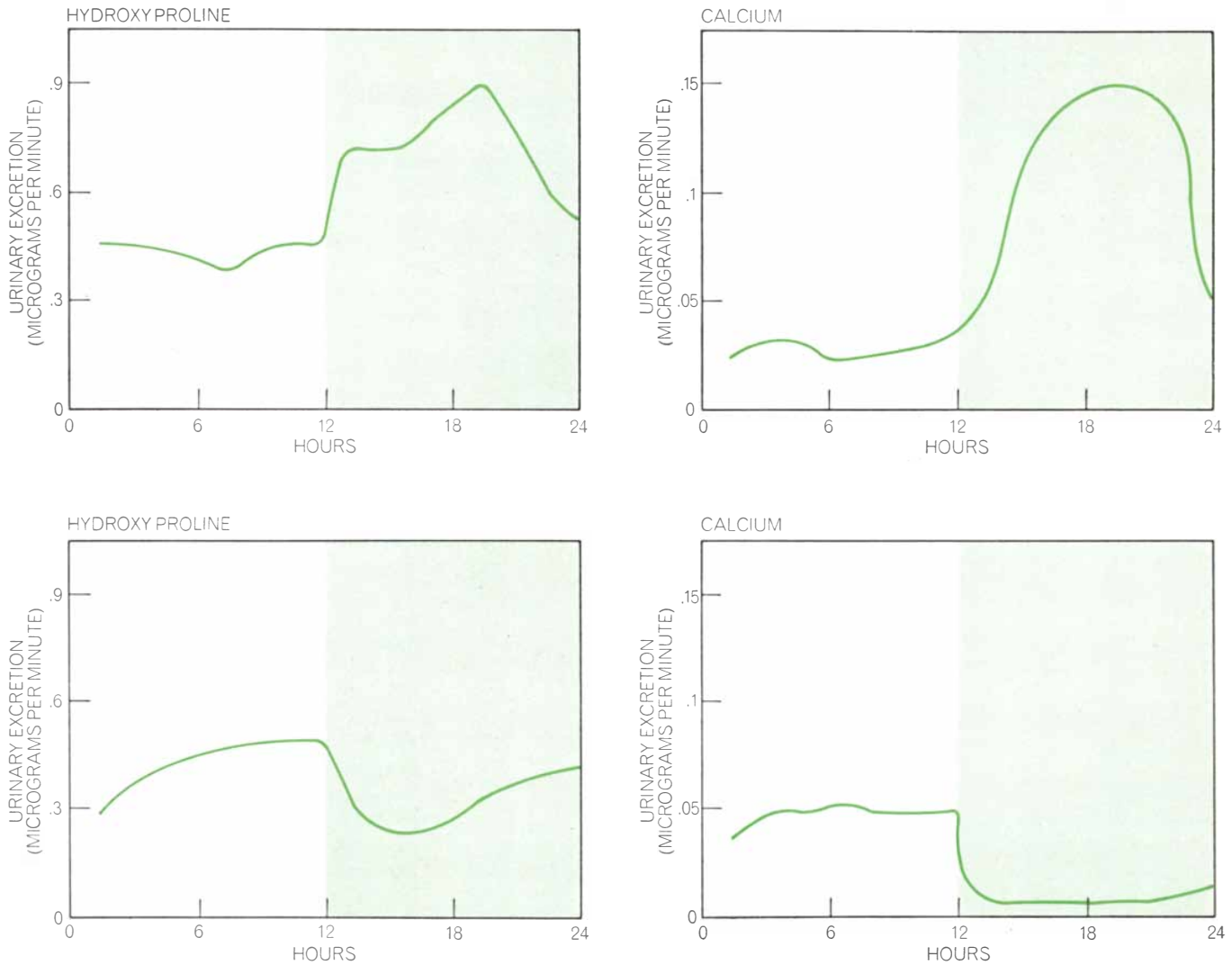

**RAT EXPERIMENTS demonstrate clearly that calcitonin controls calcium concentration by inhibiting the resorption of bone induced by the parathyroid hormone. In first experiment (*top*) both the parathyroid and the thyroid glands are removed from the rat (*left*). First graph shows the level of hy-**

ing evidence for these conclusions: they demonstrated that the parathyroid hormone brings about an increase in the concentration of cyclic AMP in bone cells and that this increase is not affected by a simultaneous presence of calcitonin.

Evidently the answer to the problem of how bone resorption was inhibited had to be sought not in some action on the cyclic AMP system itself but in metabolic events in the cell that presumably were influenced by cyclic AMP. Andre B. Borle of the University of Pittsburgh School of Medicine produced a clue that carried the search forward. Growing cells in a tissue culture, he found that when he added the parathyroid hormone to the culture medium, the cells increased their uptake of calcium. Did this effect also take place in cells growing normally in a living organism? Following up Borle's clue, one of us (Rasmussen) and a co-worker, Naokazu Nagata, established that the hormone did indeed affect calcium uptake in natural conditions, and we learned some details of the associated events.

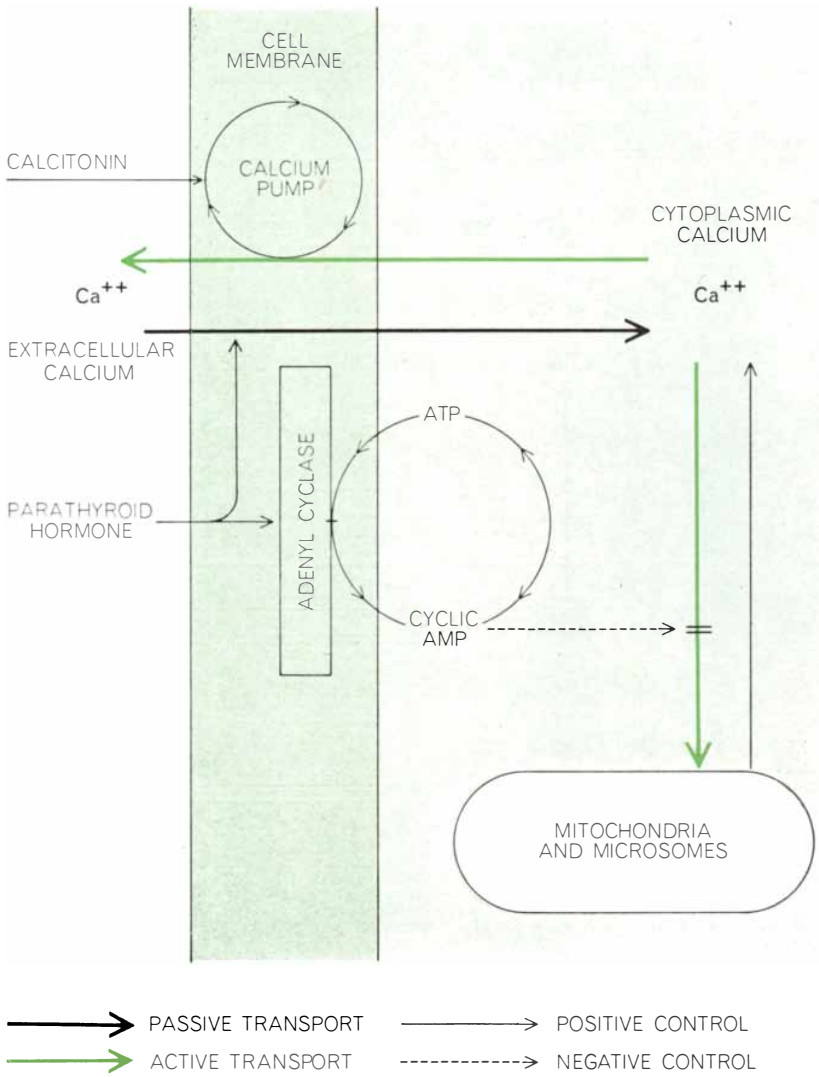
Our first experiments were on whole animals. After removing the thyroid and parathyroid glands from rats, we injected some of the animals with the parathyroid hormone and others with calcium chloride. We then rapidly removed the kidneys, froze them to stop the many metabolic reactions going on in the cells, inactivated all the enzymes with cold perchloric acid and extracted the collection of metabolites, and then by a complex of techniques determined the concentrations of the various important metabolic intermediates.

We found that the infusion of calcium salt produced much the same metabolic picture as that resulting from the parathyroid hormone infusion. In order to obtain a more detailed picture under conditions enabling us to control some of the variables, we followed up with test-tube studies of kidney tissue, broken down with two enzymes, collagenase and hyaluronidase, that split apart the many thousands of small kidney tubules. The experiments on small segments of




**droxyproline, an amino acid produced by the breakdown of bone collagen, in the rat's urine. The second graph shows the calcium levels in the urine. The white area in each graph represents control period. The colored area represents the period during which the rat is constantly infused with the parathyroid hormone. During the control period in the first experiment, hydroxyproline levels and calcium levels are low. During the infusion period, however, both calcium and hydroxyproline levels are high, indicating considerable release of bone material. In the second experiment (*bottom*) glandless rat receives both parathyroid hormone and calcitonin. The first graph shows that the hydroxyproline level falls during infusions, indicating that calcitonin has blocked resorption of bone tissue. The second graph shows that calcium excretion also falls, confirming that the resorption of bone has been inhibited.**

isolated tubules confirmed that the pattern of metabolism brought about by adding to the cells' calcium supply was almost identical with that produced by supplying the parathyroid hormone. This indicated that both treatments somehow operated on the same enzymes in the cell. Both, for example, speeded up the rate at which the cells convert lactic or malic acid to glucose. The rate depends on the cells' uptake of calcium, acting as a signal, and it appears that the amount of calcium entering the cells can be enhanced either by increasing the supply of calcium outside the cell or by providing the parathyroid hormone. Thus in these cells calcium is an important second messenger relaying the hormonal, or first, message into changes in cellular activity.

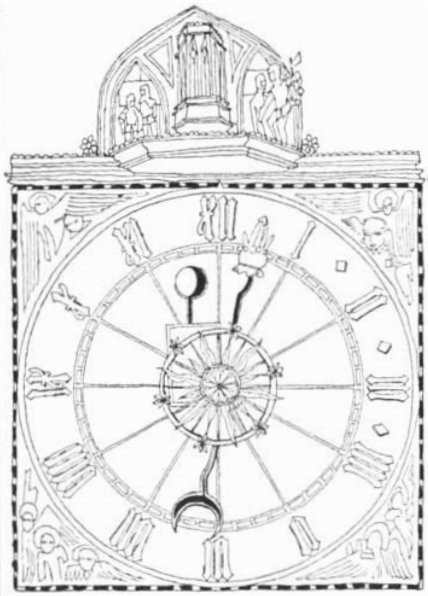



**ACTION OF HORMONES ON CELLS** controls body's calcium levels. When parathyroid hormone (*left*) reaches a cell wall (*dark colored area at left*), it stimulates the uptake of calcium by the cell from the extracellular space. At the same time the hormone activates adenyl cyclase, an enzyme in the membrane. Adenyl cyclase acts on ATP (adenosine triphosphate) to produce cyclic AMP (3′5′ adenosine monophosphate). As calcium enters the cytoplasm (*light colored area at right*), cyclic AMP (*center*) interferes with active movement of calcium out of the cytoplasm and into the mitochondria and other organelles (*right*). Since this active transport is interrupted, the calcium remains in the cytoplasm. Meanwhile calcium continues to flow passively from the organelles back into the cytoplasm. As a result calcium accumulates there. This accumulation is the key signal to the cell to begin resorbing the surrounding matrix of bone tissue. Calcitonin (*left*), however, counteracts this chain of events by activating a "calcium pump" represented by circular arrows at top left. This process pumps calcium out of the cell's cytoplasm, across the membrane and into the extracellular space, in effect "canceling" the message. Key at bottom shows that colored arrows indicate active transport of calcium and heavy black arrows passive transport. Small black arrows represent positive control; broken arrow shows negative control.

How does the parathyroid hormone produce that effect on cell calcium? Here we may find an answer to the still mysterious question of cyclic AMP's function. Alan M. Tenenhouse of McGill University and one of us (Rasmussen) have suggested as a working hypothesis that the parathyroid hormone has two simultaneous effects on responsive cells: it increases the uptake of calcium and it stimulates the production of cyclic AMP. The increased intracellular concentration of cyclic AMP has two important effects related to calcium. It activates certain enzymes that now become calcium-sensitive, and it alters the intracellular distribution of calcium among various cell organelles.

In the light of this hypothesis and all the experimental findings, we can now see a possible explanation of the counteracting effect of calcitonin. That hormone may block the uptake of calcium by bone cells, a passive process and the one increased by parathyroid hormone, or alternatively it may somehow bring into play energy for active pumping of calcium out of the cells, thereby altering the changes induced by parathyroid hormone in calcium transport and bone resorption. The latter alternative seems more likely, and recently I. Radde of the University of Toronto reported early results in experiments on red blood cells that indicate calcitonin does stimulate the calcium pump in those cells.

The Ciba group of investigators announced several months ago that they had achieved total synthesis of the human form of calcitonin. This has opened the way for large-scale trials of the hormone for the treatment of various bone diseases. Some important uses in diseases characterized by derangement of calcium and bone metabolism had already been established. Unfortunately calcitonin does not appear promising as a cure for osteoporosis, by far the most common of the metabolic bone diseases. (It is particularly common in women over the age of 55 and in severe cases frequently leads to the fracture of bones because they cannot withstand ordinary mechanical stresses.) The discovery of calcitonin has, however, given a great impetus to the study of the fundamental processes of bone metabolism and turnover of the bone substances, and the rapid growth of knowledge in this field may soon bring forth a rational therapy for the disease. If so, the bringing to light of this remarkable new hormone will have served a most important catalytic function in medicine.



# SCIENCE AND

*Growth and Differentiation*

A massive movement from central cities to their suburbs, a population boom in the West and Southwest, a lower rate of population growth in the 1960's than in the 1950's and the displacement of New York by California as the most populous state are the findings that stand out in the preliminary results of the 1970 Census as issued by the U.S. Bureau of the Census. The preliminary figures put the U.S. population at 200,263,721, but the total is expected to rise above 204 million when servicemen, transients and others are taken into account. If the figure reaches 204.8 million, which is what census experts had predicted earlier, the increase over 1960 would be 14.2 percent. Between 1950 and 1960 the rise was 18.5 percent. The final figure for 1960 was 179,323,175.

The movement to the suburbs was pervasive. Its extent is indicated by the fact that 13 of the 25 largest cities lost population, whereas 24 of the 25 largest metropolitan areas gained. Washington, D.C., was characteristic: the population of the city changed little between 1960 and 1970 but the metropolitan area grew by 800,000, or more than 38 percent.

Although the national increase in population was about 14 percent, only 15 states reached or exceeded that level. Eight of them are in the West and Southwest: Nevada, 68.9 percent; Arizona, 34.6; California, 25.3; Colorado, 25.2; Utah, 19.1; Washington, 17.5; Oregon, 16.3, and Texas, 14.7. The other states that gained 14 percent or more are Florida, 34.7; Maryland, 25; Delaware, 21.7; New Hampshire, 19.1; Connecticut, 17.9; New Jersey, 16.9, and Virginia, 14.5. Five states—West Virginia, North Dakota, South Dakota, Mississippi and Wyoming—lost population in amounts ranging from 8.5 percent to .4 percent.

Although California replaced New York as the largest state, New York City remained by far the largest city, having at 7,771,730 more than twice the population of Chicago. The ranking of the five largest cities (New York, Chicago, Los Angeles, Philadelphia and Detroit) was unchanged from 1960, but if the trends of the 1960's continue, it appears likely that Chicago will in time be overtaken by Los Angeles and Detroit by Houston. The five largest states in 1960 were New York, California, Pennsylvania, Illinois and Ohio; this year the order is California, New York, Pennsylvania, Texas and Illinois.

A number of consequences will flow from the census results. The seats in the U.S. House of Representatives will be reapportioned. At present it appears that California will gain five, Florida three and Arizona, Colorado, Connecticut and Texas one each. New York and Pennsylvania will each lose two, and Alabama, Iowa, North Dakota, Ohio, Oklahoma, Tennessee, West Virginia and Wisconsin will each lose one. Another consequence is that the apportionment of Federal aid to states and of state aid to cities and counties will be changed to reflect the shifts of population. A more speculative possibility is that the growth of suburban areas will benefit the Republican party, which has traditionally done well there.

*Metrication in America*

The National Bureau of Standards has embarked on a series of public conferences aimed at assessing the effects on the U.S. of more extensive use of the metric system. Conferences were held during the summer with engineering groups and with groups involved in consumer industries; this month the bureau is meeting with educators, the construction industry and labor, and next month there will be conferences with groups from other sectors of the economy. The conferences are being held as part of the U.S. Metric Study, which was autho-

# THE CITIZEN

rized by Congress in 1968 to determine the impact on the U.S. of the increasing use of metric units both here and abroad and to recommend what action, if any, the U.S. ought to take.

At the first conference the director of the bureau, Lewis M. Branscomb, predicted that "if the U.S. decides to go metric, it will be done through a coordinated national program based on the voluntary cooperation of all sectors of the society." He set out three alternative programs: accommodation, which would entail "changing no measuring equipment but using mental conversion or conversion tables in order to translate one measurement language to another"; adaptation, which means the use of dual dimensions and labeling without changing sizes, and conversion, wherein "the U.S. would change not only its measurement language but also many designs and practices." Under the law the bureau must report its findings and recommendations to Congress by next August.

*Smoker's Paradise*

Although the life expectancy of a newborn child in the U.S. has increased by 11.2 years since 1920, the life expectancy of American men who have reached the age of 40 has increased by less than two years. Men in their thirties living in such "poor" countries as Albania, Costa Rica and Portugal now have longer life expectancies than American men of the same age. Various hypotheses have been offered to account for the virtual halt in the extension of life expectancy for middle-aged men in the U.S. and Britain: obesity, high-fat diet, lack of exercise, stress accompanying urbanization and even genetic susceptibility. After reviewing death statistics in 17 nations Samuel H. Preston of the University of California at Berkeley has concluded that by far the strongest factor limiting the life expectancy of adults is cigarette smoking. His findings are published in a monograph, "Older Male Mortality and Cigarette Smoking: A Demographic Analysis."

Preston notes that American men increased their average annual consumption of cigarettes from 220 in 1910 to 1,370 in 1930 and to 3,810 in 1960. The life expectancy of women has not been similarly affected, evidently because

they have smoked much less than men. For example, in 1935 only 1.7 percent of American women smoked regularly, compared with 28.1 percent of American men. Nevertheless, women smokers in the 40-to-69 age group now have a mortality rate 28 percent higher than that for women nonsmokers; for men of the same age the mortality among smokers is 88 percent higher than it is for nonsmokers. Preston finds that country by country the amount of smoking is closely correlated with the amount of excess mortality attributable to three categories of disease: cancer, cardiovascular disease and bronchitis.

## *Black Holes*

The giant elliptical galaxies present a puzzle because they are about 70 times more massive than they should be if they are made up entirely of stars like the sun. Either the average star in an elliptical galaxy is only a seventieth as bright as the sun or else a great deal of mass within the galaxy is in the form of nonluminous matter such as gas and dust. Even if one assumes that elliptical galaxies are extraordinarily rich in dim white dwarf stars, the excess ratio of mass to visible light is still about four to one.

Noting that there is no observational evidence for large amounts of gas or of dust, A. M. Wolfe of the University of Cambridge and Geoffrey R. Burbidge of the University of California at San Diego propose in *The Astrophysical Journal* that the missing mass may consist of "black holes." These are defined as masses that have condensed to a certain radius (the "Schwarzschild radius") below which they collapse under the influence of gravity. The gravitational field inside such a black hole is so strong that light can no longer escape from it. The Schwarzschild radius is $3 \times 10^5$ centimeters multiplied by the ratio of the mass of the star with respect to the mass of the sun. Thus for the sun itself the Schwarzschild radius is simply $3 \times 10^5$ centimeters, or three kilometers. In actuality only stars more than 1.2 times as massive as the sun can collapse to the critical radius; lighter stars (such as the sun) always generate sufficient internal pressure to resist collapse.

Wolfe and Burbidge propose that an elliptical galaxy may contain a single very massive black hole near its center or a large number of smaller black holes widely distributed. They point out that the explosive phenomena observed in the nuclei of many galaxies suggest that large masses are present within very small volumes (a few light-years or less) and hence provide conditions suitable for gravitational collapse. If, for example, a few billion solar masses were packed into a sphere whose radius equaled that of the solar system, the sphere would spontaneously collapse into a large black hole.

On the basis of various arguments Wolfe and Burbidge show that a single black hole could not contain more than about 10 billion solar masses, which would account for no more than about 1 percent of the missing mass. If such a hole were present, however, it might be detectable when high-resolution telescopes are placed in orbit around the earth. There are fewer restrictions on the existence of many small black holes, sufficient to account for the missing mass, scattered throughout a galaxy, but Wolfe and Burbidge can think of no way to detect them.

## *Breathing Easy*

The fear that human activities may be changing the amount of oxygen in the atmosphere appears to be without foundation. This is the conclusion reached by two investigators who have reviewed past measurements of the amount of oxygen in the air and compared them with the amount found in 88 samples of air collected at sea and on land between 1967 and February, 1970. The differences among the recent samples were either nil or less than the uncertainty of the measurements. With a single exception, the percentage of oxygen remained a consistent 20.94. The exception was a sample taken at sea in September, 1968, which proved to contain the maximum amount of oxygen encountered: 20.952 percent. The minimum reading, taken at sea in June, 1967, was 20.942 percent.

Reporting their investigation in *Science,* Lester Machta of the Environmental Science Services Administration and Ernest Hughes of the National Bureau of Standards note that a variety of techniques were used in the early measurements, made between 1910 and 1942. When the differences in these techniques are taken into account, all the measurements (with the exception of a suspect series in the Antarctic that averaged 20.92 percent) show that the percentage of oxygen in the atmosphere was then about 20.94, or the same as in recent years. Machta and Hughes conclude that there should be little concern about a decrease in the production of oxygen by photosynthesis in green plants. They also undertake to estimate the amount of oxygen depletion to be expected by the time the last of the world's fossil fuel has been oxidized. The effect, they find, will be equal to what is encountered when an oxygen-breather today goes from sea level to an altitude of 250 feet.

## *Minilaser*

A semiconductor laser that operates continuously at room temperature has been developed by the Bell Telephone Laboratories. Comparable in size to the tiny transistors in integrated circuits, it can be powered by ordinary dry-cell batteries and produces a 20-milliwatt beam of infrared radiation. Earlier semiconductor lasers could be operated continuously only at low temperatures; at room temperature they quickly overheated unless they were operated in bursts of less than a thousandth of a second. The new Bell Laboratories laser is the first that shows promise for routine use in telecommunication systems.

The laser is built up of four layers of semiconductor materials: gallium aluminum arsenide alternating with gallium arsenide, both doped with traces of tin, silicon, zinc and germanium. Two of the layers, each about 1.5 microns thick, confine the laser output to a thin central layer about .5 micron thick. When confined to such a small region, the amount of current needed to induce laser action causes a negligible buildup of heat. The lower threshold of operation is 2,700 amperes per square centimeter, compared with almost 100,000 amperes required by the first semiconductor lasers (built in 1962). The new laser was designed by Izuo Hayashi and Morton Panish, assisted by P. W. Foy and S. Sumski.

## *Corn Blight*

The mutant form of Southern leaf blight (the fungus *Helminthosporium maydis*) that is making substantial inroads on the U.S. corn crop this year may continue to be a serious problem next year, according to officials of the U.S. Department of Agriculture. The only certain way to curb the blight is to develop strains of corn that are resistant to it, and that will take time. The department has estimated that the blight may destroy nearly 9 percent of this year's crop, reducing the harvest from the 4.8 billion bushels forecast in July to 4.4 billion. Even so, a harvest of 4.4 billion bushels would be the nation's third-largest corn crop.

About 99 percent of the corn crop is

In the minds of many, modern technology has created a monster.

The computer.

We've all heard the stories about people making, say, a $30 purchase. And then being billed for $3,000 by the computer.

Nonsense.

The danger is not that the computer makes mistakes, but that human errors remain uncorrected while the machine rolls on, compounding them.

Computers are literal minded. They must be correctly instructed to help us in the solution of problems. They do exactly what they are told. Not what they ought to have been told.

The computer is man's assistant. Not his replacement.

The unaided human mind needs help to cope successfully with the complexity of our society.

Intellectual aids, such as computers, will not only increase the skill of our minds, but leave more time for human creativity by freeing man of burdensome routine tasks.

Do we really believe that our achievements in space could have been accomplished without computer assistance?

Do we really believe that we can function efficiently in our complex modern environment without computer assistance?

The answer, of course, is obvious.

In truth, the invention of the computer can be compared with the invention of the printing press.

Engineers engaged in the development of computer systems are convinced that over the next decade it is possible to develop networks of interconnected computer systems capable of offering a wide variety of services to the public.

By necessity, one-way mass communications — radio, television—deal with a common denominator of entertainment. This situation can be changed by developing computer-based systems that offer each individual an almost unlimited range of entertainment and information. Each individual will select what he wants, and to how great a depth he wants to delve into the areas in which he is interested.

At his choice of time.

Apply this principle to education.

What it amounts to is individualized instruction. To meet simultaneously the needs of many students.

From a practical standpoint, limits to excellence in education are almost purely economic.

The computer provides a solution by performing high quality instruction for large numbers of students, economically.

Our goal is to make it possible for a teacher to provide individual guidance to many students, instead of few.

Yet, computer-assisted instruction is not a concept which has been enthusiastically embraced by all. There are many who feel that the computer will replace teachers.

Not so.

This interpretation implies mechanizing, rather than personalizing, education.

Everywhere in our lives is the effect and promise of the computer.

Its ability to predict demand makes it possible to apply the economies of mass production to a wide variety of customized products.

It will allow for the use of a computer terminal device for greater efficiency in home shopping and much wider diversity in home entertainment.

It can be a safeguard against the boom and bust cycle of our economy.

In short, the computer means accuracy, efficiency, progress.

The computer affords us the way to store knowledge in a directly usable form—in a way that permits people to apply it without having to master it in detail.

And without the concomitant human delays.

The computer is indicative of our present-day technology —a technology which has advanced to such an extent that man now is capable, literally, of changing his world.

We must insure that this technological potential is applied for the benefit of all mankind.

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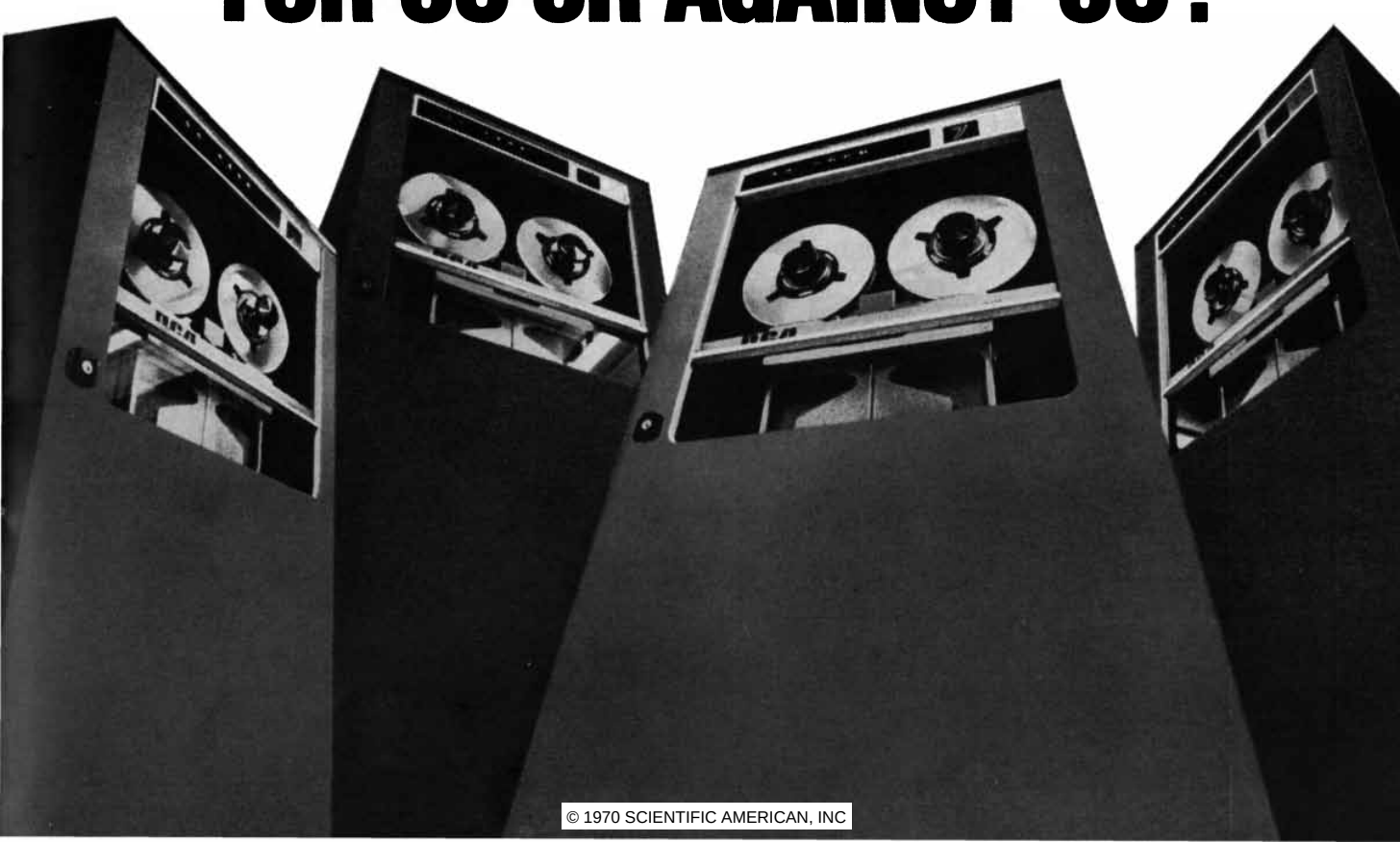
# ARE THEY FOR US OR AGAINST US?



# The fishing is

When fishermen first saw oilmen drilling in the Gulf of Mexico some twenty years ago, they were shocked. "The fishing will never be the same," they said. And they were right.

Nearly a thousand oil-producing platforms now rise from gulf waters and the fishing is better than ever. Far better.

Not only are catches more abundant. The variety is more interesting. At least a dozen species of fish, which were seldom seen in the area before, are turning up near the platforms. Among these are the aristocratic pompano.

And the big fellows seem to be moving closer too. The annual Tarpon Rodeo at Grand Isle, in the heart of Louisiana's offshore oilfields, is now one of the largest fishing contests in the United States.

Jersey's affiliate, Humble Oil & Refining Company, operates many of the offshore wells. Here's how they explain the fish phenomenon.

# better than ever.

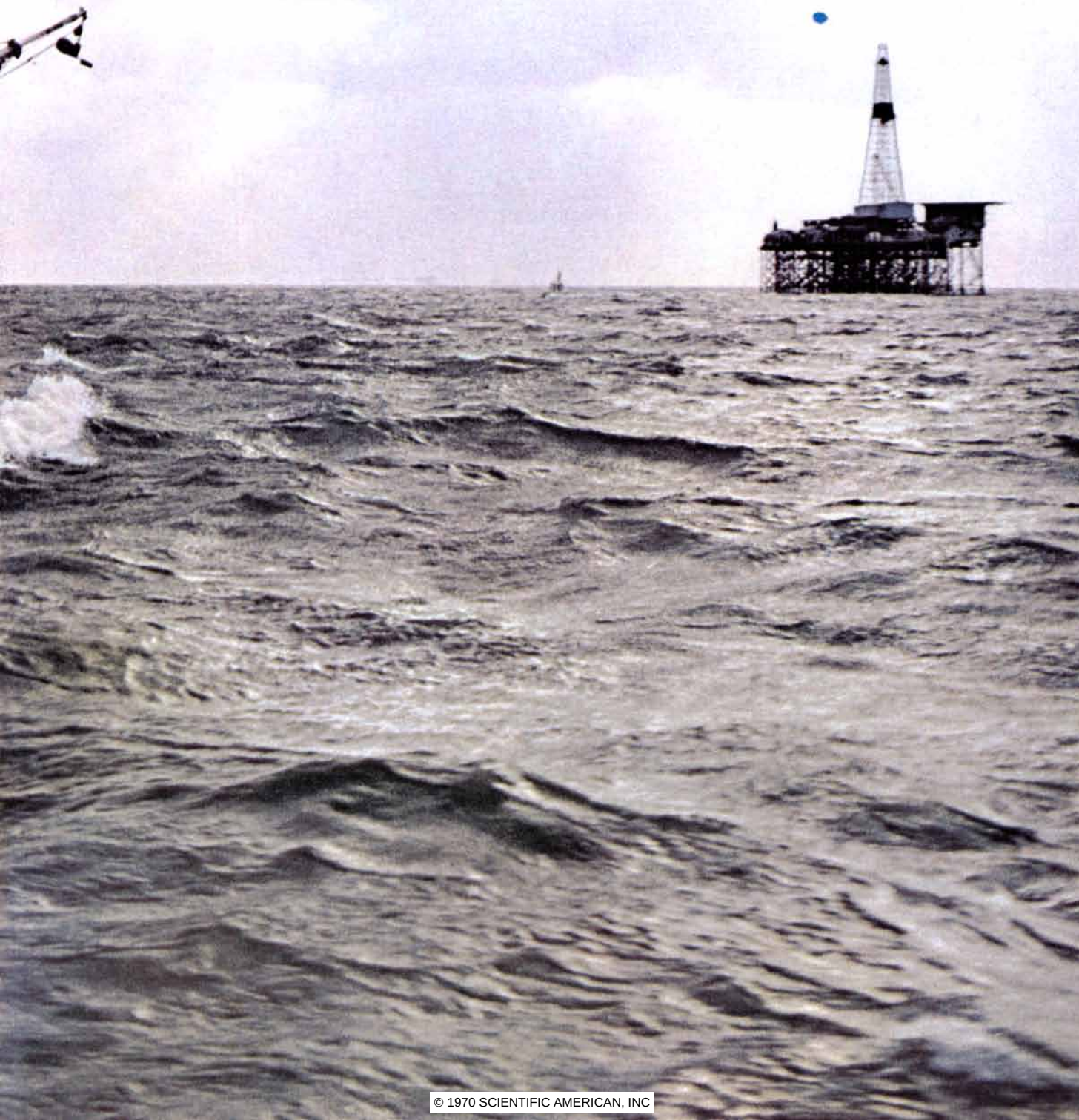
When the legs of a platform are thrust into the ocean floor, they attract various forms of marine life, such as plankton, algae and barnacles. These attract small fish. And the small fish attract big fish. And so on and so on, in the fish-eat-fish rhythms of the sea.

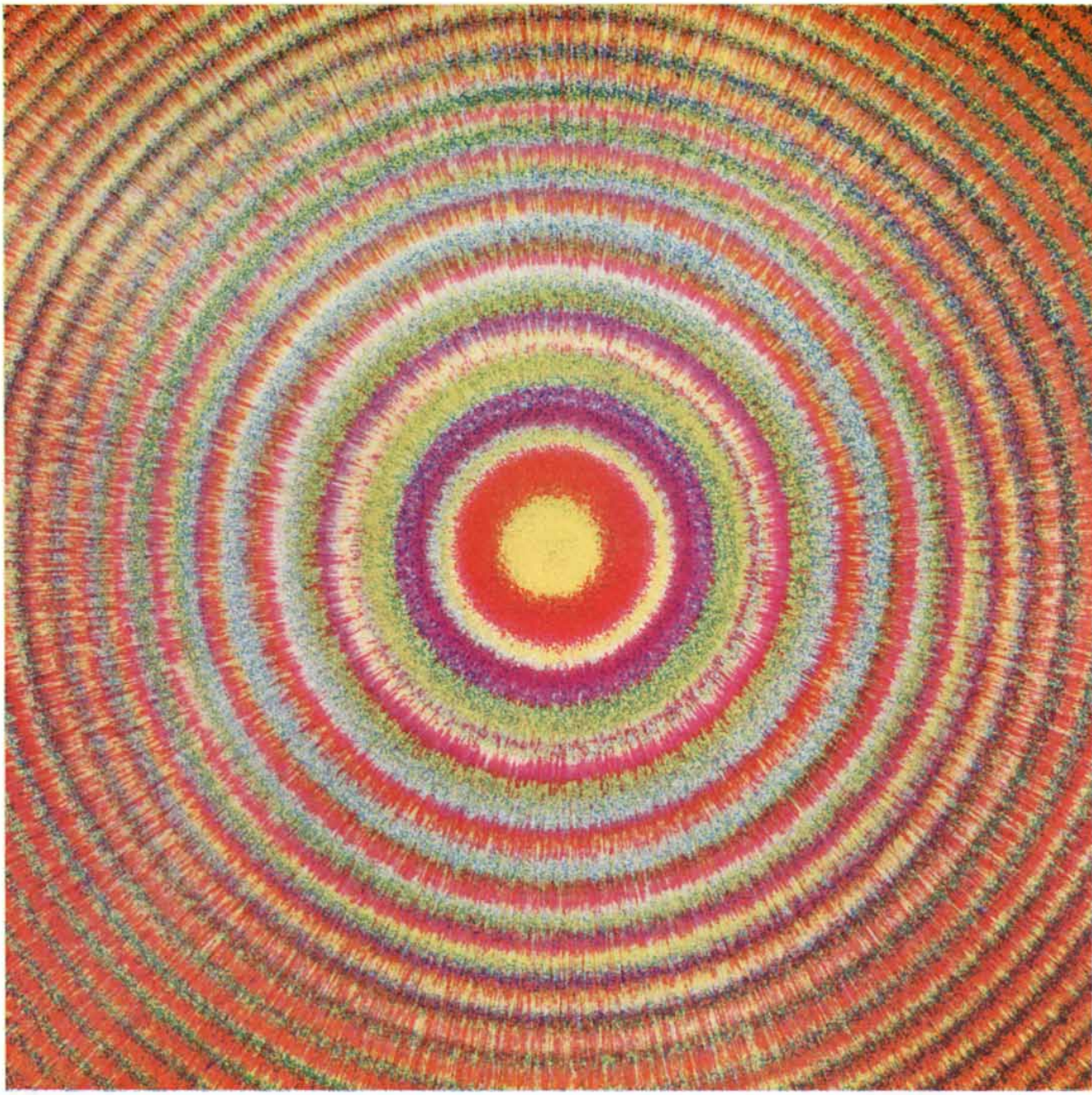
For Jersey or Humble to claim credit for this natural process would clearly be absurd. We simply point out that it might not happen at all if we ran our oil platforms without caring about the waters in which they stand.

By the way, commercial fishing in the gulf is going great guns too. Trawlers are now catching over four times the weight of fish they caught in 1940.

**Standard Oil Company (New Jersey)**

Esso





# "LASER LIGHT"

## A SCIENTIFIC AMERICAN FILM

Almost everyone has heard of lasers, but relatively few people have seen them in action. The Editors of SCIENTIFIC AMERICAN now present "LASER LIGHT," a 16-millimeter sound film about lasers: what they are, how they work, the marvelously pure and curiously scintillating light they produce, how they are being used and how they may be used in the near future. The film is in color and lasts 37½ minutes. It is available for sale or rent.

A few highlights of the film are:

- **Computer-generated animation explaining stimulated emission and resonant optical cavities.**
- **Ripple-tank and oscilloscope demonstrations explaining the wave principles underlying laser action and holography.**
- **Holograms, their three-dimensionality dramatically evoked by the moving camera.**
- **A 600-foot, 8.8 - kilowatt laser in action.**
- **Tunable lasers.**
- **A television picture transmitted by laser beam.**
- **The laser chalkline for the San Francisco Bay tunnel.**
- **Laser interferometry.**
- **Gas, solid and organic-liquid lasers.**
- **An experiment on the use of holography in a computer memory.**
- **Original musical score.**

"LASER LIGHT" is recommended for general audiences with an interest in science and technology, and for use in conjunction with the teaching of physics and optics. The film is accompanied by a selection of five SCIENTIFIC AMERICAN articles on lasers and holography, written by leading authorities in these fields.

The sale price per print is $375, the rental price $37.50 for a booking of three days. If the film is purchased after rental, the rental price will be deducted. If rental booking is desired, kindly specify date. Write Motion Picture Department, SCIENTIFIC AMERICAN, 415 Madison Avenue, New York, N.Y. 10017

Left: Fabry-Perot interferometer pattern in krypton-ion laser beam

fed to livestock or used in industry. Even though there is a reserve supply of corn from earlier crops, news of the blight has pushed up the price of corn ordered for future delivery by more than 10 percent. If the price continues to rise, it can be expected to drive up the price of meat.

The blight can be curbed to some extent by hot and dry weather and by spraying. During much of this year's growing season the weather in the corn belt has been cool and moist, which is apparently one reason the blight has gained such a foothold. Spraying is expensive; moreover, it must be started before the fungus attacks the corn. Officials of the Department of Agriculture are optimistic about producing resistant strains, but it is unlikely that they will be available until about 1973.

### *On with the Dance*

It was some 25 years ago that Karl von Frisch of Austria conducted the series of experiments that led him to his remarkable hypothesis about the "dance" of the bee. Observing that a certain class of "forager" honeybees, after finding a source of food, return to the hive and perform a peculiar "waggle dance" that encodes rather precise correlates of the distance and direction to the feeding place, he proposed that the function of the dance was to communicate to honeybee "recruits" enough symbolic information to locate the new food supply. Some years later two investigators at the University of California at Santa Barbara, Adrian M. Wenner and D. L. Johnson, repeated von Frisch's experiments, with certain modifications, and came to a different conclusion. They maintained that the recruiting behavior of the bees they observed could be explained on the basis of olfactory cues alone. Subsequently Wenner suggested that the dancing bees might actually be in the process of communicating information by sound.

Confronted by this apparent contradiction, three biology students at the California Institute of Technology and the University of Oregon, set out recently to test von Frisch's dance-language hypothesis by means of a rigorously controlled experimental arrangement designed to minimize or cancel olfactory cues, so that only the question of communication by dancing was considered. The experimenters, James L. Gould and Michael Henery of Cal Tech and Michael C. MacLeod of Oregon, describe their procedures and findings in a recent article in *Science*.

The procedures followed by the students were, like those of Wenner and Johnson, essentially variations of von Frisch's original experiments. Food stations were set out at various distances and directions from the main hive and forager bees were identified and trained to seek only one of them. Untrained bees arriving at the several stations were then captured and counted, in order to establish whether or not these bees showed any preference for the training station. (Von Frisch found such a preference; Johnson did not.)

In the students' view, both sets of earlier experiments lacked adequate controls to discount the influence of a multitude of variables that might affect the bees' foraging behavior, dancing and recruitment. Accordingly they took great pains to include such controls in their own experiments. (For example, in one test they individually tagged 5,000 bees with 2,200 distinct markers in order to avoid counting the same bee at a given station more than once.)

Gould, Henery and MacLeod found that "in the presence of controls for site- and path-specific odors, observer and food-source scents, Nasanov gland and alarm odors, visual cues, wind, and general site taxis, recruited bees were able to locate the food source indicated by the dances of the returning foragers in preference to a food source located at an equal distance in the opposite direction." Therefore, they conclude, "our experiments appear to confirm von Frisch's contention that the directional information contained in the forager's waggle dance does, indeed, contain additional information which can be utilized by recruits."

### *Slippery Liquids*

Development work on a number of fronts is turning up new applications of the phenomenon in which the flow of liquid through a pipe or the movement of a solid body through a liquid is aided by the addition to the liquid of a small amount of soluble polymer. The addition of as little as 10 parts per million by weight can result in the reduction of friction or drag by as much as 40 percent. The phenomenon is known as the Toms effect after the British chemist Bryan A. Toms, who first described it in 1949.

The Toms effect has already been used to reduce the diameter of pipe and the power required in various pumping situations, such as the delivery of oil by pipeline or of water through a fire hose. Among the other applications that seem promising are increasing the speed of ships, reducing the wear of ball bearings and improving the rate of delivery of irrigation water. Achievement of the effect requires the use of long-chain polymers of high molecular weight. So far the applications are limited to situations where the liquid is used only once. The polymers tend to be degraded in recycling, thereby becoming less effective.

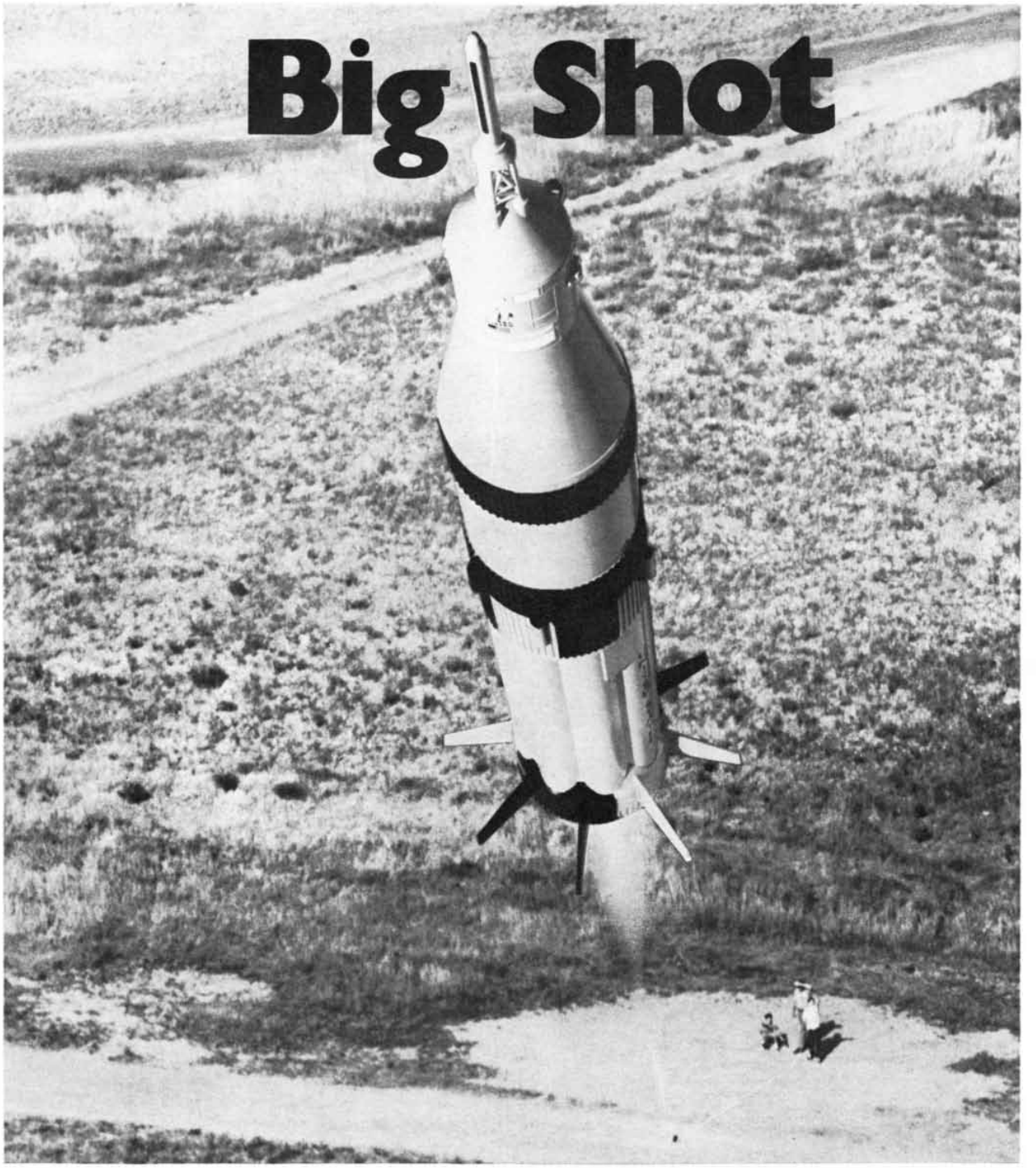
### *When Two Hearts Beat as Two*

The human heart has a daily rhythm as well as the rhythm of its beat. This daily rhythm is expressed in a regular 24-hour cycle of a slight increase and decrease in the rate of the heartbeat. What happens to the daily rhythm when the heart of one man is transplanted into the body of another man? Does the rhythm of the donor persist or does the rhythm of the donee take over?

The answer, according to a group of physicians at the Baylor College of Medicine, is that under certain circumstances both rhythms continue. Writing in *Science*, Robert D. Leachman, Irvin A. Kraft, Harry S. Lipscomb and two students, Steven Alexander and Delbert Foster, describe their study of the electrocardiogram of a man who had recently received a heart transplant. Two sets of rhythms were clearly apparent: one was controlled by the sinoatrial node (that is, the natural pacemaker) of the donor's heart and the other by the sinoatrial node in the small amount of heart tissue remaining in the donee. Leaving this tissue in place is the standard heart-transplant technique: when a patient is prepared for transplantation, all of his heart is removed except for the back part of the right atrium. This tissue, which acts as a "bed" for the new heart, contains the sinoatrial node.

Under these conditions the new heart obeys the signals of its own pacemaker. Both pacemakers, however, maintain separate daily rhythms. In this particular case the transplanted heart's cycle was about 135 minutes ahead of the recipient's heart cycle.

Observations suggest that the transplanted heart's daily rhythms and its rate of beat are under its own control and are independent of the donee's pacemaker and nervous system. This conclusion is supported by the fact that when the patient exercised, his heart rate did not increase until about two minutes later. Apparently the new heart was responding to chemical stimuli rather than to the patient's nerve impulses.

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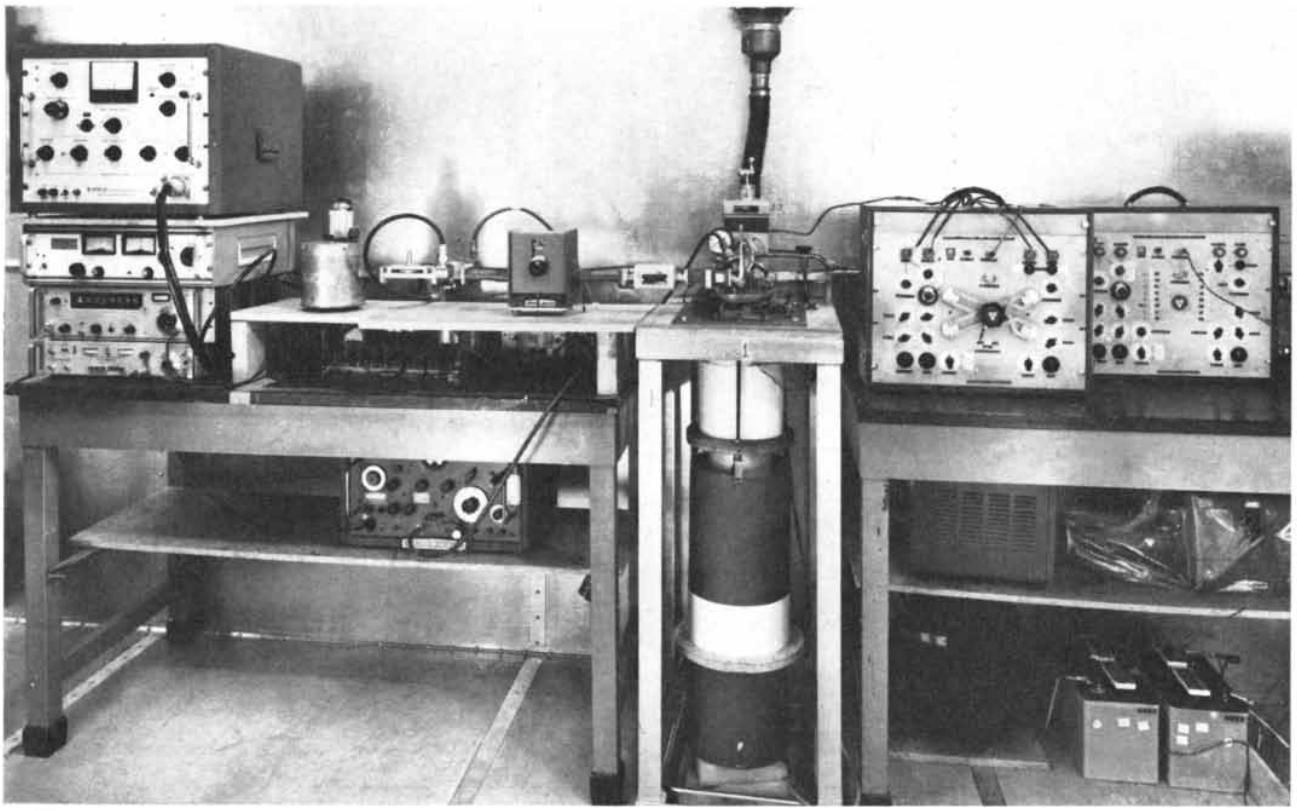
# The Fundamental Physical Constants

*Experiments designed to redetermine the numerical values of these quantities to ever greater levels of accuracy can yield information concerning the overall correctness of the basic theories of physics*

by Barry N. Taylor, Donald N. Langenberg and William H. Parker

Contrary to popular opinion, physics is usually not a very exact science. A physicist is often quite pleased with himself if he measures some property of matter to an accuracy of within a few percent and finds that his measurement agrees with a theoretical prediction, again to within a few percent. In some cases finding agreement to within an order of magnitude (a factor of 10) is a considerable achievement. This comparative lack of precision arises from two main sources. First, most experiments deal with a complex system in which a variety of interrelated and often poorly understood phenomena are involved. Second, the pertinent theory usually provides only an approximation based on a simplified conceptual model of the system.

There are, on the other hand, a few special quantities in physics that can—indeed must—be known to a much greater accuracy. These are the fundamental



**EXPERIMENTAL APPARATUS** in the physics laboratory of the University of Pennsylvania is a later version of the one used by the authors and Arnold Denenstein to measure the ratio of two fundamental constants, the charge of the electron ($e$) divided by Planck's constant ($h$), by means of the a.c. Josephson effect. The Josephson junction is mounted inside the Dewar vessel (*center*), in which liquid helium is used to cool the junction to one or two degrees above absolute zero, thereby making the metal films that comprise the junction superconducting. The boxes of electronic equipment at far left are used to measure the frequency of the oscillating supercurrent in the junction. The boxes at right are used to measure the voltage across the junction. The smaller pieces of equipment at near left are used to supply microwave radiation to the junction through a rectangular tube called a wave guide.

physical constants. They include such quantities as the velocity of light in a vacuum ($c$), Planck's constant ($h$), the charge of the electron ($e$), the mass of the electron ($m_e$) and the fine-structure constant ($\alpha$). We have chosen to list these five constants rather than others of comparable importance because they exemplify particularly well the varied origins of the fundamental constants.

The velocity of light and Planck's constant are examples of quantities that occur naturally in the mathematical formulation of certain basic theories of physics. In Einstein's general theory of relativity, for instance, the energy ($E$) and mass ($m$) of an atom are related by the famous equation $E = mc^2$, whereas in quantum theory the energy and frequency ($\nu$) of a photon are related by the equation $E = h\nu$.

The charge and mass of the electron are examples of constants that, in addition to characterizing a particular elementary particle, are the fundamental units whose multiples are used to characterize all the other elementary particles that constitute matter. The charge of an alpha particle, say, is twice the fundamental unit of charge (or $2e$), whereas the mass of the neutral pi meson is 264.1 times the fundamental unit of mass (or $264.1m_e$).

The fine-structure constant is an example of a fundamental constant that can be expressed as a combination of other constants ($\alpha$ is equal to $2\pi e^2/hc$). Because such combinations always appear in theoretical equations in exactly the same way, they are really fundamental constants in their own right. The fine-structure constant is the basic constant of quantum electrodynamics, the quantum theory that describes the interactions of elementary particles with electromagnetic fields ($\alpha$ is a measure of the strength of these interactions). Another example of this type of fundamental constant is the Rydberg constant ($R_\infty$), which is equal to $2\pi^2 m_e e^4/h^3 c$. It sets the scale of the allowed electron energy levels in atoms such as hydrogen.

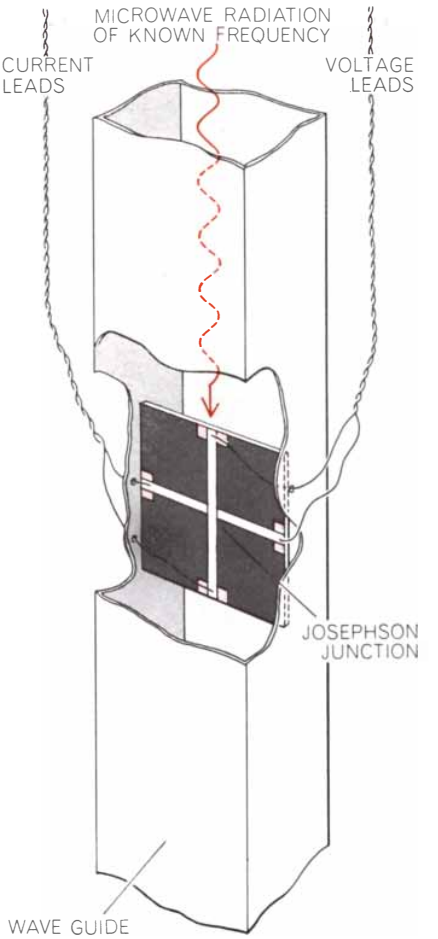
There are of course many other quantities in nature that can be measured with high accuracy—for example the density of a particular piece of gold or the distance from the earth to the sun. Such quantities, however, are generally not considered to be fundamental constants. They are too closely associated with the particular properties of the material or system on which the measurements are carried out. A different sample of gold would give different results, and a Martian would no doubt argue that the distance from Mars to the sun is just as fundamental as the distance from the earth to the sun. In essence, such quantities lack universality; they do not consistently appear in the basic theoretical equations of physics, nor are they properties of the fundamental particles of physics. They are macroscopic in nature and therefore specific, rather than microscopic in nature and therefore general.

(Some theoretical physicists have considered the possibility that the fundamental constants change with time, for example that $e$ was slightly different in 1870 from what it is in 1970. At the moment, however, there is no concrete experimental evidence that the fundamental constants are not constant, and we shall not dwell on the matter further.)

## The Importance of Accuracy

Why is it important to know the numerical values of the fundamental constants with great accuracy? First of all, the quantitative predictions of the basic theories of physics depend on the numerical values of the constants that appear in the theories. An accurate knowledge of these values is therefore essential if one hopes to achieve an accurate quantitative description of the physical universe. More important, the careful study of the numerical values of these constants, as determined from experiments in the different fields of physics, can in turn test the overall consistency and correctness of the basic theories of physics themselves. If one looks at the entire structure of physics, one sees a vast array of apparently divergent fields: solid-state physics, atomic physics, nuclear physics, elementary-particle physics and so on. The unifying force that binds all these fields together is theory; the basic concepts contained in quantum mechanics, electromagnetic theory, special relativity, statistical mechanics and so forth are present in all of them. And the fundamental constants are the quantitative links in the web of theory that binds physics together. Measurements of these constants to ever greater levels of accuracy are important, therefore, not just because they add another decimal point but because the added decimal point may lead to the discovery of a previously unknown inconsistency, or the removal of a known inconsistency, in our physical description of nature.

The accuracy with which many of the fundamental constants can be currently measured is a few parts in a million. By accuracy here is meant the relative size of the uncertainty that must be assigned

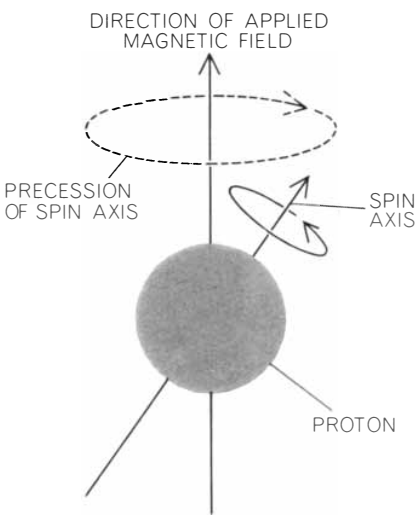



**$e/h$ IS DETERMINED by irradiating with microwaves of a known frequency a Josephson junction mounted inside a wave guide immersed in the liquid-helium Dewar (*diagram at top*). The microwaves induce a series of steps in the current v. voltage graph that characterizes the junction (*curve at bottom*). The junction is "biased" (through the current leads) onto one of these steps by means of an adjustable current supply (some variable resistors and a battery) and the voltage of the step is measured (through the voltage leads) with a potentiometer. The frequency of the microwaves and the voltage of the step are proportional to each other, the constant of proportionality being $2e/h$.**

| NAME OF CONSTANT | SYMBOL | UNITS | VALUE | UNCERTAINTY |
|---|---|---|---|---|
| VELOCITY OF LIGHT IN VACUUM | c | $10^8$ METERS PER SECOND | 2.9979250(10) | .33 |
| CHARGE OF THE ELECTRON | e | $10^{-19}$ COULOMB | 1.6021917(70) | 4.4 |
| PLANCK'S CONSTANT | h | $10^{-34}$ JOULE-SECOND | 6.626196(50) | 7.6 |
| MASS OF ELECTRON | $m_e$ | $10^{-31}$ KILOGRAM | 9.109558(54) | 6.0 |
| INVERSE OF FINE-STRUCTURE CONSTANT | $\alpha^{-1}$ | | 137.03602(21) | 1.5 |
| RYDBERG CONSTANT | $R_\infty$ | $10^7$ PER METER | 1.09737312(11) | .10 |

**PRESENT BEST VALUES of the six fundamental constants discussed in the text are given in this table. ($\alpha^{-1}$, the inverse of the fine-structure constant, is listed rather than $\alpha$ because it is a simpler number.) The third column from the left gives the units in terms of which the various quantities are measured. ($\alpha^{-1}$ is a pure number and therefore has no units.) The numbers in parentheses in the "Value" column indicate the uncertainty in the last two digits of the main number. Last column gives the corresponding uncertainty in parts per million.**

to the numerical value of any quantity in order to indicate how far from the true value it may be. This uncertainty is a quantitative estimate of the extent of the doubts associated with the value. The most commonly used uncertainty, the standard deviation ($\sigma$), is such that there is about a 68 percent chance that the true value lies within plus $\sigma$ or minus $\sigma$. For example, if the length of a table is measured 10 times and its mean length is found to be $100 \pm 3$ inches, with the three-inch uncertainty corresponding to $\sigma$, then there is a 68 percent chance that the true length lies somewhere between 97 and 103 inches. Moreover, there is a 95 percent chance that the true value lies between plus $2\sigma$ and minus $2\sigma$ (between 94 and 106 inches) and a 99.7 percent chance that the true value lies between plus $3\sigma$ and minus $3\sigma$ (between 91 and 109 inches).




**SPIN AXIS OF PROTON precesses around the direction of an applied magnetic field in a manner similar to the wobbling of a top. The ratio of the precession frequency to the strength of the applied field is referred to as the gyromagnetic ratio of the proton ($\gamma_p$).**

In practice an accuracy of one part per million is really rather respectable. It corresponds to determining the length of a football field to within the thickness of one of the pages this article is printed on. There are several quantities that have actually been measured with accuracies approaching one part per trillion. This corresponds to determining the distance from New York to San Francisco to within less than a tenth the thickness of the page! In a world where confusion and uncertainty are the rule there is a certain aesthetic pleasure to be had from establishing the value of a quantity with such accuracy.

## Lessons from the Past

An easily understood example of how the accurate redetermination of a fundamental constant with improved methods can lead to an improved understanding of a particular physical phenomenon can be found by looking back at attempts to measure the fundamental unit of electric charge. Robert A. Millikan conducted his famous oil-drop experiments to determine $e$ from about 1907 to 1917. In this experimental method the motion of small, weakly charged oil drops moving in air between two horizontal and parallel metal plates is followed as a function of time. First the time it takes a particular drop to fall a measured distance under the influence of gravity alone is determined. Next a voltage difference is established between the two plates in such a way that the resulting force on the charged drop causes it to rise (that is, to move against gravity), and the time it takes the drop to rise a measured distance is determined. The value of $e$ is then calculated on the basis of many such measurements on different drops (combined with a knowledge of other relevant quantities such as the local value of the acceleration due to gravity, distance between the plates, the voltage difference between the plates, the pressure and viscosity of the air and the density of the oil). Millikan's final value, reported in 1917, was $4.774 \pm .002$ (in a certain set of units with which we shall not concern ourselves here).

That this value was significantly in error became clear in the 1930's with the development of a new method for obtaining $e$. The technique consisted of separately measuring two other physical quantities: the Avogadro number ($N$) and the faraday ($F$). The Avogadro number is the number of atoms or molecules contained in a mole, which is defined as a mass in grams equal to the atomic or molecular weight of a substance; the faraday is the amount of charge that must pass through a solution in order to electrolytically deposit a mole of an element contained in the solution. These two quantities are related by the simple equation $F = Ne$. It therefore follows that $e$ equals $F/N$, so that $e$ can readily be obtained if $F$ and $N$ are known. The Avogadro number was determined by carefully measuring the density, atomic weight and crystal-lattice spacing (the distance between the planes of atoms) of a particular substance with X-ray techniques. The faraday was determined by measuring the mass of material electrolytically deposited on an electrode when a known current flowing for a known time was allowed to pass through a solution containing the material.

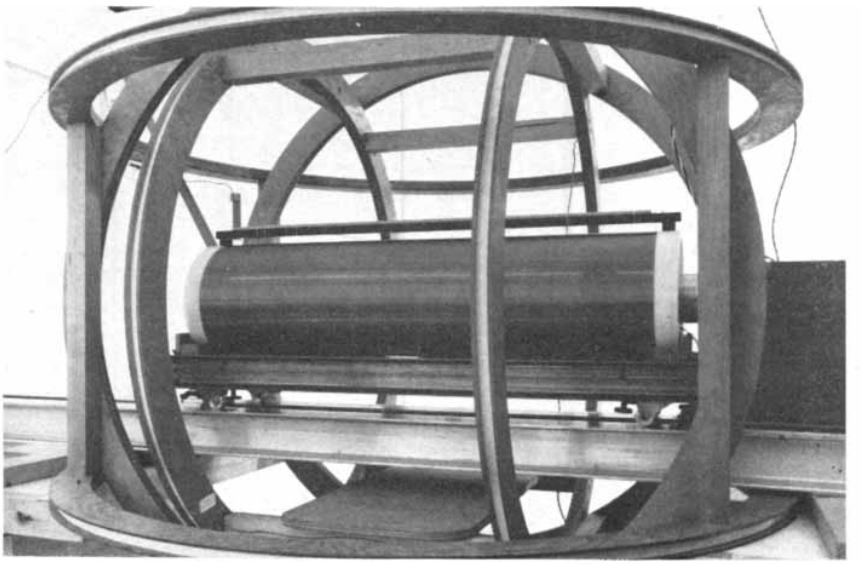
The value of $e$ deduced in this way was $4.8021 \pm .0009$, significantly different from the Millikan value. The major

source of this disturbing discrepancy was later traced to the use by Millikan of an incorrect value for the viscosity of air. Millikan had taken a value that was almost entirely based on a measurement by one of his students, but it was subsequently shown that the student had made a rather subtle mistake. In order to measure the torsion constant of a certain wire used in the viscosity-determination experiment he had used a mass that was entirely different from the mass the wire supported during the experiment, and it was later discovered that the torsion constant of a wire varies both with the mass supported and with the geometry of the mass. When Millikan's data were reevaluated with a correctly determined value for the viscosity of air, the value of $e$ obtained agreed with the indirect value calculated from the Avogadro number and the faraday.

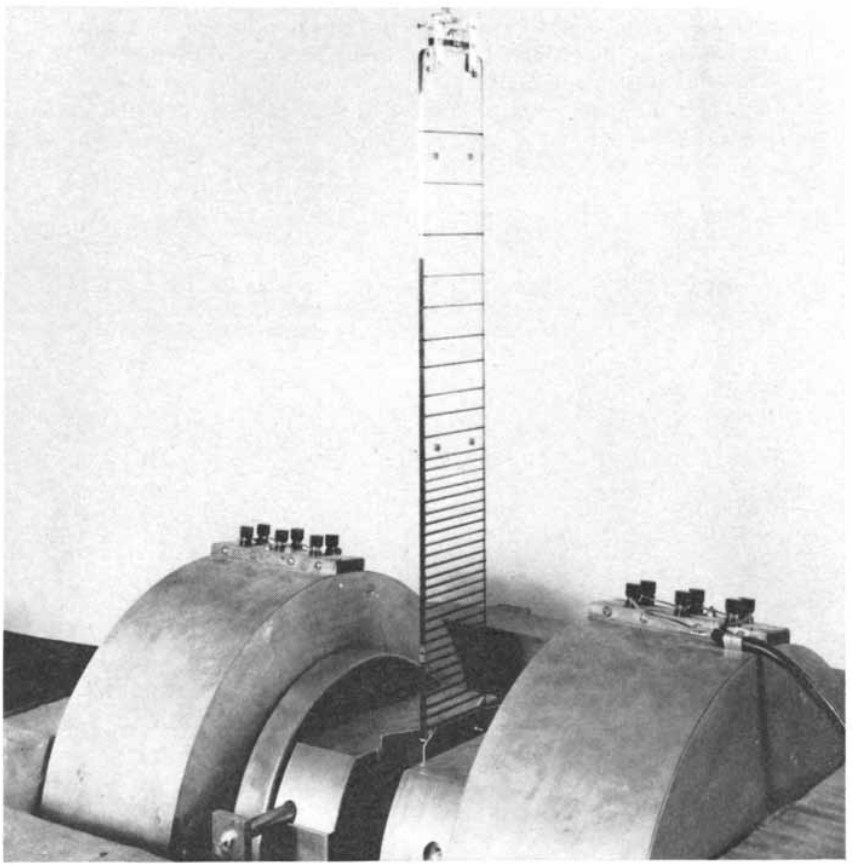
This case demonstrates the general fact that the experimentally determined value of a constant varies with each determination. The reason for this is the difficulty of measuring any quantity to high accuracy; every conceivable effect that might influence the result must be given careful and lengthy consideration. Even then it often happens that an important effect is overlooked.

On the other hand, there is sometimes a tendency for just the opposite to happen. From time to time different experimental determinations of a particular quantity will agree with one another exceedingly well. Later, however, a new series of measurements exploiting improved methods will show that this value of the quantity was incorrect, that the new value differs from the old "consensus" value by many times the uncertainty assigned the old value. (This phenomenon seems particularly likely to occur when the first of the older values was obtained by an eminent physicist rather than by one less distinguished.) A good example is provided by the successive measurements of the velocity of light. Up to about 1950 several different and apparently reliable measurements of $c$ were carried out, and all were in good agreement with one another. Then more precise measurements made in the 1950's showed that the earlier measurements were incorrect by something like four times the uncertainty assigned to the older value.

A possible explanation for this phenomenon, which has been called "intellectual phase-locking" (or in some cases just plain "fudging"), has been attributed to Ernest O. Lawrence, the inventor of the cyclotron. He pointed out that when the apparatus for any high-precision ex-



**LOW-FIELD METHOD of determining $\gamma_p$ is carried out with this apparatus at the National Bureau of Standards. The dimensions of a precision solenoid (a helical-coil magnet) are accurately measured and the magnetic field at the center of the solenoid is calculated in terms of the current that is passed through the coil. The corresponding precession frequency of the protons in a water sample at the center of the solenoid is then measured using standard electronic techniques. The particular solenoid shown is about 40 inches long and is wound with 1,000 turns of wire in a single layer. The large coils on the plywood frame surrounding the solenoid are used to eliminate the effect of the earth's magnetic field.**



**HIGH-FIELD METHOD of determining $\gamma_p$ uses a large electromagnet to establish the magnetic field, which is calculated by measuring the force exerted on a current-carrying rectangular coil. In this photograph of a high-field apparatus used at the National Bureau of Standards around 1950 the coil is wound along the edges of a long plate of glass. (The horizontal lines across the width of the glass are threads to help hold the windings in place.)**

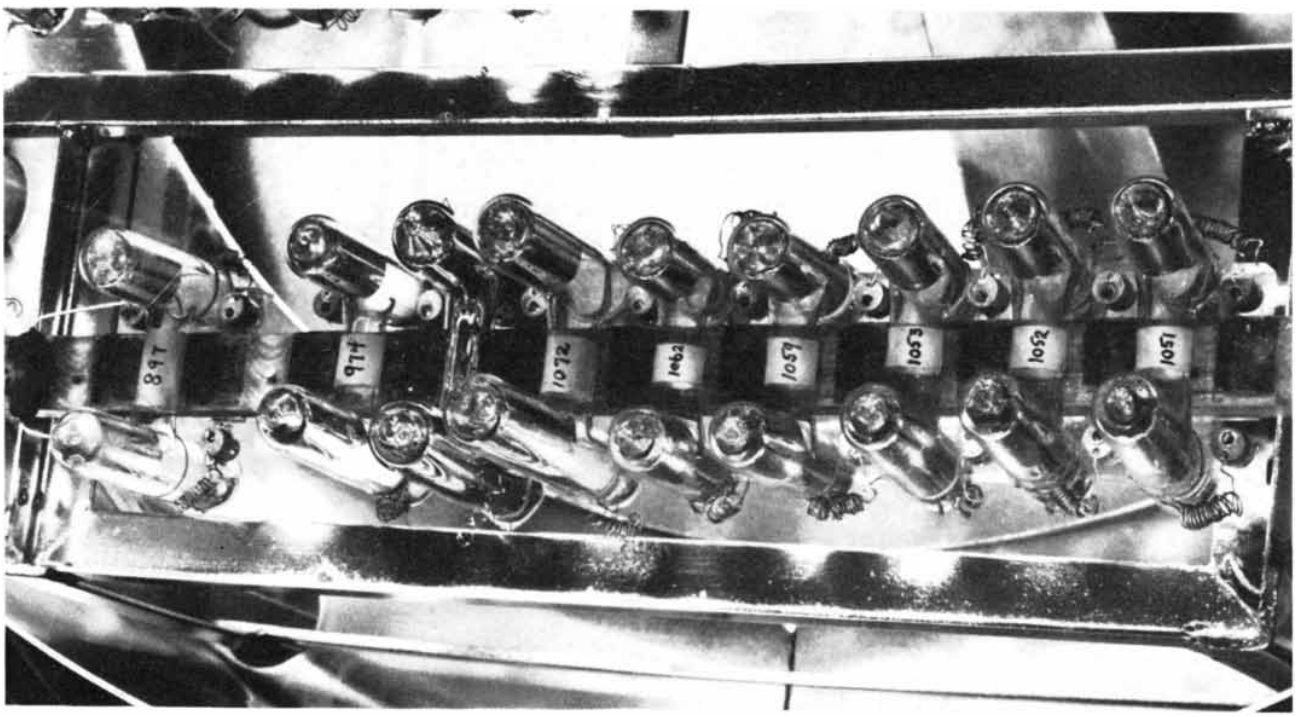
periment is initially set up and put into operation, there are many instrumental and technical difficulties that may lead to a value for the quantity being measured that is far from the currently accepted value (or from the experimenter's preconceived notion of what the value of the quantity should be). The experimenter then searches for the sources of the disagreement (he "debugs" his apparatus) until he gets a result close to the accepted or expected value. Then he stops! The problem is of course that he may have overlooked additional sources of error. Such a set of circumstances may well account for the good agreement of several different results and for the fact that at a later date they are all found to be in error by a large amount. It is just these variations in the measured numerical values of the constants, however, that often furnish important clues to errors in experiment and/or theory.

## Redetermining $e/h$

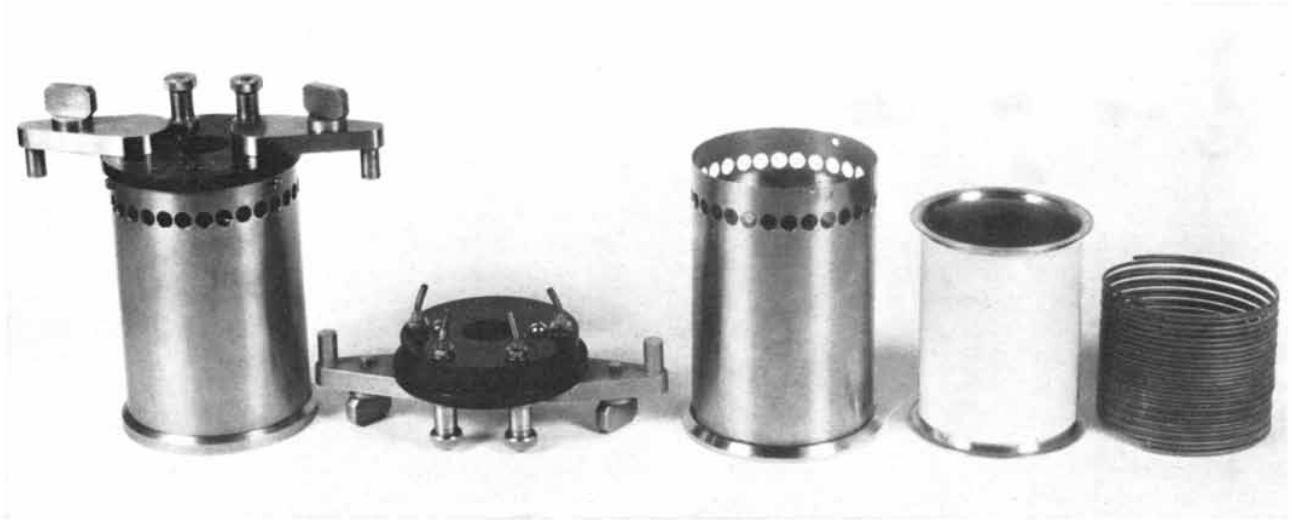
Probably the best example in recent years of the important consequences that can follow from an extremely accurate redetermination of a fundamental constant is the measurement of the quantity $e/h$ by a group at the University of Pennsylvania consisting of the authors of this article and their colleague Arnold Denenstein. This measurement, which was made by means of a low-temperature solid-state physics experiment, has made significant contributions to fields as far removed from solid-state physics as elementary-particle physics, quantum electrodynamics, X-ray physics and atomic physics. It is based on a remarkable phenomenon in superconducting materials known as the alternating-current Josephson effect [see "The Josephson Effects," by Donald N. Langenberg, Douglas J. Scalapino and Barry N. Taylor; SCIENTIFIC AMERICAN, May, 1966].

The a.c. Josephson effect was first predicted by Brian Josephson of the University of Cambridge in 1962. He showed theoretically that if two superconductors (that is, materials that lose all resistance to an electric current at temperatures near absolute zero) were "weakly" connected together, then an alternating resistanceless current, or "a.c. supercurrent," would flow between them when they were maintained at a finite voltage difference ($V$). (A photograph of one type of device in which such a "weak" coupling can be achieved appears on the cover of this issue of *Scientific American*. It shows a sandwich-like superconducting junction consisting of two superconducting films separated by an insulating barrier about 40 billionths of an inch thick.) Josephson predicted that the frequency ($\nu$) of the a.c. supercurrent would be proportional to the voltage difference, the constant of proportionality being simply $2e/h$. Thus $\nu = (2e/h)V$. The ratio $2e/h$ and therefore the frequency of the supercurrent are numerically equal to about 484 million megahertz (cycles per second) for a voltage difference of a microvolt (a millionth of a volt). This Josephson frequency-voltage relation, which can be shown to follow from some quite general assumptions about superconductors, is believed to be exact and independent of a wide variety of experimental variables such as temperature, magnetic field and type of superconductor.

The determination of the ratio $e/h$ turned out to be rather simple compared with most other fundamental-constant experiments. It was only necessary to measure the voltage difference between the two superconductors and the frequency of the oscillating supercurrent. In practice the measurement of the small voltages involved (typically only a few thousandths of a volt) to a few parts per million is a challenging but solvable technical problem. In contrast, modern electronic counting techniques make it possible to determine the frequency to within a few hundredths of a part per million or better. The final result of the measurements was $2e/h = 483.5976 \pm .0012$ megahertz per microvolt, where the stated uncertainty $\pm.0012$ corresponds to a fractional uncertainty of




**U.S. AS-MAINTAINED VOLT is defined by means of groups of electrochemical standard cells kept at the National Bureau of Standards. The cells are mounted in a temperature-regulated, stirred oil bath to reduce variations in output voltage caused by fluctuations in temperature. A change in temperature of one degree Celsius would result in a voltage shift of about 55 parts per million.**



**U.S. AS-MAINTAINED OHM is defined by groups of one-ohm resistors similar to the one shown in this photograph made at the National Bureau of Standards. The fully assembled resistor is shown at left and its disassembled components at right. The actual resistance element is the helical coil at far right. The U.S. as-maintained ampere is derived through Ohm's law (current = voltage/resistance).**

±2.4 parts per million. This value of $e/h$ is some 20 times more accurate than the best previous value, which was determined from an X-ray experiment.

### A Better $e/h$ Means a Better $\alpha$

The Josephson-effect measurement of $e/h$ has probably had its greatest impact in the field of quantum electrodynamics. As noted above, this is the quantum theory that describes the interaction of elementary particles and electromagnetic fields, the fine-structure constant ($\alpha$) being a measure of the strength of the interactions. Quantum electrodynamics is one of the most important modern theories of physics and one of the few that are capable of making highly accurate numerical predictions. Such predictions are only possible, however, if an accurate value of $\alpha$ is available, since the theoretical expressions that describe the various physical quantities of interest (for example certain energy-level differences in the hydrogen atom) are generally in the form of mathematical expressions involving $\alpha$. An accurate value of $\alpha$ is therefore essential for comparing the theoretical predictions of quantum electrodynamics with experiment.

Heretofore the most accurate values of $\alpha$ were obtained from experiments with the aid of theoretical equations containing significant contributions from quantum electrodynamics itself. That made it difficult to compare the predictions of the theory with the experimental results unambiguously, since the theory had to be evaluated using values of $\alpha$ derived from the experiments. Such comparisons were therefore limited to testing for internal consistency among various experiments of this type. Now, however, by combining the value of $e/h$ obtained from the Josephson-effect experiment with the measured values of certain other constants, a highly accurate indirect value of $\alpha$ can be obtained without any essential use of quantum-electrodynamic theory. As a result direct and unambiguous comparisons can be made between quantum-electrodynamic theory and experiment.

In practice there are several mathematical recipes for obtaining an indirect value of $\alpha$ from $e/h$. One method involves combining it with some very accurately known constants (such as $R_\infty$ and $c$) and the value for the gyromagnetic ratio of the proton ($\gamma_p$). This latter quantity, which can be measured to an accuracy comparable to that of $e/h$, is a measure of how fast the spin axis of the proton "precesses" in a magnetic field [*see bottom illustration on page 64*]. To determine $\gamma_p$, a precision solenoid (a helical-coil magnet) wound with a single layer of wire is constructed and its dimensions are accurately measured. The solenoid is then used to establish a known magnetic field by passing a current through its windings and calculating the magnitude of the field from the dimensions and the current. The precession frequency of protons in a water sample inside the solenoid is then measured with standard electronic techniques. This is called the low-field method for determining $\gamma_p$; the magnetic field is only about 20 times stronger than the earth's field [*see top illustration on page 65*]. In the high-field method the magnetic field is established by a large electromagnet and may be 10,000 times stronger than the earth's field; here the field is determined by measuring the force on a coil of known dimensions carrying a known current [*see bottom illustration on page 65*].

Another method for obtaining $\alpha$, currently less accurate than the one above, involves combining $e/h$ with an experimental value for the faraday, some very accurately known constants and a value for the magnetic moment of the proton in Bohr magnetons ($\mu_p/\mu_n$). This quantity is the ratio of the above-mentioned spin-axis precession frequency of a proton in a magnetic field to the frequency of the proton's orbital motion in the same field.

The Josephson-effect value of $e/h$ has important implications for the numerical values of other fundamental constants besides $\alpha$. The reason is that only a few of the constants of interest can be measured to high accuracy directly. The remaining constants must be calculated from appropriate combinations of those directly measured. Furthermore, for some of the constants that can be directly determined to high accuracy an indirect value obtainable from combinations of other directly measured constants will have a comparable uncertainty. Hence some type of average of the direct and indirect values must be taken in order to arrive at an appropriate "best" value.

Unfortunately the problem of determining a best value for $\alpha$ that is independent of quantum-electrodynamic theory, as well as similar values for other fundamental constants, is more difficult than our discussion up to this point might suggest because of the existence of

conversion factors relating "absolute" units to "as maintained" units. Since this problem is of considerable importance, we pause to discuss it in some detail.

## The Standards Problem

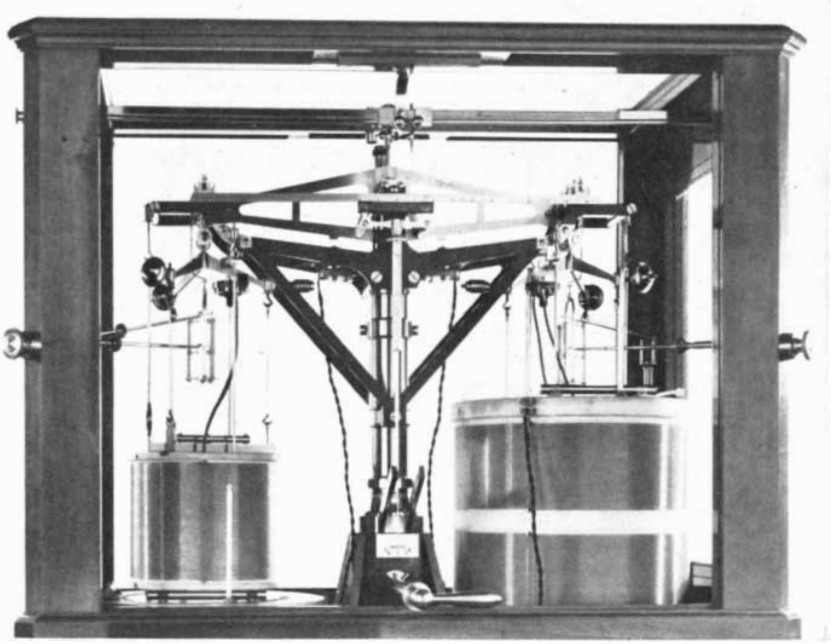
The measurement of any quantity must be carried out in terms of certain units. The dominant system of units currently in use throughout the world is called the Système International [see "Standards of Measurement," by Allen V. Astin; SCIENTIFIC AMERICAN, June, 1968]. It is based in part on the kilogram, the meter, the second and the ampere. The kilogram, the unit of mass, is equal to the mass of the international prototype of the kilogram kept at the International Bureau of Weights and Measures in France; the meter, the unit of length, is equal to 1,650,763.73 wavelengths (in a vacuum) of the orange light emitted by an atom of krypton 86; the second, the unit of time, is the duration of 9,192,631,770 periods of the radiation corresponding to a certain energy-level difference in the cesium-133 atom; the ampere, the unit of current, is defined as that constant current which, if maintained in two hypothetical conductors arranged in a certain prescribed way, will give rise to a specified force between the two conductors.

In practice everyday working standards of mass, length and time can be constructed that are directly traceable to their fundamental definitions and that have an accuracy comparable to the accuracy implicit in the definition. For example, sets of platinum-iridium masses and quartz length standards can be constructed that approach the few-parts-in-$10^9$ accuracy respectively inherent in the prototype kilogram and the definition of the meter, and various types of quartz-crystal and "atomic" clocks can be made that approach the inherent five-parts-in-$10^{13}$ accuracy of the definition of the second.

This convenient state of affairs is not true of the ampere. Since a current is a flow of charge, it is not easy to construct a storable working current standard. Instead, standards of voltage and resistance must be separately maintained and a standard of current must be derived on the basis of Ohm's law (current equals voltage divided by resistance). Therefore national standards laboratories throughout the world maintain their own system of electrical units by means of groups of a very stable type of battery known as a standard cell and groups of precision wire resistors [*see illustrations on preceding two pages*]. The mean voltage of the cells at the National Bureau of Standards, for example, defines the U.S. as-maintained volt, and the mean resistance of the resistors defines the U.S. as-maintained ohm. Their ratio then defines the U.S. as-maintained ampere.

In terms of as-maintained amperes currents can usually be measured to an accuracy of about one-tenth of a part per million. No experiment has yet been devised, however, that will allow a given current to be determined in absolute units to anything like the accuracy of approximately one part in $10^8$ inherent in the definition of the international or absolute ampere; present current balances (which measure the force between current-carrying coils) can at best give a result accurate to between five and 10 parts per million. This means that the uncertainties in the conversion factors that relate the different as-maintained amperes to the defined absolute ampere are five to 10 parts per million. Since many fundamental-constant experiments require the accurate measurement of a current or a voltage (for example the determinations of $F$, $\gamma_p$ and $e/h$ by means of the Josephson effect), the rather large uncertainty in the conversion factor is of great significance.

Indeed, the conversion factor may be considered equal in importance to the associated fundamental constants, and separate experiments must be undertaken for its determination. The current balance mentioned above is used for just such a determination [*see illustration at left*]. Currents and voltages are almost always measured in terms of as-maintained units and converted to absolute units based on the measured value of the conversion factor. (Surprisingly, however, a somewhat more accurate indirect value for the conversion factor can be obtained by combining low-field and high-field values of $\gamma_p$. The final best value for the conversion factor must then be obtained by averaging this indirect value with the directly determined current-balance value.)



**CURRENT BALANCE, photographed at the National Physical Laboratory in Teddington, England, is used to determine the relation between the British as-maintained ampere and the absolute ampere. This is done by measuring the force between a pair of concentric coils of known dimensions when a current known in terms of the as-maintained ampere flows through the coils. This particular current balance has two sets of concentric coils, so that the force is doubled. The fixed outer coil of the pair at left has been removed to reveal the movable inner coil. The large outer coils are about 12½ inches in diameter.**

## The Least-Squares Stratagem

It should now be clear that information bearing on the value of any specific constant can come from several different experiments. Stated another way, there are many different routes one can follow (both direct and indirect) in order to obtain a value for a particular constant. In general each route will give a slightly different value. The best way to handle such a situation is by a mathematical approach known as the least-squares technique. This method provides a self-consistent procedure for calculating "best" compromise values of the constants from

| | QUANTITY | SYMBOL | YEAR MEASUREMENT WAS REPORTED | METHOD | UNCERTAINTY |
|---|---|---|---|---|---|
| 1 | RATIO OF ELECTRON CHARGE TO PLANCK'S CONSTANT | $e/h$ | 1969 | JOSEPHSON EFFECT | 2.4 |
| 2 | CONVERSION FACTOR RELATING U.S. AS-MAINTAINED AMPERE TO ABSOLUTE AMPERE | K | 1958 | CURRENT BALANCE | 7.7 |
| 3 | SAME | K | 1965 | CURRENT BALANCE | 6 |
| 4 | SAME | K | 1968 | PELLAT ELECTRO-DYNAMOMETER | 9.7 |
| 5 | FARADAY | F | 1960 | SILVER-PERCHLORIC ACID COULOMETER | 6.8 |
| 6 | GYROMAGNETIC RATIO OF PROTON | $\gamma_p$ | 1962 | LOW-FIELD METHOD | 5.8 |
| 7 | SAME | $\gamma_p$ | 1968 | LOW-FIELD METHOD | 3.7 |
| 8 | SAME | $\gamma_p$ | 1966 | HIGH-FIELD METHOD | 7.4 |
| 9 | MAGNETIC MOMENT OF PROTON IN NUCLEAR MAGNETONS | $\mu_p/\mu_n$ | 1951 | OMEGATRON | 11 |
| 10 | SAME | $\mu_p/\mu_n$ | 1961 | CYCLOTRON | 20 |
| 11 | SAME | $\mu_p/\mu_n$ | 1963 | INVERSE CYCLOTRON | 26 |
| 12 | SAME | $\mu_p/\mu_n$ | 1965 | MASS SPECTROMETER | 6.2 |
| 13 | SAME | $\mu_p/\mu_n$ | 1967 | OMEGATRON | 19 |

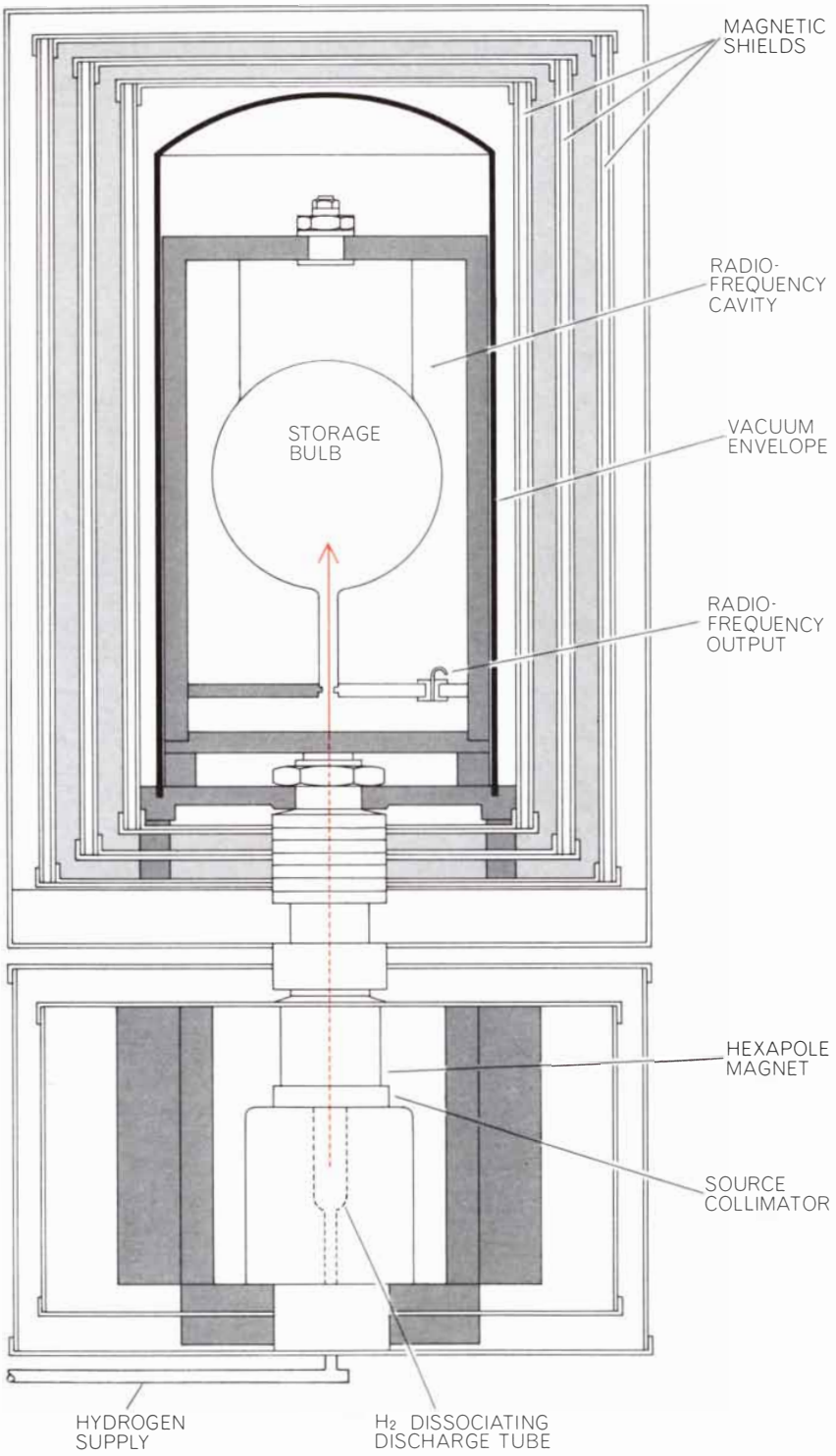
**THIRTEEN PIECES of comparatively imprecise input data are considered for the "least squares" adjustment required to obtain the best values of the pertinent fundamental constants independent of quantum-electrodynamic theory. The "Uncertainty" column gives the uncertainties of the measurements in parts per million. The Pellat electrodynamometer is similar in function to a current balance except that it measures the torque between two coils rather than the force. In the silver-perchloric acid coulometer metallic silver is electrolytically dissolved in a solution of perchloric acid. The different methods used to measure $\mu_p/\mu_n$ are similar in that they all used radio-frequency electromagnetic fields to alter the motion of protons (or other ions) in a fixed magnetic field.**

all the available measurements. For a given set of data it automatically takes into account all the possible routes for obtaining values for each of the constants being calculated. It then determines a single final value for each constant by automatically weighting the values of the constant obtained from the various routes according to their relative reliability or uncertainty. The uncertainty for each route is determined from the uncertainties of the individual measurements comprising the original set of data. Least-squares studies of the constants were pioneered by R. T. Birge of the University of California at Berkeley in the late 1920's and were continued by him into the mid-1940's. Similar studies have been continued to the present by a number of workers, including Jesse W. M. DuMond and E. Richard Cohen of the California Institute of Technology and North American Rockwell respectively, and J. A. Bearden, H. M. Watts and John S. Thomsen of Johns Hopkins University. The most recent critical analysis and least-squares adjustment of the constants were carried out by the present authors in 1969. Since the application of the least-squares technique to the fundamental constants is the backbone of the field, we shall now discuss it in more detail.

A least-squares adjustment of the fundamental constants is generally carried out by first dividing the available measurements into two groups. One group, known as the auxiliary constants, consists of quantities that have uncertainties small enough for them to be considered as being exactly known. Examples are the Rydberg constant ($R_\infty$), which has an uncertainty of a tenth of a part per million, and the velocity of light ($c$), which has an uncertainty of three tenths of a part per million. The other group consists of the more imprecise input data. Examples of these are $e/h$, with its uncertainty of 2.4 parts per million, and $\gamma_p$, with its uncertainty of approximately four parts per million.

Next a subset of constants is chosen in terms of which all the comparatively imprecise input data can be individually expressed, if necessary, with the aid of the auxiliary constants. The constants comprising this subset are the ones that are directly subject to adjustment; they are accordingly termed the adjustable constants. In the adjustment carried out by the authors in 1969 the adjustable constants were taken to be the fine-structure constant ($\alpha$), the unit of charge ($e$), the conversion factor ($K$) equal to the ratio of the U.S. as-maintained ampere to the absolute ampere, and the Avogadro number ($N$). With just these four quantities and the aid of the auxiliary constants a set of equations was formed for all the imprecise input data, with each equation containing only one datum as required by the least-squares procedure [*see illustration above*]. It should be kept in mind that all the imprecise input data in this table were obtained without any essential resort to quantum-electrodynamic theory. As a consequence the resulting value of $\alpha$ (which is determined primarily by the Josephson-effect measurement of $e/h$) can be used to compare quantum-electrodynamic theory and experiment unambiguously.

Once all the appropriate equations are formed and actual numbers are substituted for the auxiliary constants and the imprecise data, it is a rather straightforward procedure (with the aid of a com-




**HYDROGEN MASER** is used to measure the hyperfine splitting of the lowest energy level of the hydrogen atom. The hydrogen atoms are generated by a radio-frequency discharge (*bottom*) and pass through a collimator and a hexapole magnet that serves to put many of them in particular energy states. The atoms then enter a Teflon-lined quartz storage bulb inside a radio-frequency cavity (*top*). They stay in the bulb for nearly a second, with some of them changing their energy states and radiating at the hyperfine-splitting frequency. Sustained maser oscillations take place when sufficient power is radiated to overcome energy losses in the radio-frequency tuned cavity. Measuring the frequency of this radiation gives the hyperfine splitting. Since this splitting is sensitive to magnetic fields, the storage bulb and cavity must be shielded from the earth's magnetic field. The temperature must also be controlled so that the cavity stays tuned to the hyperfine-splitting frequency.

puter) to solve the equations for the least-squares-adjusted values of the four adjustable constants: $\alpha$, $e$, $K$ and $N$. Although numerical values (with uncertainties) for these four quantities are the sole product of the adjustment, optimum values for all the constants are actually obtained, since any constant not chosen for direct adjustment can readily be calculated from appropriate combinations of those constants subject to the adjustment. Thus the mass of the electron can be obtained from the equation $m_e = 4\pi R_\infty e^2/\alpha^3 c^2$, the faraday from the equation $F = Ne$ and Planck's constant from the equation $h = 2\pi e^2/\alpha c$.

## Uncertainty and Other Problems

The most difficult task in carrying out a least-squares adjustment of the constants is to analyze the input data critically in order to decide what uncertainty should be assigned to each measurement. This step is of the utmost importance, since the weight any given experiment carries in an adjustment is proportional to the reciprocal of the square of its uncertainty. Thus if one measurement of a particular quantity has half the uncertainty of another, it carries four times as much weight. One reason for the uncertainty problem is that in most experiments enough data are taken to reduce the random, or statistical, uncertainty to negligible amounts, and the final uncertainty assigned to the measurement is determined from estimates of the systematic uncertainties. These uncertainties arise from effects about which the experimenter knows little; their estimation is somewhat subjective and hence they are usually obtained from what can only be called educated guesses. An example might be the effect of a change in room temperature on a measurement, or the uncertainty in a known correction that must be applied to a particular experiment.

An equally important factor contributing to the uncertainty problem is the fact that different experimenters approach the estimation of systematic uncertainty with completely different philosophies. Some cautiously assign unreasonably large uncertainties so that a later measurement will not prove their work to have been incorrect. Others tend to underestimate the sources of systematic uncertainty in their experiment, perhaps from an unconscious (or conscious) desire to have done the "best experiment." Such variations in attitude, although out of keeping with scientific objectivity, are nevertheless unavoidable as long as scientists are also human beings. It results,

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# Karsh on Karsh on Polaroid Land Film

Yousuf Karsh, famous for his photographic portraits of the world's great (7 have been used on postage stamps), is also a prolific author. He is the recipient of numerous awards and honorary degrees, and his photographic work is represented in museums throughout the world.

"Ravi Shankar's mastery of his ancient Indian instrument, the sitar, has opened the ears of the world to the traditional music—the raga—of his native country.

Shankar is a dedicated artist, a gifted teacher, and a spirited conversationalist.

I felt that his expressive face, immersed in the intricate harmonic traceries of his music, would make him an exotic subject for Polaroid's Polacolor film.

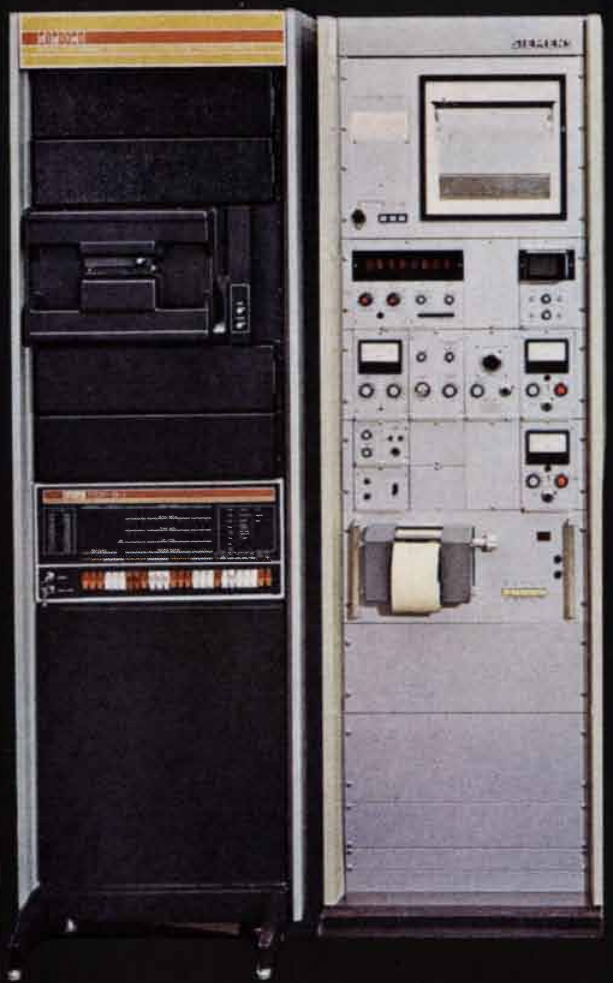
Its muted hues have a symphonic quality—a perfect orchestration of color tones. The subtlety of Shankar's music and the subtlety of this film seemed to complement each other.

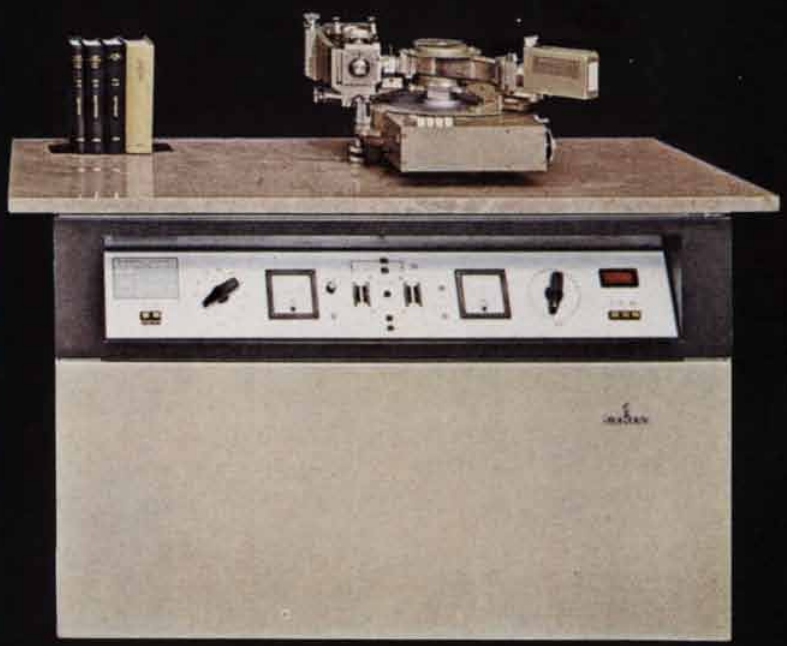
I have written: 'There is a brief moment when all that a man is may be reflected through his eyes, his hands, his attitude. I look for a quality I know exists in the personality before me—a quality I call the "inward power."'

With Polaroid Land color film, I could see immediately the portrait I had already envisaged in my mind's eye—a confirmation of the blending of Polaroid's Western technology and Shankar's artistic Eastern mystique.

In this case, East did indeed meet West."

SIEMENS





# Siemens

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X-ray spectrometry is one of the most important tools used in modern production control systems.

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The production control system could be programmed to handle only a few sample types. It wasn't accurate enough for many processes. Nor was it flexible enough to cope with the frequent changes necessary in the processes it was supposed to control.

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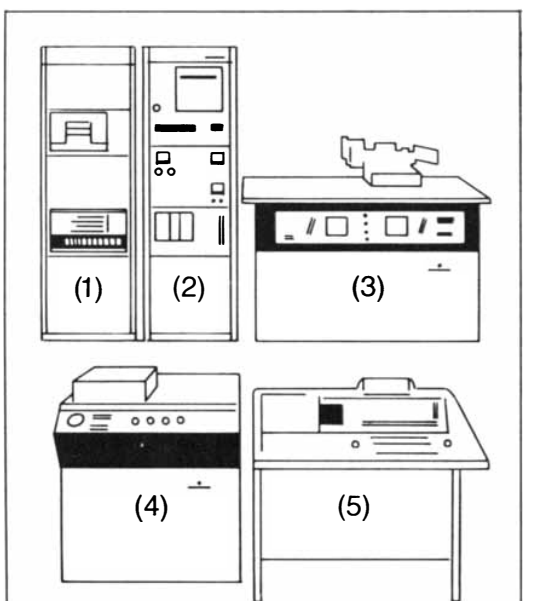
The Siemens automated sequential X-ray spectrometer system bridges this gap. It combines the versatility demanded of a laboratory unit with the speed and accuracy demanded of a production control system.

The automated X-ray spectrometer can handle up to 10 samples in each run. (Solids, liquids or powders.) Each sample can be analyzed for up to 128 element/matrix combinations.

An important feature is the asymmetrically located target in the X-ray tube. This feature makes the "target-to-sample" distance of Siemens equipment the shortest in its field. It's one reason why Siemens X-ray spectrometers have the lowest detection limits, from uranium (atomic no. 92) all the way down to fluorine (atomic no. 9).

In spite of its sensitivity, a Siemens automated X-ray spectrometer can be operated by production or laboratory personnel with no special technical training.




Basic components include (1) Digital computer. (2) Electronic panel. (3) X-ray generator. (4) Sequential spectrometer. (5) Teletypewriter.

After samples are placed in the unit, operation is rapid and completely automatic. Analytical results are printed out by the teletypewriter in percent concentration for each element in each matrix.

The base price of a system is $75,000. For complete details and a list of users of Siemens X-ray spectrometers in the U.S., write to Mr. Dieter Meusel at Siemens, 186 Wood Avenue South, Iselin, N.J. 08830.

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however, in quoted uncertainties for different experiments that cannot be compared in a straightforward manner.

To circumvent these difficulties the conscientious constants-adjuster must get in touch with the experimenters themselves and go behind the scenes in order to find out what really was done. Only then can the adjuster have any real confidence in the output values of his adjustment. Rarely can sufficient information for the reliable assessment of an experiment be obtained from the experimenter's published report.

Another difficult problem associated with constants-adjusting is deciding what to do with discrepant data, that is, measurements for which the assigned uncertainty seems to be correct but that differ from one another "more than they should." An example of such discrepant data in our 1969 adjustment is the five different measurements of the magnetic moment of the proton ($\mu_p/\mu_n$) [*see illustration on page 69*]. Two values were high and agreed with each other; two values were low and agreed with each other. The difference between the weighted means of the two groups was so large, however, that it had a statistical probability of occurring by chance of only one in 400. (The fifth value was right in the middle, but its error was large enough so that it was not in disagreement with either group.)

The data were reexamined to see if some explanation for the discrepancy could be found. It was concluded that one of the high values was sufficiently suspect on experimental grounds that it could probably not be trusted, and that not enough information was available concerning the other high value to warrant its inclusion in the adjustment. Additional support for the two low values also came from an indirect value calculated from the direct measurements of $F$ and $\gamma_p$. The two high values were therefore discarded in favor of the other three. As Murphy's law predicts, however, if there is any possibility that such a choice can be wrong, it most certainly will be wrong. More recent information and measurements seem to be indicating that the high values of $\mu_p/\mu_n$ are more correct, not the low values! Further experiments will be needed to resolve the discrepancy. (Fortunately this problem has no effect on $\alpha$.)

As a matter of fact, the value of $\alpha$ resulting from the Josephson-effect measurement of $e/h$ directly (that is, the value before being adjusted by reference to quantum-electrodynamic theory) has solved a similar difficulty associated with recent values of $\alpha$ and a problem in quantum electrodynamics as well. The result of the adjustment is that $\alpha^{-1}$ equals 137.03608, with an uncertainty of $\pm.00026$ (equivalent to $\pm 1.9$ parts per million). (The reciprocal, or inverse of $\alpha$, $\alpha^{-1}$, is given rather than $\alpha$ because it is a simpler number to look at and remember.) Prior to the Josephson-effect measurement of $e/h$ the accepted value of $\alpha^{-1}$ was $137.0388 \pm .0006$ ($\pm 4.4$ parts per million). The two values are in clear disagreement: their difference exceeds their combined uncertainty by more than four times. The probability of this happening by chance is less than one in 15,000.

The previously accepted value of $\alpha$ was obtained by combining an experimental measurement of a certain energy-level difference in the deuterium atom known as the fine-structure splitting with a theoretical equation for the splitting. (The deuterium atom is similar to the hydrogen atom in that it has only one orbital electron, but its nucleus contains a proton and a neutron, not just a proton.) This approach is possible because the theoretical equation contains only accurately known auxiliary constants and $\alpha$. The deuterium value of $\alpha$ was adopted by Cohen and DuMond for inclusion as an input datum for their 1963 adjustment and therefore played a major role in determining the accepted values of the other constants of interest such as $e$ and $m_e$. It also led during the mid-1960's to what was termed at the time one of the major unsolved problems of quantum electrodynamics.

The problem concerned an apparent discrepancy between the theoretically calculated and experimentally measured values for another energy-level difference in the hydrogen atom known as the hyperfine splitting. The hyperfine splitting is the difference in energy between a hydrogen atom in which the spin of the orbital electron is in the same direction as that of the central proton and a hydrogen atom in which the spins of the electron and proton are in opposite directions. It can be measured to the phenomenal accuracy of about one part in a trillion by means of the hydrogen maser

| NAME OF CONSTANT | SYMBOL | UNITS | VALUE 1969 ADJUSTMENT | UNCERTAINTY | VALUE 1963 ADJUSTMENT | UNCERTAINTY | CHANGE |
|---|---|---|---|---|---|---|---|
| INVERSE OF FINE-STRUCTURE CONSTANT | $\alpha^{-1}$ | | 137 03602(21) | 1.5 | 137.0338(6) | 4.4 | −20 |
| CHARGE OF THE ELECTRON | e | $10^{-19}$ COULOMB | 1.6021917(70) | 4.4 | 1.60210(2) | 12 | +57 |
| PLANCK'S CONSTANT | h | $10^{-34}$ JOULE-SECOND | 6.626196(50) | 7.6 | 6.62559(16) | 24 | +91 |
| MASS OF ELECTRON | $m_e$ | $10^{-31}$ KILOGRAM | 9.109558(54) | 6 | 9.10908(13) | 14 | +52 |
| AVOGADRO'S NUMBER | N | $10^{26}$ PER KILOMOLE | 6.022169(40) | 6.6 | 6.02252(9) | 15 | −58 |

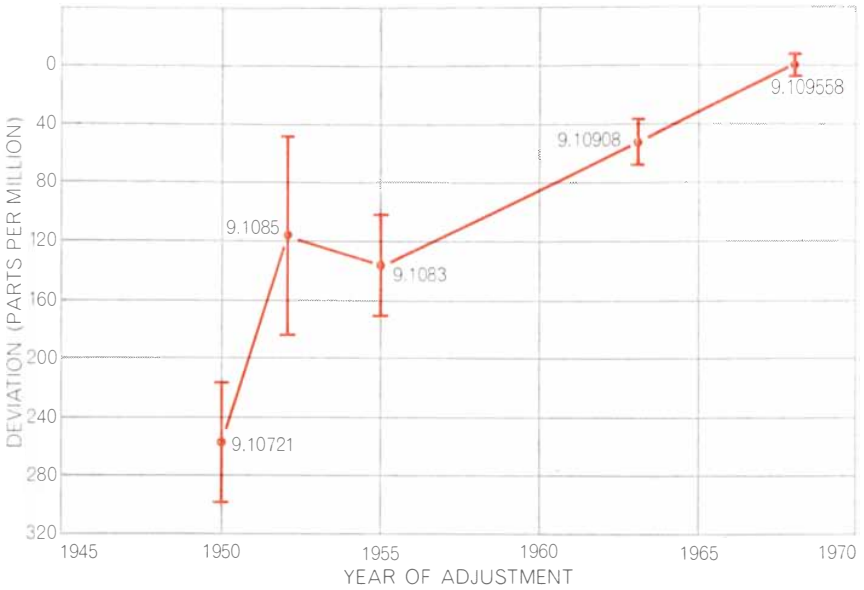
**NEW VALUES of five important physical constants resulting from the authors' 1969 adjustment based on their redetermination of $e/h$ are compared in this table with the corresponding values resulting from the 1963 adjustment of E. Richard Cohen of North American Rockwell and Jesse W. M. DuMond of the California Institute of Technology. The last column gives the differences between the two sets of values in parts per million. Changes in the values range from three to five times the uncertainties of the 1963 values.**

[*see illustration on page 70*]. The theoretical equation for the hydrogen hyperfine splitting obtained from quantum-electrodynamic theory involves only auxiliary constants and $\alpha$, but it is limited to an accuracy of a few parts per million because of the difficulty in calculating from theory some of the terms in the equation.

One such term is called the proton polarizability correction ($\delta_N$). This correction arises from the fact that the proton in the hydrogen atom cannot be regarded as simply a charged spinning ball. The proton has an internal structure of its own and can be excited to different energy states. The existence of these states affects the magnitude of the hyperfine splitting. So far, however, all calculations of $\delta_N$ show it to be rather small—one or two parts per million at most.

The small size of the theoretical value for $\delta_N$ is in marked contrast to what is implied by the deuterium value of $\alpha$. If this value of $\alpha$ is used to calculate a theoretical value for the hydrogen hyperfine splitting, and if the latter is then compared with the experimental hydrogen-maser value of the hyperfine splitting, and if their difference is assumed to arise solely from the existence of a polarizability correction, then it is found that $\delta_N = 43 \pm 9$ parts per million. This means that the probability of $\delta_N$'s being as small as predicted by theory, that is, one or two parts per million, is only one chance in 20,000. The discrepancy and the resulting challenge to quantum electrodynamics are clear. On the other hand, an entirely different picture emerges if one uses the value of $\alpha$ obtained from the Josephson-effect measurement of $e/h$. In this case it is found that $\delta_N$ equals $2.5 \pm 4$ parts per million, which is quite consistent with what is predicted theoretically. Thus the Josephson-effect value of $\alpha$ removes the discrepancy and the challenge to quantum electrodynamics. (We should add that recent measurements of the fine-structure splitting in hydrogen strongly support the Josephson-effect value. The source of the error in the deuterium fine-structure measurements that this implies has yet to be established.)

The above case is an excellent example of how fundamental-constants experiments carried out in one field of physics can have important implications for other fields. In particular it has been shown how a low-temperature solid-state physics experiment can give information about the excited, or higher-energy, states of the proton. This is a subject usually associated with the field of high-energy physics, the study of the properties and interactions of the elementary particles. One could not imagine two areas of physics further removed from each other. (Before the Josephson-effect measurement of $e/h$ the idea that a reliable value for a fundamental constant could be obtained from a complex solid with its $10^{22}$ interacting atoms would have been considered absurd.) It is therefore a good example of the overall unity of physics and of the important role that can be played by highly accurate measurements of the fundamental constants in illuminating apparent inconsistencies in our physical description of nature.




**VARIATION IN ACCEPTED VALUE** of the mass of the electron ($m_e$) is evident in this graph, which presents the results of the least-squares adjustments of the constants made in the years indicated. The actual quantity plotted is the parts-per-million deviation from the authors' 1969 adjusted value (*top right*). The actual values of $m_e$ resulting from the various adjustments are also given (in units of $10^{-34}$ kilogram). The vertical bars correspond to plus and minus the assigned uncertainty. The striking changes in the value of $m_e$ from one adjustment to another illustrate the close relations that exist among the constants; a large shift in the value of one will generally cause significant shifts in the values of others.

## A Final Adjustment

We now turn to the matter of obtaining a final best set of fundamental constants from all the available data, not merely measurements that do not require quantum electrodynamics for their analysis. In principle such a set may be readily found by combining the most reliable quantum-electrodynamic data with the nonquantum-electrodynamic data formerly used and carrying out a new least-squares adjustment. This was in fact done in the authors' 1969 work but not without some difficulty. The reason for this difficulty was that most of the quantum-electrodynamic data, which consisted of several values of the fine-structure constant derived from appropriate theoretical equations and measurements, were either of large uncertainty, inconsistent among themselves or of questionable reliability both experimentally and theoretically. After a careful and detailed analysis of the situation it was decided that one value of $\alpha$ was sufficiently reliable for it to be included in the final adjustment, namely the value derived from the theoretical equation and the experimental determination of the hyperfine splitting in hydrogen.

The resulting values of this final adjustment for some of the more important constants are given in the illustration on the opposite page along with the previously accepted best values resulting from the 1963 adjustment by Cohen and DuMond. It is evident from the table that the values have changed by several times the uncertainties assigned the old values and that the uncertainties resulting from the 1969 adjustment are significantly less than the corresponding uncertainties given by the 1963 adjustment. These changes are mainly due to the values of $\alpha$ implied by the Josephson-effect measurement of $e/h$ and the hydrogen hyperfine splitting. They are larger in magnitude and have smaller uncertainties than the value of $\alpha$ derived from the measurement of the fine-structure splitting in deuterium and used by Cohen and DuMond in their 1963 ad-

justment. The changes serve as a good example of the close relations that exist among the fundamental constants: a significant shift in the value of one constant will generally cause important shifts in the values of others.

It is also of interest to see how our knowledge of the fundamental constants has changed over the years. The variation of the accepted value of the electron mass ($m_e$), resulting from several different adjustments carried out since 1950, is a typical example [*see illustration on preceding page*]. This illustration graphically demonstrates the fact that no set of fundamental constants should be taken as the gospel truth. Although we may hope that the 1969 adjustment brings us closer to that truth, realism compels us to recognize that further significant changes in our knowledge of the numerical values of the constants may in fact take place. Goethe might well have been speaking of this when he wrote: "*Es irrt der Mensch, solang er strebt*" ("Men will always be making mistakes as long as they are striving after something"). In any event it should be borne in mind that it is this striving to make ever more accurate measurements that is the cornerstone of physics: many important advances in the field have involved high-precision measurements centered around the fundamental constants.

What of the future? Can measurements be continually refined and improved so that more and more accurate values of the constants can be obtained? Can theories also be further refined so that they may benefit from the improved values of the constants, so that more critical comparisons between theory and experiment can be made? The answer to this question is most certainly yes. There seems to be a general rule that a new effect will be discovered or a new advance in experimental technique or theory will be made just when previous methods are being pushed to their limits. There is no reason to believe this will not continue. Indeed, there are now under way in several laboratories experiments in which attempts are being made to harness the unique properties of superconductors to measure other constants besides $e/h$. New experiments involving X-ray techniques also promise to provide more accurate values for several different constants. If this work succeeds, two entirely new sources of information on the constants will have become available. The future of constants-adjusting seems assured as long as there are enough scientists around for whom the "romance of the next decimal place" is true love.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MECHANISM OF RENEWAL of visual cells is evident in an electron-microscope autoradiogram of cells from the retina of a frog. The darker areas at left and upper right are parts of the outer segments of rods, and between them is the entire outer segment of a cone. New protein, labeled by the injection of radioactive amino acids, appears as black dots. In the rods most of it has been built into new disks that are assembled at the base of the outer segment. In the cone it has not accumulated at the base, indicating that there has been no formation of new disks and that the new protein is diffusing through the cell. The enlargement is 19,500 diameters.

# VISUAL CELLS

## The rod and cone cells are exquisitely sensitive, yet they are also durable. It turns out that rods steadily regenerate the thin disks containing visual pigment. Cones renew themselves in another way

by Richard W. Young

The visual cells in the retina of the eye play an indispensable part in the process of vision: they detect light. Working together with other cells in the retina and the brain, they participate in a process so successful that our eyes are sensitive enough to detect a single quantum of light and so versatile that we can re-create in our minds a three-dimensional, colored moving picture of the changing world around us.

The visual cells unfortunately pay a price for their exquisite specialization. They are vulnerable to damage from a wide variety of causes. If the retina becomes detached from the adjoining tissue, the cells immediately begin to degenerate. They are readily destroyed by heat. Such damage can result when the eye is exposed to the direct rays of the sun. (Galileo suffered an eye injury from looking at the sun through his telescope, and many people have been partly blinded by watching a solar eclipse.) We now have evidence that light energy alone, without heat, can also damage or kill the visual cells.

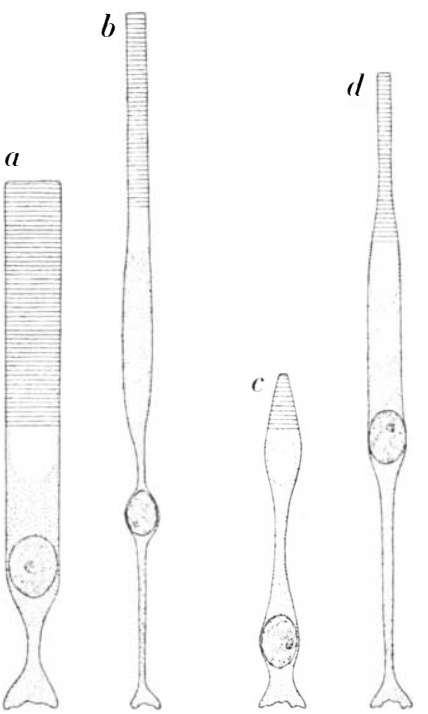
If these cells are so delicate as to be injured by an overdose of the very energy they are designed to detect, how is it that we do not all gradually go blind from a progressive accumulation of injuries to the visual cells? The decline of vision in old age, when it occurs, is usually due to impairment of other parts of the eye rather than to failure of the visual cells. Recent studies have disclosed an explanation of their durability. It turns out that the visual cells are endowed with a built-in system for self-renewal.

The visual cells, which are also called photoreceptor cells, are arranged in a single layer on the back of the retina, which coats the inner posterior surface of the eye. The form of these cells is itself extraordinary. The visual cell is a long, slender structure composed of several specialized compartments [*see illustration on page 83*]. At the end pointing away from the lens of the eye there is an "outer segment" that performs the cell's key function: trapping the light that arrives at the retina. The outer segment is made up of hundreds of disks piled like a stack of poker chips. These thin disks (a stack of a million of them would be less than an inch high) contain the molecules of visual pigment, which detect the presence of light by absorbing it. About 125 million visual cells are packed side by side in the human retina. The large number of cells concentrated in a small area provides detailed resolution of the image projected on the retina.

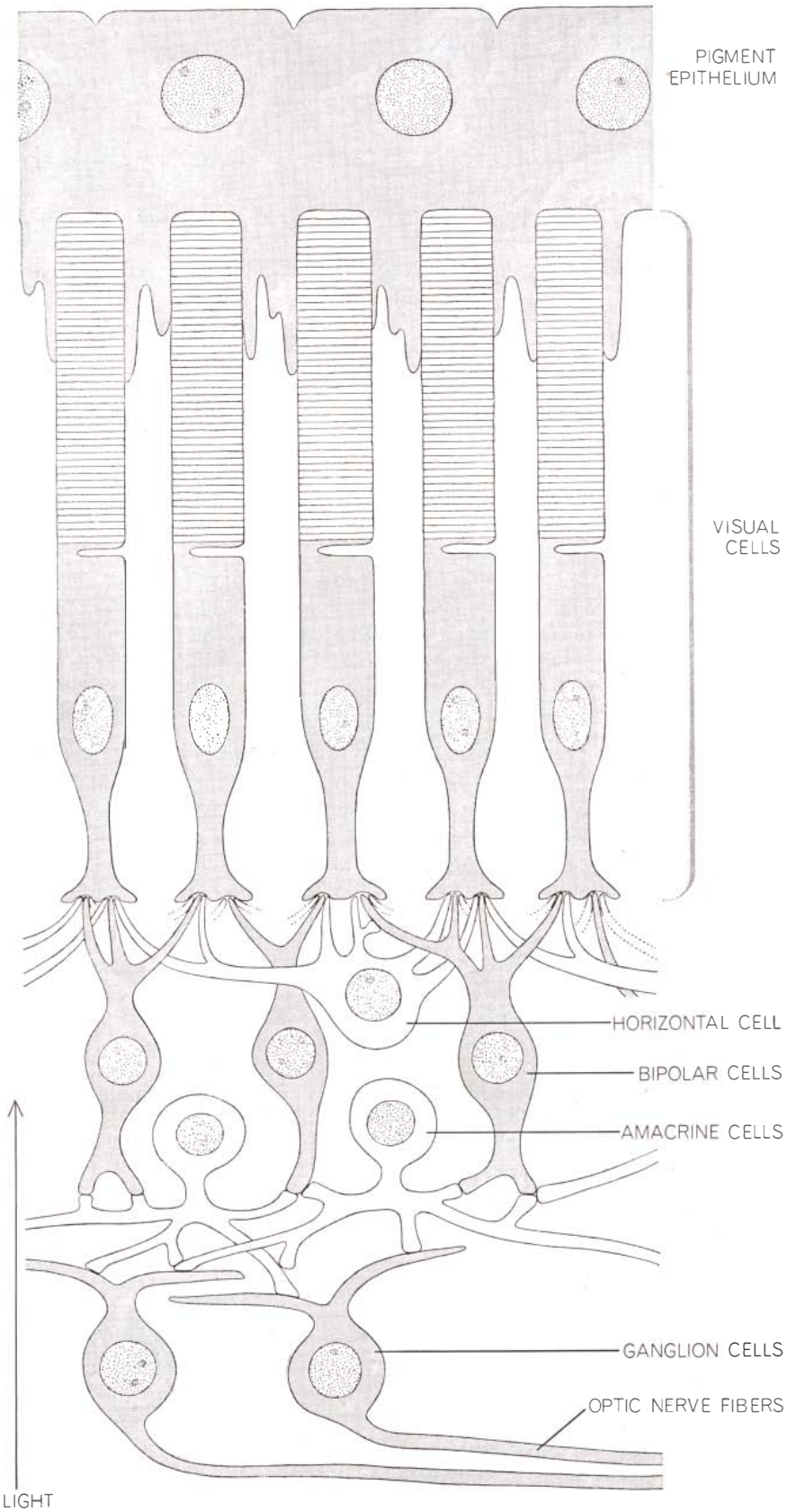
The outer segment is connected to the rest of the cell by an extremely narrow stalk, so small in diameter that its existence was not even suspected until it was discovered with the electron microscope. As we shall see, this modified cilium serves to convey materials from the main body of the cell to the outer segment. Massed near the end of the cilium in the inner segment is a dense cluster of mitochondria: the particles that supply the cell's fuel. Beyond this is a zone containing ribosomes and the Golgi complex, which constitute the cell's machinery for manufacturing proteins and complex carbohydrates.

The last segment of the cell closely resembles a nerve fiber, both in structure and in function. The nucleus, containing the genetic material, is located in the fiber or at its junction with the inner segment. The fiber ends in a synaptic body to which other types of cell are attached. At this site the visual message, coded in the form of a moving electrical disturbance, is passed on for further processing in the retina and ultimate transmission to the visual centers of the brain.

Investigators dissecting the operations of the visual cell have traced the outlines of the complex process by which the cell converts absorbed light into an electrical signal. The process begins with the absorption of the incident light by the visual pigments in the disks. These pigments consist of a combination of vitamin A aldehyde, known as retinal (formerly called retinene), with a protein of




**ROD AND CONE CELLS are similarly organized in all vertebrate animals. At left are typical rod cells from the retina of the frog (*a*) and man (*b*). At right are cone cells from the retina of the frog (*c*) and man (*d*).**




**CELL RELATIONS** in the retina are depicted schematically. Light passes through most of the layers of the retina before it reaches the visual cells (*top*). When they are stimulated by light, they pass the excitation on to the bipolar cells, which in turn relay the signal to the ganglion cells. The axons of the ganglion cells are collected together to form the optic nerve, which transmits signals to the brain. The horizontal and amacrine cells participate in the synapses, or junctions, between the other three types of cell in the retinal system.

the class called opsins. Because of the difficulty of isolating these pigments chemically, little was known about their detailed composition until recently. Joram Heller, working at the Jules Stein Eye Institute of the University of California at Los Angeles, has now succeeded in extracting a highly purified visual pigment (from cattle, rat and frog retinas). It proved to be a very insoluble protein with one retinal group per molecule, a carbohydrate side chain, little or no phospholipid and a molecular weight of about 27,000.

George Wald and his co-workers at Harvard University have shown that retinal, when combined with opsin, exists in a bent and twisted form (described as 11-*cis*). When the pigment molecule absorbs a quantum of light, the retinal changes its shape to a straight-chain form (all-*trans*). This apparently breaks the relation between the retinal and the opsin, and the protein then undergoes a series of physical rearrangements. Somehow the change of shape almost instantaneously (within 25 millionths of a second) produces a state of excitation in the cell, involving a change of electric potential. This is followed immediately by a second, enormously amplified potential that is probably associated with the transmission of the signal along the visual-cell fiber to the synaptic body. The entire sequence of events, from the absorption of light by the visual pigment to the relay of a nerve signal at the synaptic body, takes place in about two thousandths of a second.

Meanwhile the cell is recombining retinal and opsin in the light-absorbing shape of the pigment molecule. The cell is capable of reconstituting the pigment at the rate of thousands of molecules per second; this accounts for the ability of the retina to absorb and respond continuously, even in bright light.

The visual cells of all vertebrate animals are organized in a similar fashion, but we are able to distinguish two distinctive types of photoreceptor, the rods and cones, so named because of differences in the shape of their outer segments. Rod outer segments are cylindrical; all the disks have the same diameter. Cone outer segments are conical; the disks at the bottom of the stack are progressively larger than those at the top.

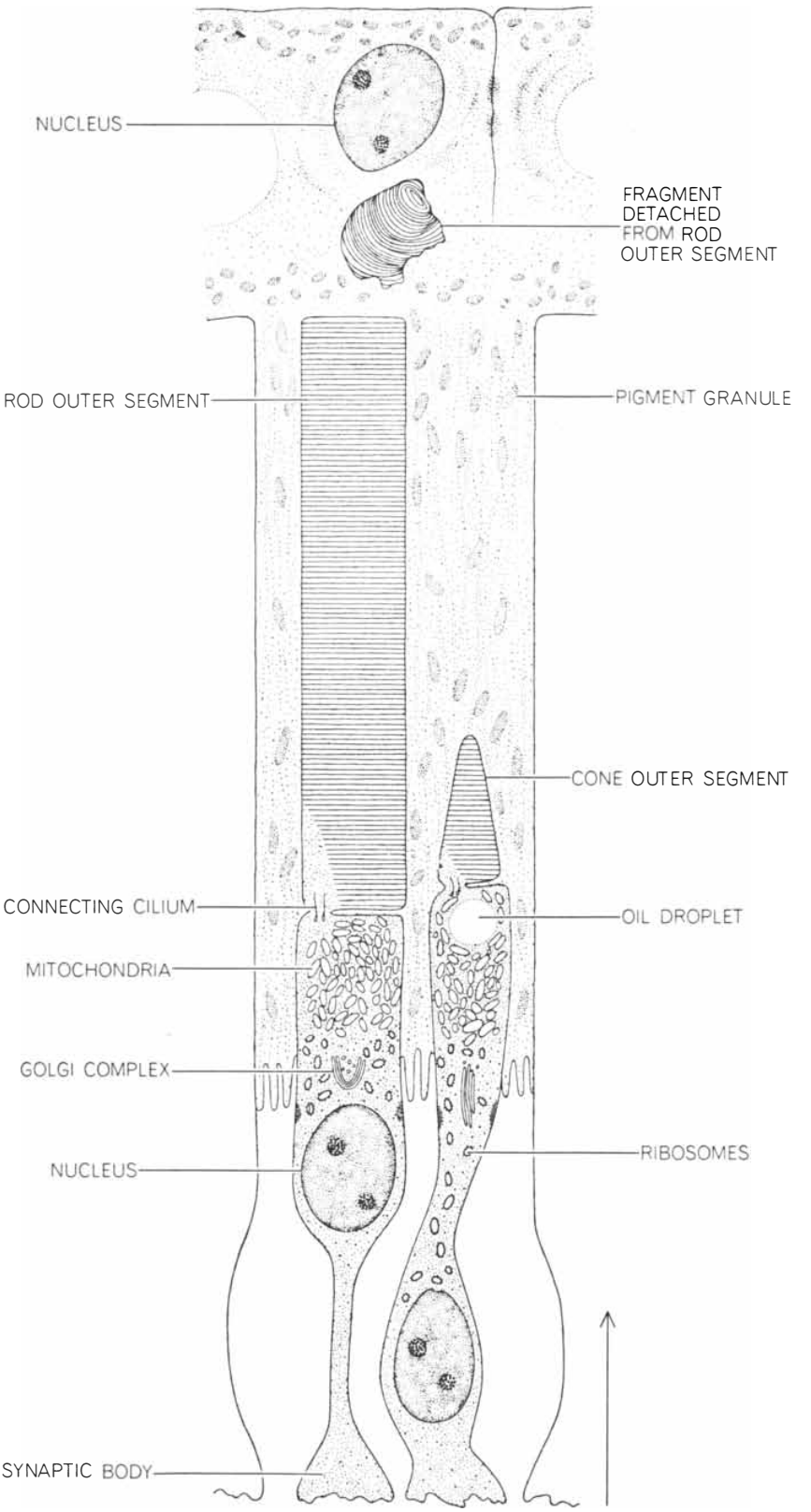
It was a German anatomist, Max Schultze, who a century ago first observed that animals active at night, such as rats and mice, have many rods and a few or no cones in their retinas, whereas the retinas of animals that are active

only in daylight consist mainly of cones and sometimes lack rods entirely. He concluded that rods are highly sensitive and function when the light is dim, whereas cones are stimulated only by relatively bright light. Schultze not only discovered the respective roles of the rods and cones in night and day vision but also surmised that color vision depends entirely on the cones. We now know that this is certainly true of the human eye. In dim light, when only the rods are stimulated, we are unable to discriminate colors: the world presents itself in shades of gray. The dependence of color vision on the cones seems to hold generally for the vertebrates. Like man, other animals that clearly possess color vision (bony fishes, birds and primates) have an abundance of cones in their retina. On the other hand, animals whose retina is dominated by rods (notably cats and cattle) are color-blind. (The bull sees the matador's cape but cannot perceive that it is red.)

Color perception is based on the presence of a variety of pigments in the cone cells [see "Three-Pigment Color Vision," by Edward F. MacNichol, Jr.; SCIENTIFIC AMERICAN, December, 1964]. In the human retina there are three types of cone, containing specific pigments that absorb light maximally at the red, blue or green wavelengths; other colors are perceived as a result of the blending of impulses from the three cone types. In contrast, rod cells have only one pigment (rhodopsin); it absorbs light of various wavelengths, although most efficiently in the blue-green. All the wavelengths produce the same excitation of the cell, so that no color discrimination is possible. As we shall see, the rod cells and cone cells also differ strikingly in the way they renew themselves.

How the visual cells manage to maintain their light-detecting efficiency throughout life is one of the principal questions we are exploring in my laboratory at the Jules Stein Institute. For several years we have been investigating renewal processes in the photoreceptor cells of vertebrate animals by means of tracer experiments with radioactive isotopes.

As highly specialized cells, the photoreceptors are incapable of division; hence they do not need to reproduce their genetic material (DNA), which is stable in cells that do not divide. It was therefore no surprise to find that when we supplied the cells with radioactively labeled precursors for the synthesis of DNA, autoradiograms showed that no new DNA was formed from the material. A similar




**METABOLIC MACHINERY of visual cells is compartmentalized. In the frog's retina the rod (*left*) and the cone (*right*) are oriented parallel to the path of light (*arrow*), which passes through the transparent parts of the cell and is absorbed by pigment molecules in the disk-shaped membranes of the outer segment. The visual message is transmitted back along the cell to the synaptic body and thence to other retinal cells. Mitochondria supply cell's fuel; ribosomes and Golgi complex manufacture proteins and complex carbohydrates.**

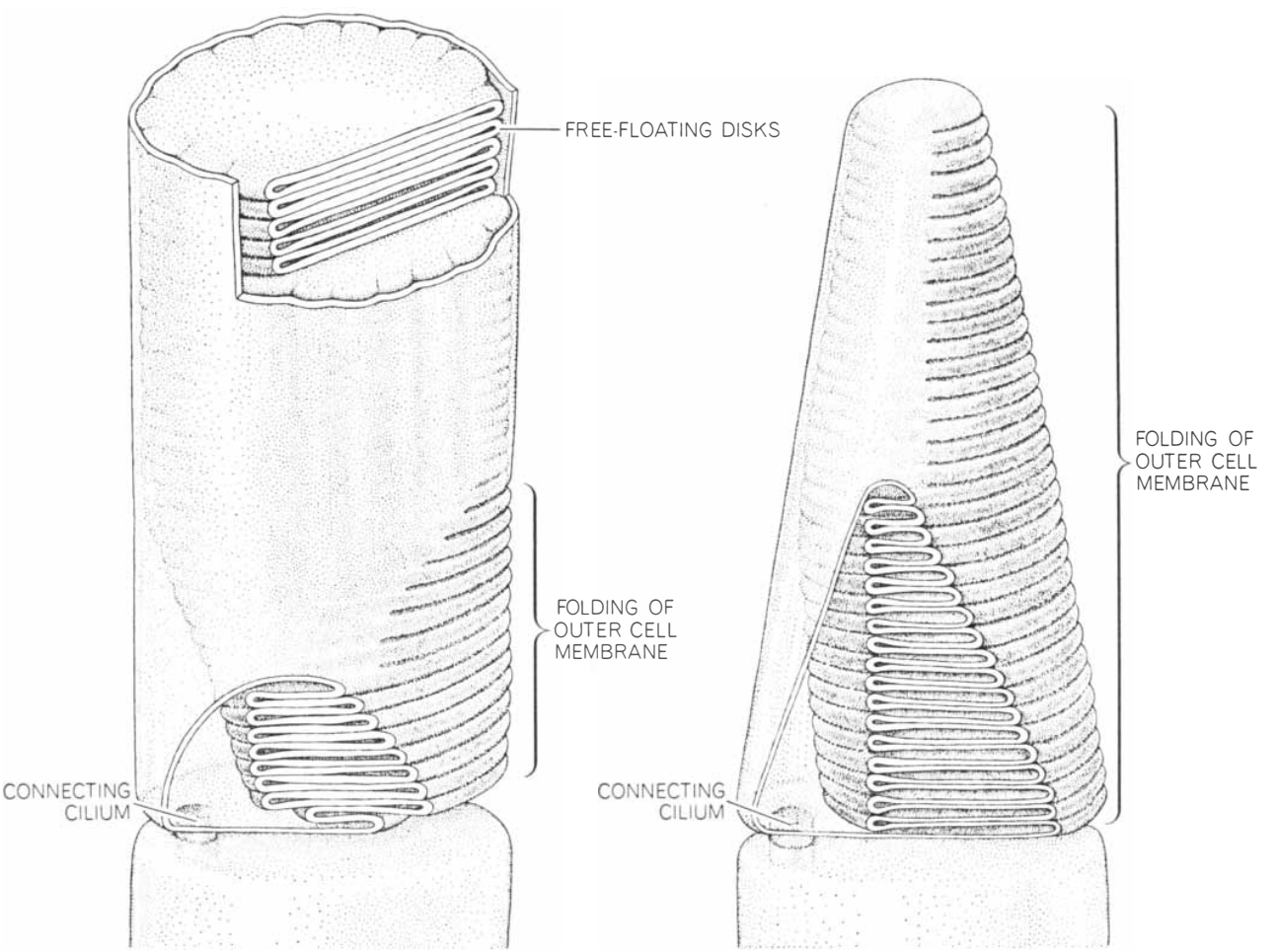
experiment in supplying precursor material for the production of RNA, however, showed that new RNA was constantly being produced by the cells. Dean Bok of the Jules Stein Institute found that the visual cells used the labeled material to synthesize RNA in the cell nuclei. The labeled RNA then moved out of the nucleus to the ribosome-containing region of the cell's inner segment, where proteins are synthesized.

In 1963 Bernard Droz, then at McGill University, reported that in studies of the rod cells of rats and mice he had found that much of the protein formed in the inner segment of these cells later migrates to the outer segment. This was the first indication that protein in the visual cells' outer segment is continually replaced. Further experiments in my laboratory revealed a most surprising additional fact. On moving into the rod cell's outer segment, the newly formed protein at first is concentrated in a thin layer at the base of the segment's cylindrical structure. I was fascinated to observe that this band of labeled protein then gradually moved along the segment until it reached the tip of the rod. (In rats and mice it took about 10 days for the band to arrive at the tip; in frogs, more than seven weeks.) Then, after arriving at the end of the rod, the band of labeled protein abruptly disappeared!

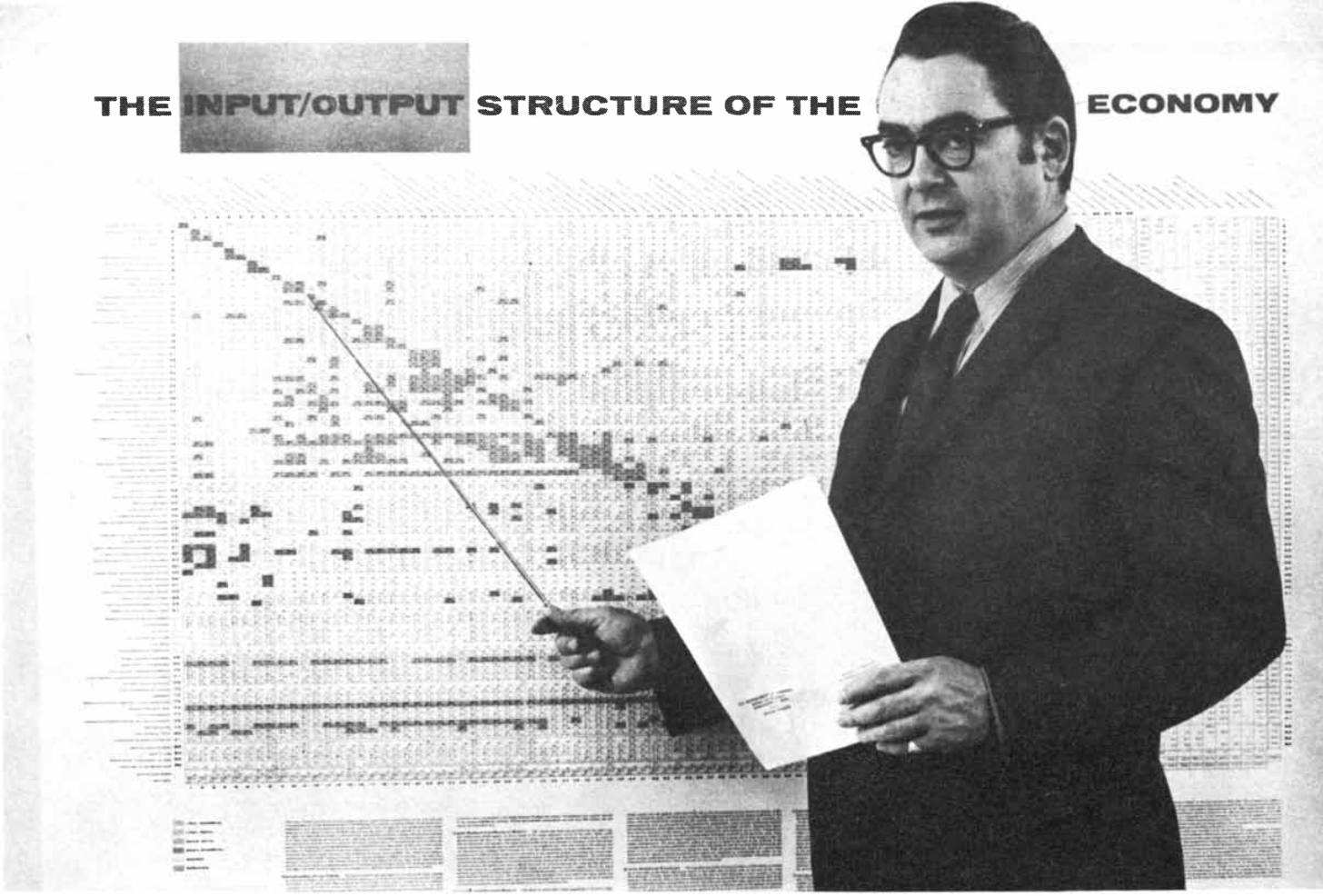
How did the protein move along the stack of disks making up the outer segment? Did it simply migrate by diffusion through the disks? This seemed unlikely. Proteins are large molecules, and the tightly packed disks constitute a rather dense barrier. Besides, diffusion would disperse the protein instead of holding it in a narrow band. When we made two separate injections of labeled material into the cell, with a time interval between them, two distinctly separate layers of radioactive protein later traveled along the segment one after the other.

It became clear that the layers represented disks, and that new disks were continually formed at the base of the rod cell's outer segment. As each disk, incorporating protein arriving from the inner segment, was assembled at the base, it pushed the others toward the tip of the rod, where the old ones were somehow disposed of so that the rod did not grow in length.

What happens to these vanishing disks? With autoradiography and the electron microscope Bok and I examined the rod photoreceptor cells in frogs just as the labeled disks reached the ends of the outer segments. We found that when radioactive disks began to disappear from the tips of the rods, radioactive fragments suddenly appeared in the retinal epithelial cells that envelop the ends of the outer segments. These fragments proved to be the broken-off rod tips. The discarded disks




**STRUCTURE OF OUTER SEGMENT** of frog's rod (*left*) and cone (*right*) differ. In the rod new disks are formed by repeated infolding of the outer membrane as visual pigment and other molecules synthesized in the inner part of the cell pass through the cilium. As the disks are displaced away from the base by the formation of newer disks, they develop notches and their attachment to the membrane grows weaker. Eventually (*top*) they become independent of the membrane and are cast off. In the cone the disks retain their attachment to the membrane and are not cast off. The drawings are based on electron micrographs of cells from the retina of the frog.




# WHAT DOES IT TAKE TO PRODUCE A $1000-BILLION GNP?

The Editors of SCIENTIFIC AMERICAN have prepared a wall chart, based upon the latest Federal input/output table, displaying the inter-industry flows of raw materials, intermediate products and business services required to carry the U.S. economy to the benchmark Gross National Product of $1000 billion.

Input/output tables provide management, government administrators, economists and market analysts with a powerful new tool for forecasting and measuring the indirect as well as the direct interindustry relationships that structure our industrial economy.

This handsome and informative wall chart (70" x 46", in eight colors) offers a unique entry into the rapidly developing discipline of interindustry (or input/output) analysis. Based upon input/output tables issued by the Office of Business Economics of the U.S. Department of Commerce, the chart can be used as a teaching tool and for study of practical and theoretical questions about the U.S. economy.

The chart presents an interindustry matrix of 99 rows and 99 columns; each of the nearly 10,000 cells in the matrix shows (1) the direct input/output coefficient, (2) the "inverse" coefficient and (3) the interindustry dollar flow for a $1000-billion Gross National Product. The input/output coefficients as published by OBE have been recomputed by the Harvard Economic Research Project to reflect gross domestic output. The 370 sectors of the detailed tabulations have been selectively aggregated to 99 sectors to provide maximum feasible detail for the wall chart. Where the ratio of input to output exceeds 1/100, the cell is tinted in the color-code of the industrial bloc from which the input comes. This device, combined with triangulation of the matrix, brings the structure of interindustry transactions into graphic visibility.

Offprints of five SCIENTIFIC AMERICAN articles on the technique of input/output analysis accompany the chart. The articles are:

Input/Output Economics
by Wassily W. Leontief

The Economic Effects of Disarmament
by Wassily W. Leontief and Marvin Hoffenberg

The Structure of Development
by Wassily W. Leontief

The Structure of the U.S. Economy
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The Economics of Technological Change
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were being engulfed and destroyed by the epithelial cells.

In short, the rod cells possess a most unusual system for renewal of their outer segment. In the inner segment they continually synthesize protein for the building of the disks. The protein migrates to the outer segment, where it is used in the assembly of one new disk after another at the base of the segment. At the same time groups of old disks are being shed from the tip of the rod and are scavenged by the epithelial cells.

During a year I spent in France in the laboratory of Droz (who had moved from McGill University to the Nuclear Research Center at Saclay near Paris) I had an opportunity to learn some details concerning the production and distribution of the protein the cell supplies for the renewal process. With a new technique of electron-microscope autoradiography we traced the movements of the protein produced in the visual cells of the frog retina. The high-resolution autoradiograms revealed that after its synthesis on the ribosomes the protein moved into the Golgi complex, a cell structure that compounds carbohydrates with protein [see "The Golgi Apparatus," by Marian Neutra and C. P. Leblond; SCIENTIFIC AMERICAN, February, 1969]. The molecules then traveled to all parts of the cell, some toward the synaptic body at one end, others to the light-sensing outer segment at the other end. They reached the outer segment, of course, by way of the narrow cilium, which proved to be a miniature pipeline for the delivery of the molecules synthesized in the manufacturing centers of the inner segment. Most of the protein was delivered to the site at the base of the outer segment where disks were built. There a new disk was formed every 40 minutes.

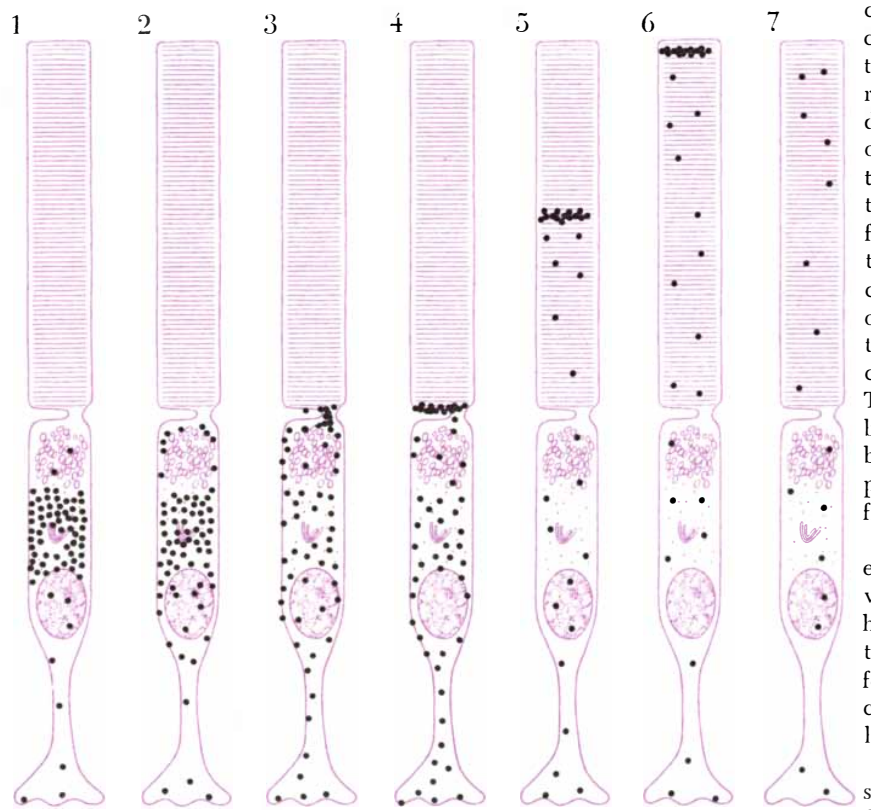
Obviously the most crucial protein that must be supplied is the visual pigment. Michael Hall, Bok and Alfred Bacharach of the Jules Stein Institute have demonstrated that new visual pigment is indeed produced continually and delivered to the disk-building site in the outer segment of rod cells. They injected adult frogs with labeled amino acids and at various intervals afterward extracted visual pigment from the rod outer segments to test the samples for radioactivity. The radioactivity suddenly began to show up in pigment when the labeled protein arrived at the disk-production site, and it fell off abruptly two months later when the labeled disks were shed at the rod tips.

The rate of outer-segment renewal in rod cells apparently is not affected to any significant degree by prolonged exposure to light or darkness. In the case of cold-blooded animals such as the frog, however, a change in the body temperature can speed up the production of disks or slow it down.

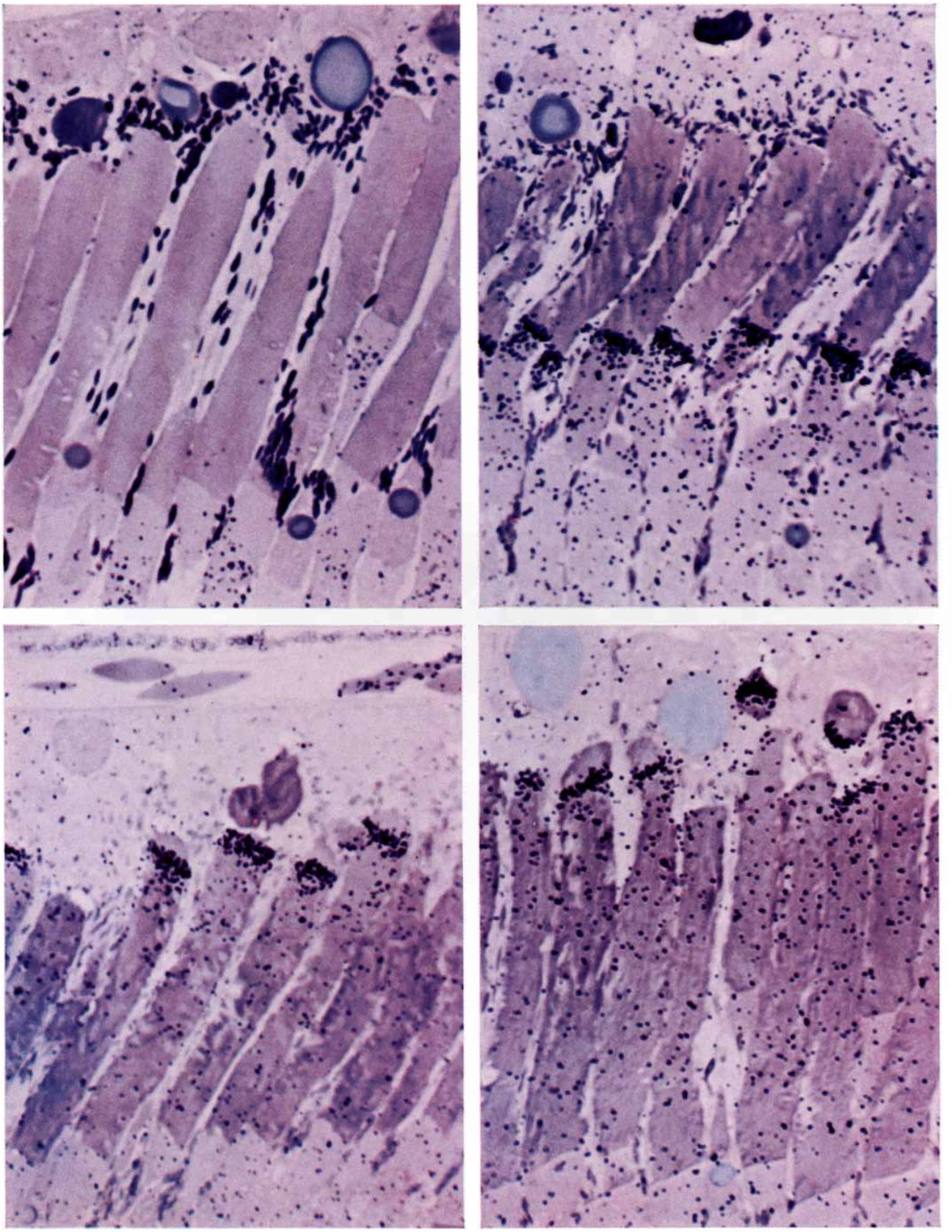
Do cone cells renew themselves in the same way as rod cells? This question did not lend itself readily to investigation, mainly because of the lack of a convenient experimental subject. The retinas of the rat and the mouse contain no cones, and the outer segment of the cone cell in the frog is so small that I could not follow the fate of its disks with the methods I had used in studying the rod cells. Electron-microscope autoradiography, however, provided a means of tracing the movement of labeled protein in the frog's cone cells. Applying this technique in Droz's laboratory, I found to my surprise that when the protein arrived in the outer segment of cone cells, it did not concentrate at the base of the segment but instead spread throughout the segment. Clearly the cone cells were not building new disks. Their outer segment was being renewed by a continual supply of fresh protein, but the method of incorporation of the protein was obviously quite different from that in rod cells.

In my own laboratory we have since examined events in the cone cells of various other vertebrate animals and have found that the distinction holds true for all of them. So far we have not found a single case in which the cone cell produces new disks once the cell has matured.

It now seems likely that cone outer segments are cone-shaped because the formation of disks has stopped. In the development of both types of visual cell—rods and cones—the first disks formed are small, and those following them are successively larger in diameter. In the early stages of the cell, therefore, the outer segment is conical. Ultimately the disks that are produced reach a limit-




RENEWAL OF PROTEIN in rod cells, as revealed by autoradiography, is depicted schematically here and photographically in the micrographs on the opposite page. New protein, represented by the dots, is first concentrated where it is synthesized, mainly in the inner segment (*1*). After moving through the Golgi complex (*2*) some of it flows around the nucleus to the synaptic end of the cell, where it is gradually used up. Much of the protein goes through the cilium (*3*) and accumulates in a disk-shaped band at the base of the outer segment (*4*). It moves along the segment (*5 and 6*) and at the end suddenly disappears (*7*).



**SEQUENCE OF EVENTS** is traced in radioautograms of frog photoreceptor cells enlarged 1,600 diameters. New protein molecules are revealed by the black dots. Ten minutes after the injection of radioactive amino acids (*top left*) the protein is located where it is formed, between the nucleus and the mitochondria. A week after injection (*top right*) much of the protein is in new outer-segment disks, which have already been displaced partway along the outer segment. Eight weeks after injection (*bottom left*) the protein is near the end of the rod. A week later (*bottom right*) it appears in the pigment epithelium, showing that rod tips have become detached.

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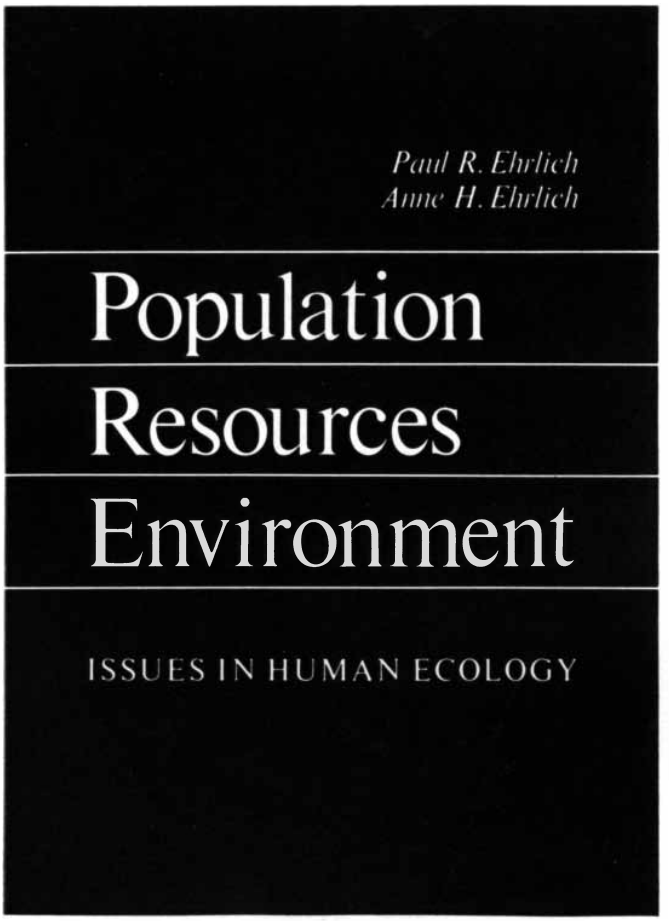


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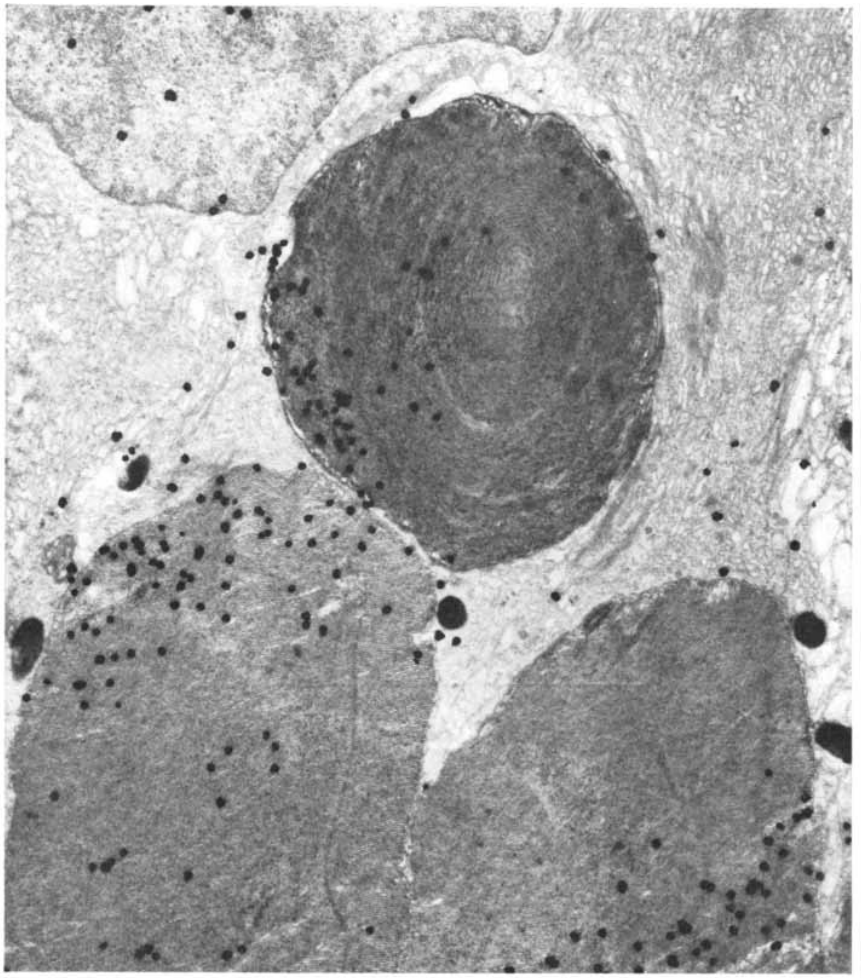


**DETACHMENT OF DISKS from the outer segment of a rod in the retina of a frog is visible in this electron-microscope autoradiogram at an enlargement of 10,200 diameters. The group of disks being detached is the circular structure at center. Also visible at lower right is the tip of another rod where the labeled disks have not yet reached end of outer segment.**

ing size. The rod cell, however, goes on building disks of the maximum size, sheds the smaller ones at the tip and thus creates a cylindrical outer segment of uniform diameter.

Events in the cells of the living human eye obviously cannot be studied in detail as they can in experimental animals. There is every reason to believe, however, that the mechanisms for self-renewal are essentially the same in the rods and cones of the human retina as they are in the visual cells of other vertebrates. Groups of rod disks have been observed being shed from the end of the outer segment and scavenged by the adjacent epithelial cells in the human retina. Recent autoradiographic studies have revealed that the rods and cones of the rhesus monkey renew their outer segments in the same way as do those of other vertebrates that have been studied, and the visual cells of this animal are remarkably similar to those in the human eye. There is some evidence that human visual cells are able to generate new disk material to heal damage to the outer segment. We believe they not only are capable of replacing parts that have been injured but also are continually replacing aging cell parts as a means of preventive maintenance.

My colleagues at the Jules Stein Institute and a research group at the University of Florida have independently reported that a hereditary blinding disease found in the rat is due to a disruption of the normal renewal process of the rod outer segment. Disks shed from the ends of the rods in these animals are not scavenged by the epithelial cells. Their abnormal accumulation is shortly followed by the degeneration and death of rods, producing blindness. Some of the poorly understood blinding diseases of man may also be due to failure of the normal renewal processes of the visual cells.

# The Nutrient Cycles of an Ecosystem

*When all vegetation was cut in a 35-acre watershed in an experimental forest in New Hampshire, the output of water and nutrients increased. The experiment illustrates ecological principles of forest management*

by F. Herbert Bormann and Gene E. Likens

An ecological system has a richly detailed budget of inputs and outputs. One of the reasons it is difficult to assess the impact of human activities on the biosphere is the lack of precise information about these inputs and outputs and about the delicate adjustments that maintain a balance. As a result the people planning a project such as the logging of a forest or the building of a power plant often cannot take into account or even foresee the full range of consequences the project will have. Even if they could, the traditional practice in the management of land resources has been to emphasize strategies that maximize the output of some product or service and give little or no thought to the secondary effects of the strategies. As a result one sees such ecological maladjustments as the export of food surpluses while natural food chains become increasingly contaminated with pesticides and runoff waters carry increasing burdens of pollutants from fertilizers and farm wastes; the cutting of forests with inadequate perception of the effects on regional water supplies, wildlife, recreation and aesthetic values, and the conversion of wetlands to commercial use with little concern over important hydrologic, biological, aesthetic and commercial values lost in the conversion.

It seems evident that a new conceptual approach to the management of resources would be desirable. One approach that has been suggested is to consider entire ecological systems. In an experimental forest in New Hampshire we and the U.S. Forest Service have been conducting a large-scale investigation aimed at supplying the kind of information that is usually lacking about ecosystems. The investigation represents a multidisciplinary collaboration between workers at a number of universities and in several government agencies.

The investigation has involved two major operations. First we attempted to determine the inputs and outputs affecting the forest under normal circumstances. Then we inflicted a serious disruption on an ecosystem by cutting down an entire section of the forest. Over a period of years we have been measuring the results of that drastic action on the ecosystem's budget of nutrients. We believe our findings help to show how a natural ecosystem works and what happens when man perturbs it. Moreover, our data provide a conceptual basis for taking into account the ecological factors that in the long run determine whether or not a new technology or a particular economic policy is wise.

An ecosystem, as we use the term, is a basic functional unit of nature comprising both organisms and their nonliving environment, intimately linked by a variety of biological, chemical and physical processes. The living and nonliving components interact among themselves and with each other; they influence each other's properties, and both are essential for the maintenance and development of the system. An ecosystem, then, can be visualized as a grouping of components—living organisms, organic debris, available nutrients, primary and secondary minerals and atmospheric gases—linked by food webs, flows of nutrients and flows of energy.

A typical forest ecosystem might be visualized as a 1,000-hectare stand of mature deciduous forest. (A hectare is 2.47 acres.) The lateral boundaries of the system can be either an edge of the stand or an arbitrarily determined line. The upper boundary is the treetop level, and the lower one is the deepest level of soil where significant biological activity takes place.

Our ecosystem is in the Hubbard Brook Experimental Forest, which is maintained in the White Mountain National Forest by the Forest Service. We have focused on the movement of nutrients across the boundary of the system (both in and out) and their circulation within it. Nutrients are found in four basic compartments of the ecosystem that are intimately linked by an array of natural processes. The organic compartment consists of the living organisms and their debris. (There are probably more than 2,500 species of plants and animals in a 1,000-hectare system.) The available-nutrient compartment is composed of nutrients held on the surface of particles of the clay-humus complex of the soil or in solution in the soil. Roots as they grow produce positively charged hydrogen ions that exchange with the nutrient ions (of calcium, magnesium and so on) held on the negatively charged particles, and the nutrients are then taken up by the roots. The third compartment consists of soil and rocks containing nutrients in forms temporarily unavailable to living organisms. The atmospheric compartment is made up of gases, which can be found not only in the air but also in the ground.

Nutrients can flow between these compartments along a variety of pathways. In most cases the flow is powered directly or indirectly by solar energy. Available nutrients are taken up and assimilated by vegetation and microor-

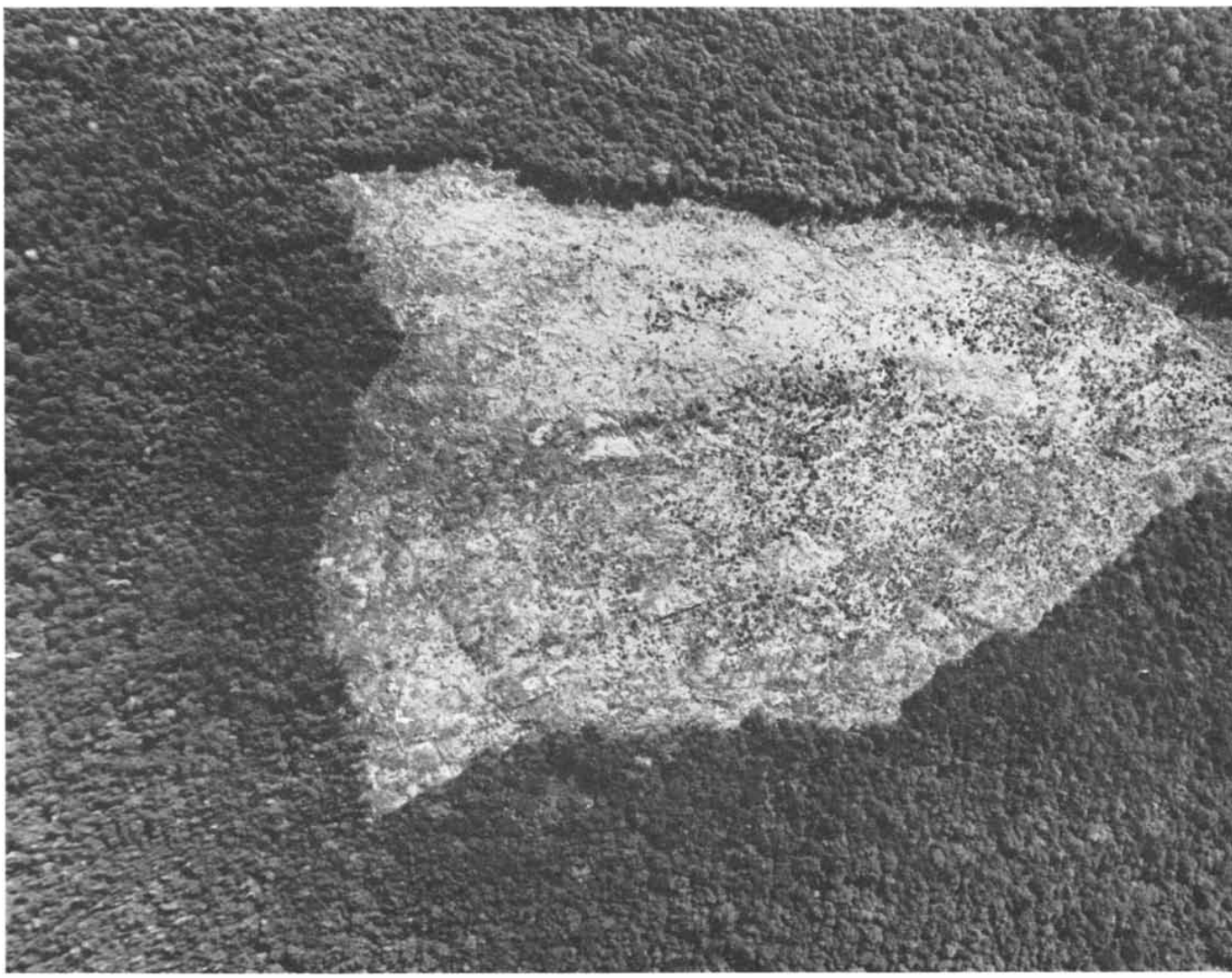
**DRAINAGE OF WATERSHED is measured by means of a weir at the base of the cut-over watershed in the White Mountain National Forest. The chemical content of the water in the stream feeding into the weir shown in the photograph on the opposite page is also ascertained by means of water samples taken from the stream periodically.**

ganisms. They also circulate in complex food webs within the organic compartment, subsequently being made available again through decomposition or leaching. Minerals in soil and rock are decomposed by weathering, so that nutrients are made available to organisms. Sometimes available nutrients are returned to the soil-and-rock compartment through the formation of new minerals such as clay. Nutrients tend to cycle between the organic, available-nutrient and soil-and-rock compartments, forming an intrasystem cycle. Nutrients in gaseous form are continually being transferred to and from other compartments by inorganic chemical reactions such as oxidation and reduction and by organic reactions related to such processes as photosynthesis, respiration and the fixation and volatilization of nitrogen.

An ecosystem is connected to the surrounding biosphere by its system of inputs and outputs. They arrive or leave in such forms as radiant energy, gases, inorganic chemicals and organic substances. Inputs and outputs can be transported across ecosystem boundaries by meteorological forces such as precipitation and wind, geological forces such as running water and gravity and biological vectors involving the movement of animals in and out of the system.

Ordinarily it is difficult to measure the input-output relations of an ecosystem, particularly those involving nutrients. The nutrient cycle is closely connected to the water cycle: precipitation brings nutrients in, water leaches them from rocks and soil and stream flow carries them away. Hence one cannot measure the input and output of nutrients without simultaneously measuring the input and output of water. The problem usually is that subsurface flows of water, which can be a significant fraction of the hydrologic cycle, are almost impossible to measure.

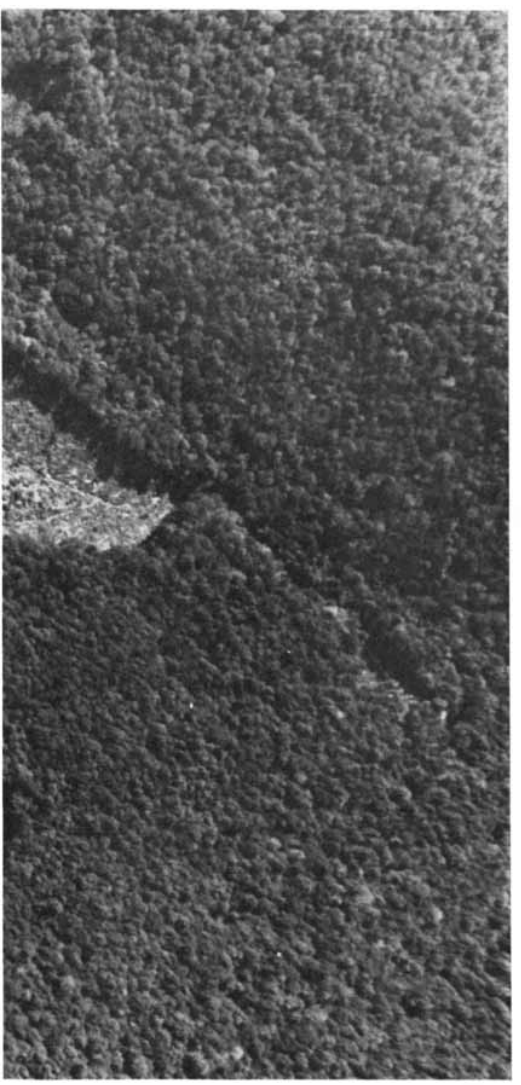
Several years ago it occurred to us that under certain circumstances the interaction of the nutrient cycle and the hydrologic cycle could be turned to good advantage in the study of an ecosystem. The requirements are that the ecosystem be a watershed underlain by tight bedrock or some other impermeable base. In that case the only inputs would be meteorological and biological; geological input need not be considered because there would be no transfer between adjacent watersheds. In humid areas where surface wind is a minor factor losses from the system would be only



**SCENE OF EXPERIMENT** is the Hubbard Brook Experimental Forest in the White Mountain National Forest. After the normal inputs and outputs of precipitation and nutrients had been ascertained in six contiguous watersheds in the forest, all vegetation in one of the watersheds was cut and dropped in place, and regrowth was inhibited by herbicide. The purpose of the treatment was to

geological and biological. Given an impermeable base, all the geological output would inevitably turn up in the streams draining the watershed. If the watershed is part of a larger and fairly homogeneous biotic unit, the biological output tends to balance the biological input because animals move randomly in and out of the watershed, randomly acquiring or discharging nutrients. Thus one need measure only the meteorological input and the geological output of nutrients in order to arrive at the net gain or loss of a given nutrient in the ecosystem.

This is the approach we use at Hubbard Brook, where we have been studying six contiguous watersheds ranging in size from 12 to 43 hectares [*see top illustration on next page*]. They are all tributary to Hubbard Brook and forested with a well-developed, second-growth stand of sugar maple, beech and yellow birch. The forest has been undisturbed by cutting or fire since 1919, when much of the first growth was removed in lumbering operations.



**ascertain the effect on the outputs of the ecological system. The drainage of the cut-over watershed is to south, which is at right.**

We measure the meteorological inputs to these watersheds by means of a network of gauging stations. We measure the geological outputs by means of a weir built at the foot of each watershed, that is, at the point where the principal stream leaves the watershed [*see illustration on page 93*]. With the weir, which also includes a ponding basin, one can both measure the water that is leaving the watershed and, by combining these data with frequent chemical measurements, ascertain the quantities of chemical substances that are leaving the watershed.

Inasmuch as the impermeable base prohibits deep seepage in these watersheds, the loss of water by evaporation and by transpiration through leaves is calculated by subtracting the hydrologic output from the hydrologic input. Water budgets for the six watersheds from 1955 to 1968 indicate an average annual precipitation of 123 centimeters and a runoff of 72 centimeters, with evapotranspiration therefore averaging 51 centimeters. Precipitation is distributed rather evenly throughout the year, but runoff is uneven. Most of the runoff (57 percent) occurs during the snowmelt period of March, April and May; indeed, 35 percent of the total runoff occurs in April. In contrast, only .7 percent of the yearly runoff takes place in August.

We accomplish chemical measurements by taking weekly samples of the water output (stream water at the weir) and collecting the total weekly water input (rain and snow) and analyzing them for calcium, magnesium, potassium, sodium, aluminum, ammonium, nitrate, sulfate, chloride, bicarbonate, hydrogen ion and silicate. The concentrations of these elements in precipitation and in stream water are entered in a computing system, where weekly concentrations are multiplied by the weekly volume of water entering and leaving the ecosystem. In this way the input and output of chemicals is computed in terms of kilograms of an element per hectare of watershed.

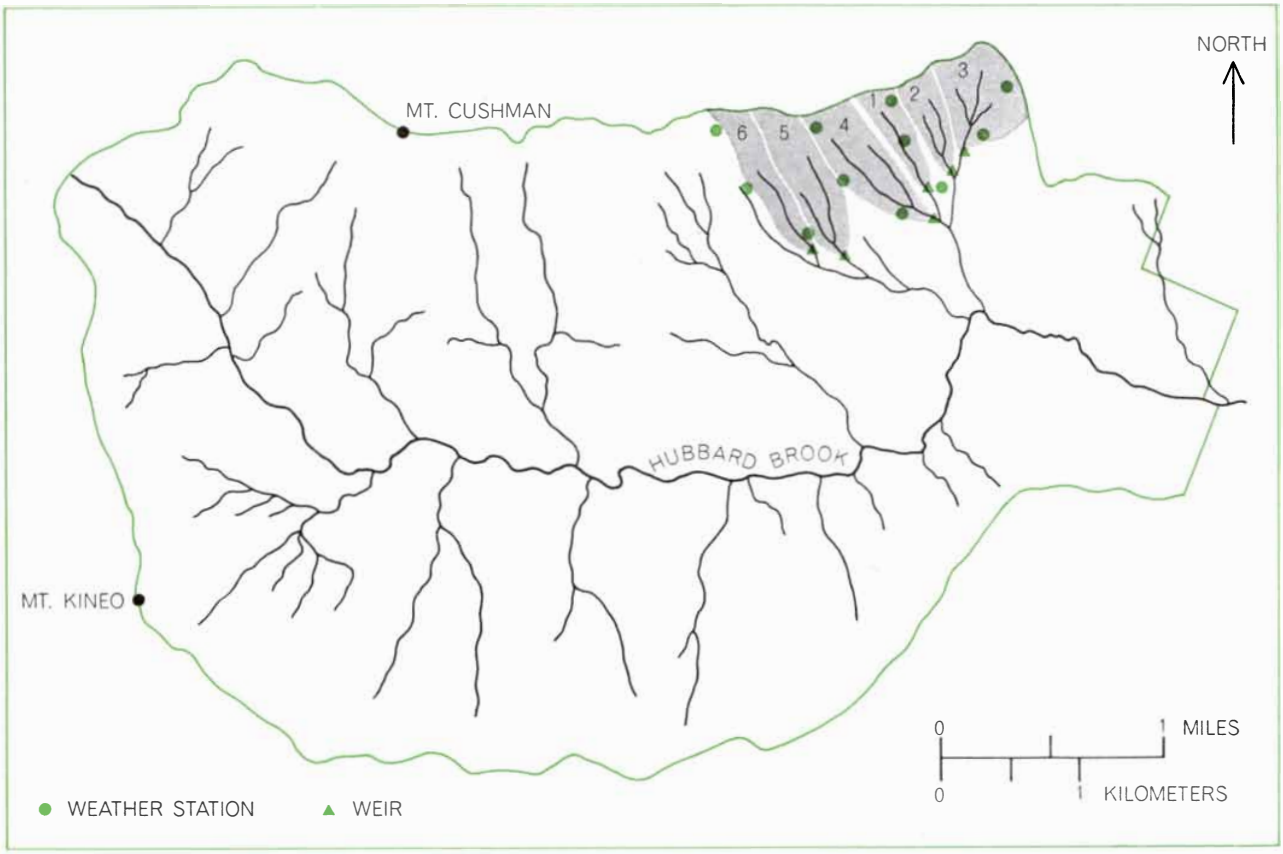
Knowing the input and output of chemicals, we have made nutrient budgets for nine elements. Considering four of the major ones, we find the following annual averages in kilograms per hectare entering the system and being flushed out of it: calcium, 2.6 and 11.8; sodium, 1.5 and 6.9; magnesium, .7 and 2.9, and potassium, 1.1 and 1.7. These inputs and outputs represent connections of the undisturbed forest ecosystem with worldwide biogeochemical systems. The data also provide a comparative basis for judging the effects of managerial practices on biogeochemical cycles.

Net losses of calcium, sodium and magnesium were recorded each year even though the period of measurement included wet and dry years as well as years of average precipitation. Potassium, a major component of the bedrock, showed net gains in two years and a smaller average net loss than was recorded for the other elements. Evidently potassium is accumulating in the ecosystem with respect to other elements. One reason may be that it is retained in the structure of illitic clays developing in the ecosystem. Perhaps also potassium is retained in proportionately larger amounts than other elements are in the slowly increasing biomass of the system.

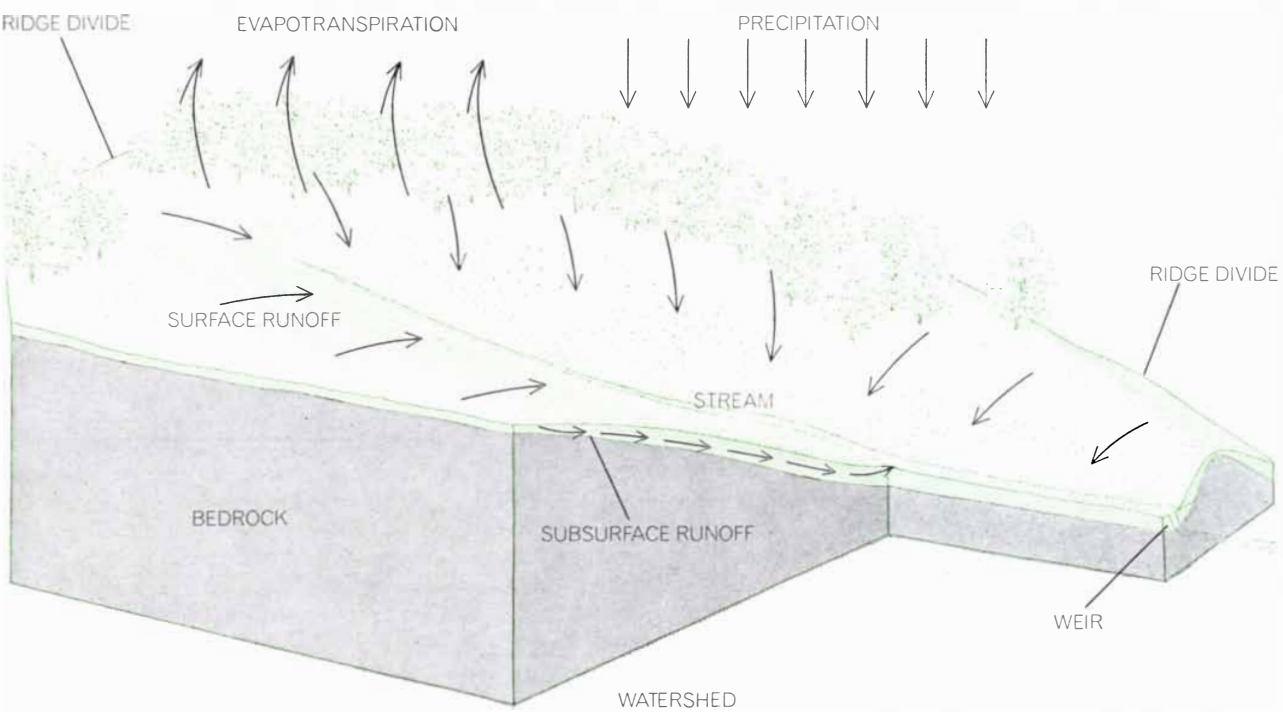
Highly predictable relations appear between the concentrations of dissolved chemicals in stream water and the discharge rates of the stream. For example, the concentrations of sodium and silica are inversely related to discharge rates, whereas the concentrations of aluminum, hydrogen ion and nitrate increase as discharge rates increase. Magnesium, calcium, sulfate, chloride and potassium are relatively independent of discharge rate.

The magnitudes of change of concentration, however, are fairly small. The concentrations of potassium, calcium and magnesium hardly change at all, and the concentration of sodium decreases by only three times as the discharge rate increases by four orders of magnitude. These results were unexpected: we had thought that during the spring melt period there would be considerable dilution, making the concentrations of elements in stream water relatively low. All these relations show how strongly stream-water chemistry is under the control of processes inherent in the forest ecosystem.

Because of the comparative constancy of chemical concentrations, the total output of elements is strongly dependent on the volume of stream flow. Hence it is now possible, knowing only the hydrologic output, to predict with fair accuracy both the output and the concentration of chemicals in the stream water draining from our mature, forested eco-



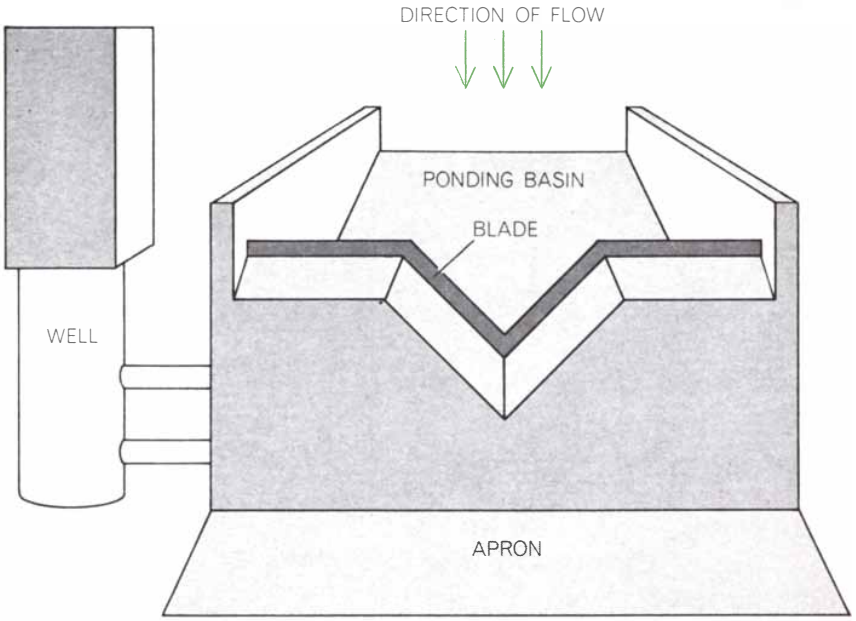

**HUBBARD BROOK EXPERIMENTAL FOREST** is in central New Hampshire, about 30 miles north of Laconia. The six watersheds figuring in experiment are in the northeast corner (*color*). Vegetation was cut and regrowth repressed in Watershed No. 2.




**UNDISTURBED WATERSHED** receives inputs from precipitation and discharges outputs through its principal stream. In many watersheds there also would be outputs arising from deep seepage, which is almost impossible to measure, but watersheds of Hubbard Brook ecosystem are underlain by impermeable bedrock, so that all liquid output is by stream. Another aspect of the ecosystem is the intrasystem cycle, involving the release of nutrients into the soil by weathering of rocks, the uptake of nutrients by vegetation and their return to the soil by decomposition and leaching. Destruction of vegetation blocks a major pathway, nutrient uptake.

system. This relation would seem to have considerable value for regional planners concerned with water quality.

A particularly interesting finding is that almost the entire loss of cations (positively charged nutrient ions) from the undisturbed forest ecosystem is balanced by the input of positively charged hydrogen ions in precipitation. The proportion of hydrogen ions is related to the amount of sulfate in precipitation. It is estimated that 50 percent of the sulfate in precipitation results from industrial activities that put sulfur dioxide and other sulfur products into the air. These sulfur compounds may ultimately form ionized sulfuric acid, which consists of hydrogen ions and sulfate ions. When the precipitation enters the ecosystem, the hydrogen ions replace the nutrient cations on the negatively charged exchange sites in the soil, and the cations are washed out of the system in stream water. Thus air pollution is directly related to a small but continuous loss of fertility from the land area of the ecosystem and a small but continuous chemical enrichment of streams and lakes. The relation appears to represent an important hidden cost of air pollution, made apparent through the analysis of ecosystems.




**STRUCTURE OF WEIR** is designed to collect all the water draining from a watershed and to release it in a measurable way over the *V*-shaped blade. Well is used to gauge water level, which is continuously recorded in well house. Each Hubbard Brook watershed has one weir.

So far we have mentioned only chemical losses appearing as dissolved substances. Losses also arise when chemicals locked up in particulate matter such as rock or soil particles and in organic matter such as leaves and twigs are washed out of the ecosystem by the stream. We have measured these outputs and developed equations expressing the loss of particulate matter as a function of the discharge rate of the stream. The loss is highly dependent on the discharge rate.

Losses of dissolved substances account for the great bulk of the chemical loss from our undisturbed ecosystem. Whereas they are largely independent of the discharge rate, losses of particulate matter are highly dependent on it. This point is of particular interest since forest-management practices can either increase or decrease stream-discharge rates and thereby shift the balance between the loss of dissolved substances and the loss of particulate matter.

Weathering, or the release of elements bound in primary minerals, is another factor that must be considered in an ecosystem, since the elements thus released are made available as nutrients to the vegetation and animals. Based on net losses of elements from our ecosystem, a relatively uniform geology in the region and a knowledge of the bulk chemistry of the rock and soil, we estimate that the nutrients contained in some 800 kilograms per hectare of rock and soil are made available each year by weathering.

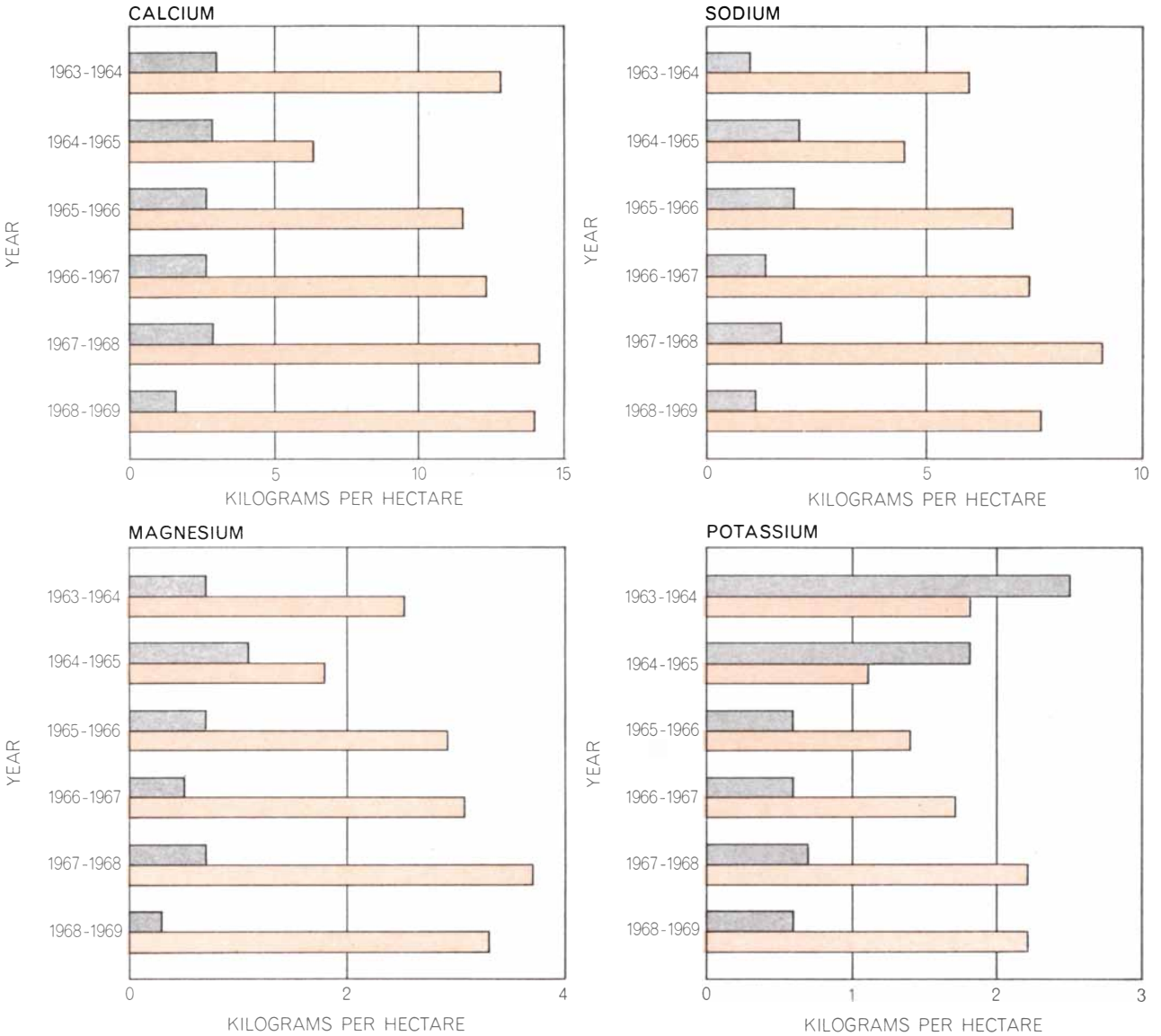
We now have for the undisturbed Northern hardwood ecosystem of Hubbard Brook estimates of chemical input in precipitation and output in stream water and the rates of generation of ions by the weathering of minerals within the system. To complete the picture of nutrient cycling it is necessary to measure the nutrient content of the four compartments and the flow rates among them arising from uptake, decomposition and leaching and the formation of new minerals. A typical set of relations, using calcium as an example, is shown in the illustration on page 99.

The annual net loss of calcium from the ecosystem is 9.2 kilograms per hectare. This loss represents only about .3 percent of the calcium in the available-nutrient and organic compartments of the system and only 1.3 percent of what is in the available-nutrient compartment alone. The data suggest that Northern hardwood forests have a remarkable ability to hold and circulate nutrients.

It was against this background that we and the Forest Service embarked on the experiment of cutting down everything that was growing in one watershed. One of the objectives of this severe treatment was to block a major pathway of the ecosystem—the uptake of nutrients by higher plants—while the pathway of ultimate decomposition continued to function. We questioned whether or not the ecosystem had the capacity under these circumstances to hold the nutrients accumulating in the available-nutrient compartment. We also wanted to determine the effect of deforestation on stream flow, to examine some of the fundamental chemical relations of the forest ecosystem and to evaluate the effects of forest manipulation on nutrient relations and the eutrophication of stream water.

The experiment was begun in the winter of 1965–1966 when the forest of Watershed No. 2, covering 15.6 hectares, was completely leveled by the Forest Service. All trees, saplings and shrubs were cut and dropped in place; their limbs were removed so that no slash was more than 1.5 meters above the ground. No products were removed from the forest, and great care was taken to prevent disturbance of the surface of the soil that might promote erosion. The following summer regrowth of vegetation was inhibited by an aerial application of the herbicide Bromacil at a rate of 28 kilograms per hectare.

Deforestation had a pronounced effect on runoff. Beginning in May, 1966, runoff from the cut watershed began to increase over the levels that would have been expected if there had been no cutting. The cumulative runoff for 1966 exceeded the expected amount by 40 percent. The largest difference was re-




**INPUT AND OUTPUT of four major nutrients were recorded for the undisturbed watersheds at Hubbard Brook. Input (*gray*) was in precipitation; output (*color*) was in stream flow, and the difference represents the net loss or gain from the ecosystem in a given year.**

corded during the four months from June through September, when the runoff was 418 percent higher than the expected amount. This difference is directly attributable to changes in the hydrologic cycle resulting from the removal of the transpiring surface. Accelerated runoff has continued through the succeeding summers.

Our treatment also resulted in a fundamental alteration of the nitrogen cycle, which in turn caused extraordinary losses of soil fertility. In an undisturbed ecosystem nitrogen incorporated in organic compounds is ultimately decomposed in a number of steps to ammonium nitrogen ($NH_4^+$), a positively charged ion that can be held fairly tightly in the soil on the negatively charged exchange sites. Ammonium ions can be taken up directly by green plants and used in the fabrication of nitrogen-containing organic compounds. Ammonium ions can also be used as the substrate for the process of nitrification. In this process two genera of soil bacteria, *Nitrosomonas* and *Nitrobacter*, oxidize ammonium to nitrate ($NO_3^-$). Two hydrogen ions are produced for every ion of ammonium oxidized to nitrate. As we have already mentioned, hydrogen ions can play a key role in the release of nutrient cations from the soil. Nitrate, being negatively charged, is highly leachable. If it is not taken up by higher plants, it can easily be removed from the ecosystem in drainage water.

The available evidence indicates that nitrification is of minor importance in undisturbed forests such as ours, underlain by acid podzol soil. The nitrate drained by our streams (invariably in low concentration) can be largely accounted for by its input in precipitation. In fact, our budgetary analyses show that undisturbed ecosystems are accumulating nitrogen at a rate of about two kilograms per hectare per year.

The concentration of nitrate in stream water from undisturbed forests shows a seasonal cycle, being higher from November through April than it is from May through October. The decline in May and the low concentration in the summer are correlated with heavy demand for nutrients by the vegetation

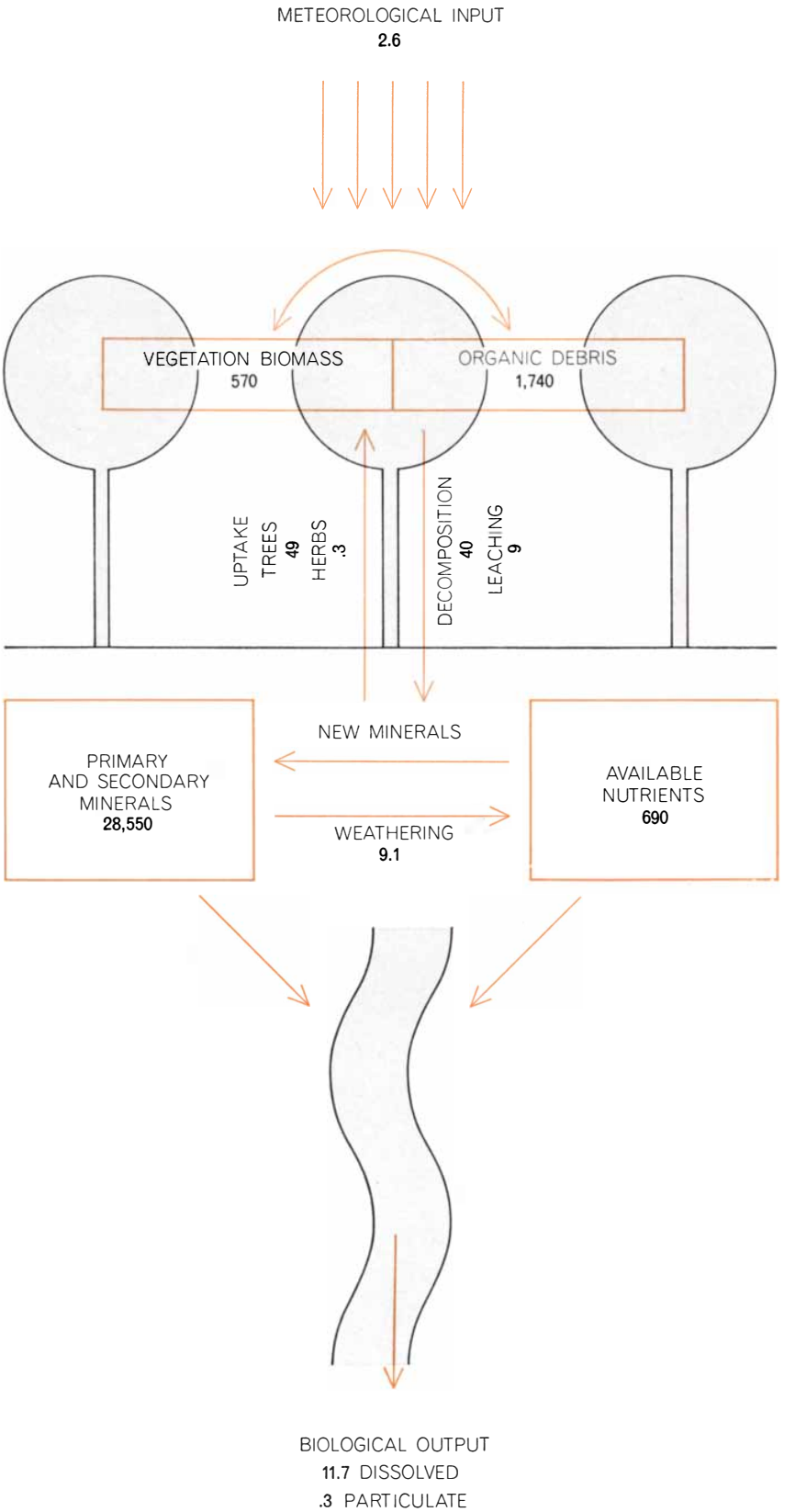
and generally increased biological activity associated with warming of the soil.

Beginning in June, 1966, the concentration of nitrate in the deforested watershed rose sharply. At the same time the undisturbed ecosystem showed the normal spring decline [*see illustration on next page*]. The high concentration has continued in the deforested watershed during the succeeding years. Average net losses of nitrate nitrogen were 120 kilograms per hectare per year from 1966 through 1968. We estimate that the annual turnover of nitrogen in our undisturbed forests is about 60 kilograms per hectare. Therefore an amount of elemental nitrogen equivalent to double the amount normally taken up by the forest has been lost from the deforested watershed each year since cutting. The magnitude of nitrate loss is a clear indication of the acceleration of nitrification in the watershed. There is no doubt that the cutting drastically altered the conditions controlling the nitrification process.

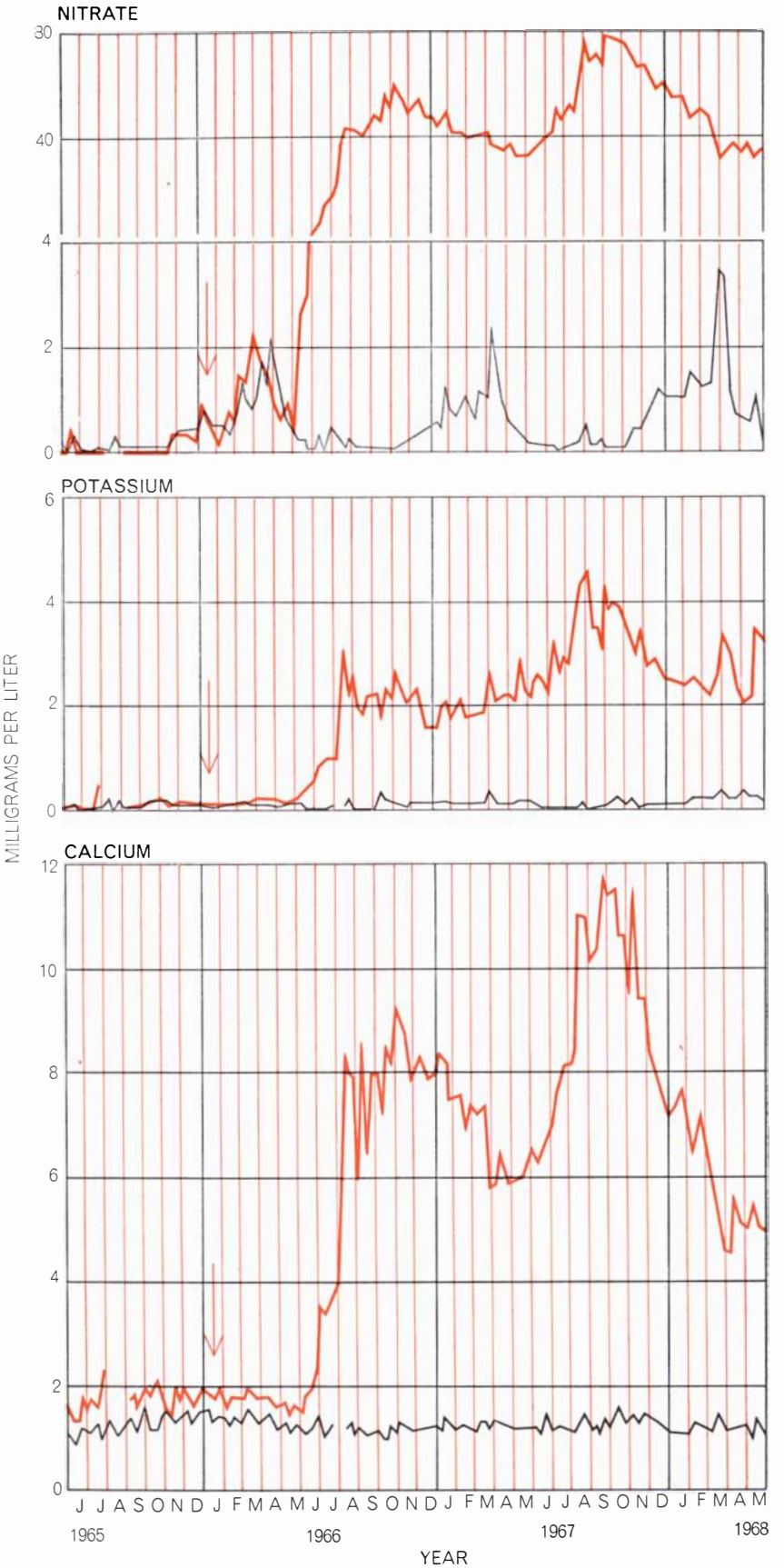
Another factor of interest about nitrification is the body of evidence from other regions that certain types of vegetation can inhibit nitrification chemically. Presumably the effect is to inhibit production of the highly leachable nitrate ion. At the same time the positively charged ammonium ions may be held within the system on the negatively charged exchange sites in the soil. If this inhibition process goes on at Hubbard Brook, cutting the vegetation would promote nitrification. The effect may account for much of the nitrate loss from the deforested ecosystem.

The export of nitrate to the small stream draining the cut watershed has resulted in nitrate concentrations exceeding the levels established by the U.S. Public Health Service for drinking water. In general the deforestation has led to eutrophication of the stream and to the development of algal "blooms." This finding indicates that in some circumstances forest-management practices can contribute significantly to the eutrophication of streams.

Since nitrification produces hydrogen ions that replace metallic cations on the exchange surfaces in the soil, one would expect a loss of metallic nutrients from the deforested watershed. We have recorded substantial losses of this kind. The concentrations of calcium, magnesium, sodium and potassium in the stream water increased almost simultaneously with the increase in nitrate. About a month later the concentration of aluminum rose sharply.




**CALCIUM CYCLE is depicted for an undisturbed forest ecosystem. Numerals represent the average number of kilograms per hectare per year. Thus the meteorological input to the ecosystem in precipitation and dust is 2.6 kilograms per hectare annually. A substantial amount of calcium is in soil and rock; 9.1 kilograms is released annually by weathering. Vegetation takes up 49.3 kilograms; 49 kilograms is returned to the soil by decomposition and leaching. Gross loss in stream drainage is 12 kilograms, so the net loss is 9.4 kilograms.**




**RESULTS OF DEFORESTATION shown by the output of three nutrients in stream water appear in a comparison of Watershed No. 6 (*black*), which was undisturbed, with Watershed No. 2 (*color*), which was deforested. The arrows indicate the time of the deforestation.**

Net losses of potassium were 21 times higher than those in an undisturbed watershed; of calcium, 10 times; of aluminum, nine; of magnesium, seven, and of sodium, three. These figures represent a substantial loss of nutrients from the ecosystem. The finding suggests that commercial forestry should focus more on the effect of harvesting practices on the loss of nutrients, giving more consideration to such corrective procedures as selective cutting and the promotion of regrowth on cut areas.

Our results indicate that the capacity of the ecosystem to retain nutrients is dependent on the maintenance of nutrient cycling within the system. When the cycle is broken, as by the destruction of vegetation, the loss of nutrients is greatly accelerated. This effect is related both to the cessation of nutrient uptake by plants and to the larger quantities of drainage water passing through the system. The loss may also be related to increased rates of decomposition resulting from such changes in the physical environment as higher soil temperature and moister soil.

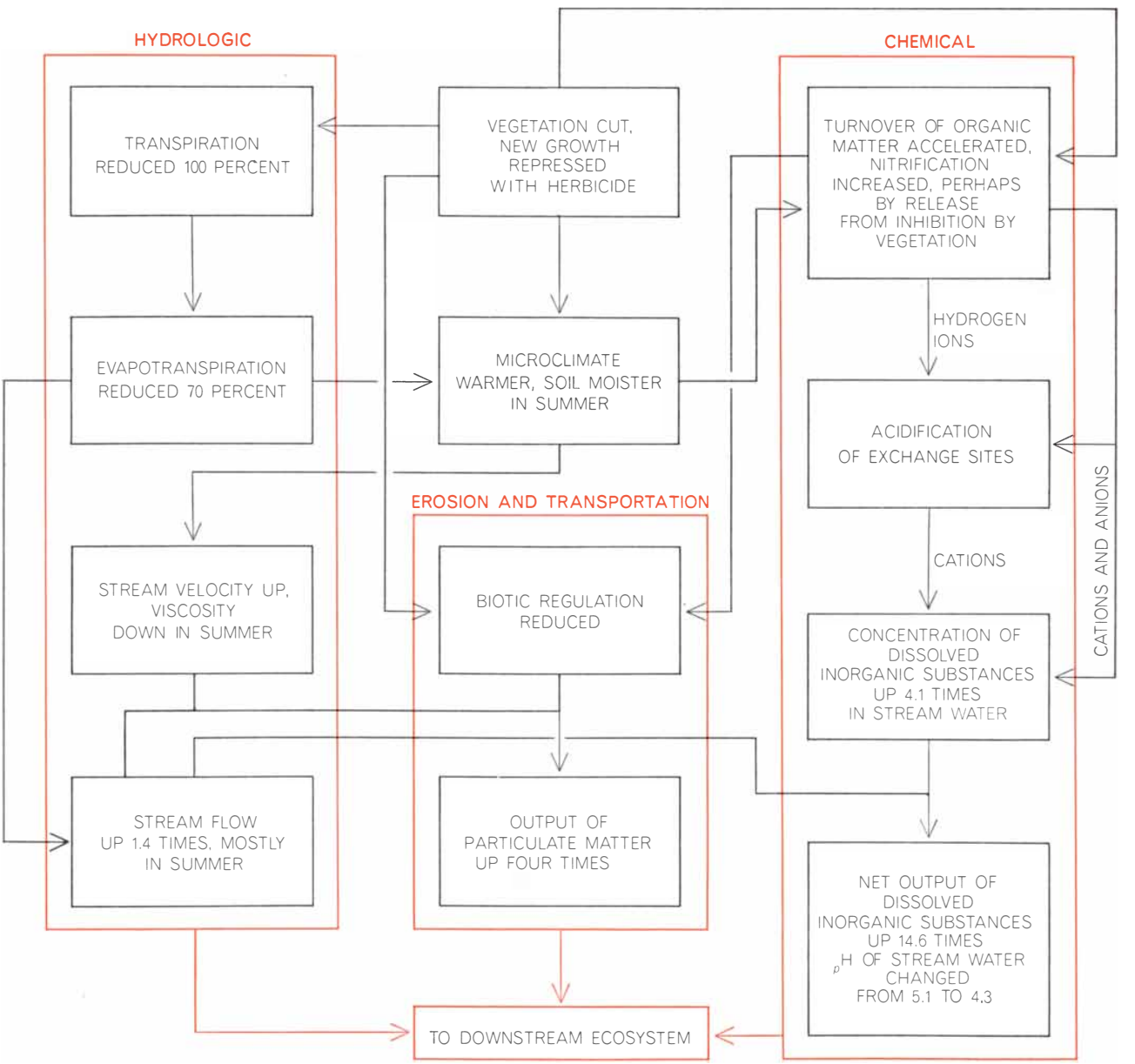
We also found a basic change in the pattern of loss of particulate matter in the deforested watershed. The data for three years indicate an increase of some ninefold over a comparable undisturbed ecosystem. After an initial surge the loss of particulate organic matter has declined as a result of the virtual elimination of the production of primary organic matter in the ecosystem. In contrast, the loss of inorganic material from the stream bed has accelerated because of the greater erosive capacity of the augmented stream flow and also because several biological barriers to the erosion of surface soil and stream banks have been greatly diminished. The continuous layer of litter that once protected the soil surface is now discontinuous. The extensive network of fine roots that tended to stabilize the stream bank is now dead, and the dead leaves that tended to plaster over exposed banks are gone. The erosive trend can be expected to rise exponentially as long as regrowth of vegetation is inhibited in the watershed.

Our study clearly shows that the stability of an ecosystem is linked to the orderly flow of nutrients between the living and the nonliving components of the system and the production and decomposition of biomass. These processes, integrated with the seasonal changes in climate, result in relatively tight nutrient cycles within the system, a minimum output of nutrients and wa-

ter and good resistance to erosion. Destruction of the vegetation sets off a chain of interactions. Their net effect is an increase in the amount and flow rate of water and the breakdown of biological barriers to erosion and transportation, coupled with an increase in the export of nutrient capital and inorganic particulate matter.

Three points, which are inherent in the ecosystem concept and are emphasized by the Hubbard Brook study, should be recognized as being basic to any wise scheme for managing the use of land. First, the ecosystem is a highly complex natural unit composed of organisms (plants and animals, including man) and their inorganic environment (air, water, soil and rock). Second, all parts of an ecosystem are intimately linked by natural processes that are part of the ecosystem, such as the uptake of nutrients, the fixation of energy, the movement of nutrients and energy through food webs, the release of nutrients by the decomposition of organic matter, the weathering of rock and soil minerals to release nutrients and the formation of new minerals. Third, individual ecosystems are linked to surrounding land and water ecosystems and to the biosphere in general by connections with food webs and the worldwide circulation of air and water.

Failures in environmental management often result from such factors as failure to appreciate the complexity of nature, the assumption that it is possible to manage one part of nature alone and the belief that somehow nature will absorb all types of manipulation. Good management of the use of land—good from the viewpoint of society at large—requires that managerial practices be imposed only after a careful analysis and evaluation of all the ramifications. A focus for this type of analysis and evaluation is the ecosystem concept.




**IMPACT OF DEFORESTATION** on the ecosystem relations of Watershed No. 2 is portrayed in terms of three types of effect (*color*). Cations are positively charged nutrient ions; anions are negatively charged. Normally cations are held fairly tightly within the ecosystem, but with deforestation they tended to leak away. The accelerated loss was related to the intensified nitrification.

# Computers in Eastern Europe

*Energetically trying to catch up in computer technology, the U.S.S.R. and six eastern European countries have set themselves the goal of building 33,000 machines by 1975*

by Ivan Berenyi

There has been much curiosity outside the U.S.S.R. and the other nations of eastern Europe about the level of development of computers in those countries. Informed observers have understood that the rate of introduction of computers, and their quality, will have more to do with the rate of economic progress in the U.S.S.R. than any number of successful expeditions into space. It is also quite clear that Russian planners share this appreciation of the role of the computer in a modern industrial society. To lack a first-rate computer technology is to fall behind on a broad front of technological, economic and social progress.

Barely 25 years have elapsed since the end of World War II, which left Russia devastated. In that period the U.S.S.R. not only had to rebuild almost its entire industrial base from scratch but also had to compete with other nations in exploiting half a dozen major new technologies, from synthetic polymers to nuclear power. In no area, however, was the U.S.S.R. less equipped to keep pace with other nations than in electronics and computer technology. Although "credit" for building the first electronic computer can be claimed by at least three countries (Germany, Britain and the U.S.), the computer as a capacious and versatile mechanism was distinctly an American creation. Every major early design was financed, directly or indirectly, by the Department of Defense. The computer was unquestionably a by-product of military research and development in the first postwar decade.

By 1955 long-range missiles and soon afterward the space program provided a second massive infusion of funds for computer development. Concurrently American computer companies adapted their new knowledge and new manufacturing techniques to the production of commercial computers, for which the American business community was to show an almost insatiable appetite. By 1965 at least 23,000 computers were in operation throughout the U.S.—in banks, insurance companies and manufacturing firms. Today the U.S. computer population is around 63,000, of which some 46,500 are general-purpose machines and the remainder special-purpose units. In the latest computers several thousand transistors are packaged in the space occupied by one of the original 1948 transistors. Reliability, once such an elusive goal, is now taken for granted.

One would expect a planned socialist society to have an urgent need for many of the most advanced computers to coordinate the activities of an entire economy and to develop long-range plans. It is clear that the U.S.S.R. has recognized the need and is moving energetically, in concert with other nations in eastern Europe, to build and exploit a new generation of powerful machines. Although specific details are lacking, members of the Supreme Soviet have spoken of creating a network of 800 regional data-processing centers by 1980. Each country, each republic and probably each province would be included in the network. Data banks would contain details of each region's population, industry, agriculture, transport, housing and so on. From such statistics one could create mathematical models of the economy and study the effects of proposed changes.

To help bring this plan to fruition the member countries of Comecon—the Council for Mutual Economic Assistance of Warsaw Pact Nations—signed a protocol in January calling for development of "a single automated system for the search and distribution of information." The occasion for the protocol was the first conference of the International Center of Scientific and Technical Information, attended by representatives from Bulgaria, Czechoslovakia, East Germany, Hungary, Mongolia, Poland, Romania and the U.S.S.R.

The protocol is quite clearly related to the development of a projected new series of computers, designated RJAD. The manufacture of the RJAD machines will be a joint venture of the Warsaw Pact countries. It is likely that Poland will produce small central processors, tape readers, line printers and other components; East Germany will probably supply peripheral equipment; Hungary, magnetic memories and software (programs). Czechoslovakia, which has large electronics plants, will be a major source of integrated circuits. Romania and Bulgaria may contribute various subcomponents and some software. The U.S.S.R. will develop the basic designs, build most of the circuitry and central processors and be responsible for most of the software. It is also possible that the U.S.S.R. will duplicate all the facilities being provided by others so that it can be self-sufficient if necessary. This has already led to debate in the negotiations.

The road to cooperation has not been easy. For the U.S.S.R. a unified eastern European computer industry has political as well as economic advantages, but the other countries have two main grounds for reluctance. First, their assigned contributions will absorb scarce capital, for which there are many competing demands; second, the computer project will tend to restrict the technological ambitions of several of the largest countries involved (notably Czechoslovakia, East Germany, Hungary and Poland) that already have independent and

RUSSIAN COMPUTER FACTORY in Kiev is one of seven principal computer-manufacturing centers in the U.S.S.R. The Russian computer industry was not formally established until 1956, only a year before U.S. companies were ready to introduce their second generation of commercial machines. According to the author, a new line of Russian computers will resemble the IBM 360 series.

| | |
|---|---|
| U.S. | 62,500 |
| WESTERN EUROPE | 24,000 |
| U.S.S.R. | 5,500 |
| EASTERN EUROPE | 1,500 |
| OTHER | 12,500 |
| WORLD TOTAL | 106,000 |

| | |
|---|---|
| WEST GERMANY | 6,100 |
| UNITED KINGDOM | 5,900 |
| JAPAN | 5,900 |
| FRANCE | 4,500 |
| CANADA | 3,000 |
| ITALY | 2,700 |
| SCANDINAVIA | 1,500 |
| NETHERLANDS | 1,100 |

| | |
|---|---|
| U.S.S.R. | 5,500 |
| EAST GERMANY | 500 |
| POLAND | 420 |
| CZECHOSLOVAKIA | 200 |
| YUGOSLAVIA | 180 |
| HUNGARY | 120 |
| ROMANIA | 50 |
| BULGARIA | 30 |
| | 7,000 |

**PRESENT WORLD COMPUTER POPULATION** (*table at left*) **combines the author's estimates for eastern Europe and the U.S.S.R. with figures compiled by the International Data Corporation for the rest of the world as of January, 1970. Of the 62,500 computers shown for the U.S., some 46,500 are general-purpose machines, the remainder being "dedicated," or special-purpose, units. For other countries the figures represent chiefly general-purpose computers. The middle table, also based on figures from International Data, lists the top eight computer users aside from the U.S. and the U.S.S.R. The table at the right is the author's estimate of the number of computers in individual eastern European countries. According to the author, 60 to 80 percent of the computers in western Europe and the U.S. belong to the "third," or latest, generation, with the remainder being of the second generation. In eastern Europe and the U.S.S.R. fewer than 5 percent are the latest models whereas some 35 to 38 percent are still first-generation machines.**

growing computer industries. Without a strong cooperative effort it will not be easy for the U.S.S.R. and its neighbors to reach their goal of building some 33,000 RJAD computers by 1975. It is estimated that the participating countries are now operating some 7,000 computers.

The RJAD series will have five models. It is believed the first four will be similar to the first four models in the IBM 360 series: the 360/20, 360/30, 360/40 and 360/50. The fifth and largest will be based either on the IBM 360/65 or will be a development of the most powerful Russian computer: the BESM-6. The 360 series includes two models even larger than the 360/65: the 360/85 and the 360/195. The 360/195 and the still newer 370/155 and 370/165, along with the Control Data 7600, are usually considered the most advanced computers in the world. It is unlikely that any of the standard models in the RJAD series will be even half as capacious. This is not, however, to denigrate the present BESM-6, which is suitable for the most advanced applications.

In 1955, when the U.S. already had two years of experience with its first generation of vacuum-tube computers, the U.S.S.R. had only a few custom-built machines, chiefly for scientific purposes. It had no computer industry as such, and in fact Russian planners were still debating whether or not one would be needed. Japan also lacked a computer industry in 1955, but it had two advantages not possessed by the U.S.S.R.: a well-developed electronics industry and direct access, through purchase, to the latest American designs. Thus whereas Japan is now mass-producing medium-sized

**LARGEST RUSSIAN COMPUTER, the BESM-6, compares favorably with all but the most powerful American machines. The BESM-6 can perform about a million operations a second. Current models have storage space for 65,000 words, each 48 data bits in length. This substantially exceeds the word length in advanced U.S. machines of the second generation, but it is only three-fourths the word length in the Control Data 6600 and 7600, generally regarded as two of the most powerful scientific computers in the world.**

but up-to-date computers and is operating as many computers as Britain, the U.S.S.R. is still struggling to close the gap. In the U.S. the second generation of computers based on transistors appeared in 1957 and the third generation, incorporating integrated circuits, followed in 1964. It was not until 1956 that the Russian government, having overcome internal objections, agreed to support the large-scale production of computers.

The first generation of Russian machines, the M-20 and the Ural-1, appeared in 1959. Quasi-second-generation additions to the Ural family followed in 1961, the year in which several eastern European countries took their first steps in computer technology. At this point the U.S.S.R. became fully aware of the importance of computers and recognized that the demand could not be met from domestic production. Restrictions were eased to allow the importation of computers that American and western European builders were willing (or were permitted) to sell.

Two British companies, Elliott Automation and International Computers Limited (ICL), were in the best position to take advantage of the U.S.S.R.'s need. One machine in particular, the Elliott 803, achieved an early success. About a dozen were sold in Russia, mainly for process control and scientific work.

In 1964 the U.S.S.R. introduced the Minsk-22, a small, versatile scientific machine that soon became the most successful computer in eastern Europe. It was closely modeled on the Elliott 803, a fact discovered when a British company accepted one as part of a barter agreement. This was the first of several examples of emulation as the U.S.S.R. and her neighbors tried to catch up in an area of exceedingly complex technology. Early versions of the Polish Odra, for instance, followed the basic design of the Univac 1004, a machine that is smaller than the Elliott 803 and is now used mainly as a terminal or a satellite processor outside eastern Europe. The latest model in the Odra line, the 1304, is based on the ICL 1900 series, which are currently the most popular foreign computers in eastern Europe. Indeed, ICL has actively cooperated in the development of the Odra 1304 and has trained Polish computer technicians in the use of its software.

Proper programming is of particular importance in a medium-sized computer such as the Odra 1304. An efficient executive program can effectively increase the power of the machine by a factor of

**U.S.S.R.**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 1 | 802 | | | 1959 |
| | | 1 | ARCH 8000 | | | 1961 |
| | | 1 | 803 | | | 1961 |
| | | 1 | 803 | | | 1962 |
| | | 5 | ARCH 1000 | | | 1964/65 |
| | | 1 | 503 | | | 1965 |
| | | 2 | ARCH 8000 | | | 1966 |
| | | 2 | ARCH 102 | | | 1967/70 |
| Ferranti | U.K. | 3 | ARGUS 500 | | | 1969 |
| | | 2 | ARGUS 300 | | | 1969/70 |
| ICL | U.K. | 1 | 2400 | | | 1966 |
| | | | | 2 | 4/50 | 1969 |
| | | | | 1 | 1905E | 1970 |
| | | | | 2 | 4/70 | 1970 |
| | | | | 3 | 1903A | 1970/71 |
| | | | | 2 | 1906A | 1971/72 |
| Bull-GE | FRANCE | 1 | GAMMA 10 | | | 1967 |
| | | | | 2 | 415 | 1969 |
| GEISI | ITALY | | | 2 | 115 | 1969 |
| Siemens | GERMANY | | | 1 | 4004/45 | 1970 |

**BULGARIA**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 1 | ARCH 2020 | | | 1970 |
| ICL | U.K. | | | 1 | 4/50 | 1968 |
| | | | | 1 | 4/40 | 1969 |
| | | | | 1 | 1904 | 1969 |
| | | | | 1 | 1904A | 1970 |
| Gier | DENMARK | 1 | GIER | | | 1968 |
| Fujitsu | JAPAN | | | 2 | FACOM | 1969 |
| IBM | U.S. | — | 1460 | | | 1965 |
| | | | | — | 360/20 | 1968 |
| | | | | — | 360/30 | 1969 |
| | | | | — | 1130 | 1969 |

**CZECHOSLOVAKIA**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 3 | 803 | | | 1960/62 |
| | | 1 | 503 | | | 1964 |
| | | 1 | ARCH 8000 | | | 1964 |
| | | 1 | 4130 | | | 1968 |
| Ferranti | U.K. | | | 2 | ARGUS 500 | 1969 |
| ICL | U.K. | 1 | SIRIUS | | | 1964 |
| | | 1 | LEO 326 | | | 1966 |
| | | 2 | LEO 360 | | | 1967 |
| | | 1 | KDF-7 | | | 1967 |
| | | | | 2 | 1905 | 1967 |
| | | | | 2 | 1904 | 1967/68 |
| | | | | 1 | 1901 | 1968 |
| | | | | 1 | 1901A | 1968 |
| | | | | 5 | 4/50 | 1968/69 |
| | | | | 1 | 1902A | 1969 |

**FOREIGN COMPUTERS IMPORTED by the U.S.S.R. and six eastern European countries are listed in this table, which is continued on the next two pages. Compiled by the author from British and European sources, the table shows that the leading exporter in the early 1960's was the British company of Elliott, now GEC-Elliott Automation. The only machines of U.S. design bought by the U.S.S.R. are those built by foreign affiliates of General Electric.**

**CZECHOSLOVAKIA (CONTINUED)**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Marconi | U.K. | | | 1 | MIRIAD II | 1968 |
| Bull-GE | FRANCE | 1 | GAMMA 10 | | | 1964 |
| | | 5 | GAMMA 30 | | | 1965 |
| | | 4 | GAMMA 140 | | | 1968 |
| SEA | FRANCE | | | 1 | 3900 | 1968 |
| Gier | DENMARK | 2 | GIER | | | 1966/67 |
| Siemens | GERMANY | | | 1 | 3003 | 1967 |
| | | | | 1 | 4004/26 | 1968 |
| | | | | 1 | 4004/35 | 1969 |
| | | | | 1 | 4004/45 | 1969 |
| Zuse | GERMANY | 2 | 23 | | | 1964 |
| | | 1 | 25 | | | 1965 |
| Datasaab | SWEDEN | | | 3 | D21 | 1969 |
| General Precision | | 2 | LGP 30 | | | 1963 |
| | U.S. | 1 | LGP 21 | | | 1966 |
| Honeywell | U.S. | | | 2 | 3200 | 1969/70 |
| NCR | U.S. | 2 | 315 | | | 1967/68 |
| Univac | U.S. | 9 | 1004 | | | 1965/67 |
| | | 13 | 1005 | | | 1967/69 |
| | | 2 | 1050 | | | 1967/68 |
| | | | | 6 | 9300 | 1968/70 |
| | | | | 2 | 9400 | 1970 |

**EAST GERMANY**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| ICL | U.K. | | | 3 | 1905E | 1968/69 |
| Bull-GE | FRANCE | 1 | GAMMA 30 | | | 1967 |
| Siemens | GERMANY | | | 1 | 3003 | 1968 |
| Honeywell | U.S. | 4 | 1604 | | | 1967/68 |
| | | | | 2 | 516 | 1970 |
| IBM | U.S. | — | 1440 | | | 1967 |
| | | | | — | 360/40 | 1967/70 |
| NCR | U.S. | 1 | 315 | | | 1968 |
| Univac | U.S. | 2 | UCT 2 | | | 1966/67 |
| | | 4 | 1004 | | | 1967/69 |
| | | 1 | 1005 | | | 1968 |

**HUNGARY**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 4 | 803 | | | 1962/65 |
| | | 1 | 503 | | | 1965 |
| | | 1 | 2020 | | | 1966 |
| | | 1 | 2030 | | | 1967 |
| ICL | U.K. | | | 1 | 1905 | 1966 |
| | | | | 1 | 1901 | 1967 |
| | | | | 6 | 1904 | 1967/69 |
| | | | | 1 | 1905E | 1969 |
| | | | | 1 | 1903A | 1969 |
| | | | | 1 | 4/50 | 1969 |
| Bull-GE | FRANCE | 12 | GAMMA 10 | | | 1966 |
| Gier | DENMARK | 2 | GIER | | | 1965 |

**LARGEST VARIETY OF COMPUTERS has been imported by Czechoslovakia. (Table is continued from preceding page.) The leading supplier has been International Computers Limited, which has also sold many of its latest models to the U.S.S.R. Unit sales are not available for IBM machines, but probably no eastern European country has more than 10 units of any one model, all built by IBM in Europe. (Table is continued on opposite page.)**

four by arranging for several programs to run simultaneously. In addition ICL has developed and licensed to Poland a wide variety of application programs for carrying out specific tasks, such as production control, vehicle scheduling and critical-path analysis (a technique for optimizing production schedules).

The 1900 series is now more than five years old, and the Polish version is less advanced than the current British ones. For example, the Odra 1304 still uses individual transistors instead of integrated circuits, and its peripheral equipment (tape readers, printers and so on) is markedly inferior to the British counterparts. Meanwhile ICL is finishing designs on a new series of machines that will make the 1900 series obsolete within 18 months or two years. Thus the generation gap between computers inside and outside eastern Europe seems likely to be perpetuated. Some 60 percent of the Russian computers are still second-generation machines, such as the Minsk-22, whereas in the U.S. and Britain nearly 70 percent are third-generation units.

While preparing to put the new RJAD computers into mass production, the U.S.S.R. is investing heavily in research and development for the generation of machines that will replace the RJAD's. The present state of the art in the U.S.S.R. and something of its future direction can be judged from the structure of the two largest Russian-designed scientific computers: the BESM-6 and the Razdan-3.

In evaluating such machines experts pay particular attention to "word length" and the speed of the central processing unit. The word, or basic unit of storage, must be long enough to embrace the largest number likely to be created in the class of calculations the machine is designed to perform. The alternative is to spread the number over two or three words, which entails individual processing of each word and a consequent loss of speed. The need for high speed in the central processor is obvious when the main purpose of the machine is the rapid processing of lengthy and complex calculations.

Both of the advanced Russian machines have a word length of 48 data bits, long enough to hold any number up to $2^{48}$. This is 12 bits more than the word length in IBM's most powerful second-generation machines (for example the 7090), but it is smaller than the 64-bit length provided by the Control Data 6600 and 7600, two of the most advanced third-generation machines. One

can assume that the Russians accepted the 48-bit word length as a compromise, since a greater length naturally makes less efficient use of available storage space. The BESM-6 can perform about a million operations a second, which compares favorably with all but the fastest American machines. The largest Control Data computers are somewhat more than twice as fast.

In its main memory the BESM-6 currently has storage space for 65,000 words. In new models, which are just appearing, that capacity is doubled. This again puts the BESM-6 abreast of the most advanced machines outside eastern Europe. The Razdan-3, a smaller computer overall, operates at about a fourth the speed of the BESM-6 and has a storage limited to 32,000 words, which is still substantial.

A computer is no better than the software that controls its operation. The BESM-6 can be programmed in Fortran and Algol, the two universal languages for scientific computer work. More significant, however, is a highly advanced operating system that enables the machine to handle a number of different jobs simultaneously. Although similar systems are available in the West, it seems likely that the system used by the BESM-6, and by the Razdan-3 as well, compares quite favorably with any of them.

Nonetheless, the Institute of High Energy Physics in Serpukhov, home of the 70-billion-electron-volt particle accelerator, the world's largest, has recently ordered five ICL computers, including two of the British manufacturer's largest system, the 1906A. The reason for selecting the ICL machines over the BESM-6 is almost certainly owing to the superiority of the British peripheral equipment: magnetic tapes, printers, punched-card and tape readers and key punches. Delivery may also have been a factor. The BESM-6 is virtually a handmade machine, and no more than a dozen or so are in existence. The U.S.S.R. is still struggling to produce the integrated circuits that have made the third-generation machines outside eastern Europe so compact and reliable. In the fundamental design of hardware and software the Russian computer art is as clever as that to be found anywhere in the world. It is in the quality of production, not design, that the U.S.S.R. is lagging.

In emulating the IBM 360 series in the RJAD project the U.S.S.R. is evidently hoping to reap the production benefits of adhering to a well-proved design with

**HUNGARY (CONTINUED)**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Siemens | GERMANY | | | 1 | 4004/35 | 1970 |
| | | | | 1 | 4004/45 | 1970 |
| GEISI | ITALY | | | 1 | 115 | 1968 |
| Honeywell | U.S. | | | 4 | H2200 | 1969 |
| IBM | U.S. | — | 1401 | | | 1965 |
| | | | | — | 360/20 | 1968 |
| | | | | — | 360/40 | 1969 |
| Univac | U.S. | 7 | 1004 | | | 1964/67 |
| | | 9 | 1005 | | | 1965/70 |
| | | 1 | 1050 | | | 1966 |

**POLAND**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 3 | 803 | | | 1961/62 |
| | | 1 | ARCH 102 | | | 1966 |
| | | 20 | M2112 | | | 1969 |
| ICL | U.K. | 1 | 1300 | | | 1965 |
| | | | | 1 | 1903 | 1967 |
| | | | | 1 | 1905 | 1967 |
| | | | | 4 | 1904 | 1967/68 |
| | | | | 1 | 4/50 | 1969 |
| | | | | 1 | 1903 | 1969 |
| Gier | DENMARK | 1 | GIER | | | 1966 |
| Honeywell | U.S. | | | 1 | H3200 | 1970 |
| IBM | U.S. | — | 1440 | | | 1966 |
| | | | | — | 360/30 | 1969 |
| NCR | U.S. | 1 | 315 | | | 1967 |

**ROMANIA**

| MANUFACTURER | COUNTRY | SECOND GENERATION | | THIRD GENERATION | | YEAR OF DELIVERY |
|---|---|---|---|---|---|---|
| | | UNITS | MODEL | UNITS | MODEL | |
| Elliott | U.K. | 1 | 803 | | | 1963 |
| | | 2 | ARCH 1000 | | | 1964/68 |
| | | 1 | ARCH 2020 | | | 1968 |
| | | 1 | M2112 | | | 1970 |
| ICL | U.K. | | | 1 | 1903 | 1968 |
| | | | | 1 | 4/50 | 1969 |
| | | | | 1 | 1905 | 1970 |
| CII | FRANCE | | | 1 | 90/40 | 1969 |
| Bull-GE | FRANCE | 4 | GAMMA 10 | | | 1967 |
| Siemens | GERMANY | | | 1 | 4004/45 | 1968 |
| Fujitsu | JAPAN | | | 2 | FACOM | 1969 |
| IBM | U.S. | | | — | 360/20 | 1968 |
| | | | | — | 360/40 | 1968/69 |
| | | | | — | 360/30 | 1969 |

Elliott now GEC–Elliott Automation Limited
ICL International Computers Limited
CII Compagnie Internationale pour l'Informatique
SEA Société d'Électronique et d'Automatisme
Gier Regencentralen Gier
Zuse Zuse K. G.
Bull-GE Bull–General Electric; now Compagnie Honeywell Bull
GEISI General Electric Information Systems Italia; now Honeywell Information Systems Italia
IBM International Business Machines
NCR National Cash Register

**MANY THIRD-GENERATION COMPUTERS have been purchased in the past few years by Hungary, Poland and Romania. Such computers are distinguished by the use of integrated circuits. As the notes at the bottom of the table show, General Electric's computer business has recently been transferred to Honeywell Incorporated. With this merger Honeywell becomes the second-largest manufacturer of computers in the world. IBM is the largest.**

which all the eastern European countries are familiar. A second advantage is that domestic production can be supplemented by importing compatible machines, either from IBM or from other American or western European builders whose units are compatible with the 360's. A third advantage is that the 360 units being copied are precisely those models best suited for commercial data processing rather than for industrial process control or scientific computation. It is in data processing, with its need for extremely fast and reliable peripheral equipment, that Russian experience has been most limited.

When the U.S.S.R. began seriously to exploit computers for commercial work, around 1964 and 1965, it found itself with machines poorly equipped for the task. Although several of its early scientific computers, such as the Minsk-2 and the Minsk-22, were versatile enough for data processing, they did it clumsily. It was partly for this reason that imports of computers, particularly from Britain, began to increase sharply from 1964 onward.

It would not have been an insuperable problem for the U.S.S.R. to have designed a line of data-processing computers from scratch, but design of software is a different matter, involving as it does complex file-handling systems, multiprogramming and facilities for telecommunication. IBM devoted several years of immense effort in developing the operating system for the 360 series, and even then many modifications had to be made before the system could be said to be working satisfactorily. The U.S.S.R. plans to short-cut this costly stage by adopting IBM software along with the hardware, although it can hardly expect the cooperation from IBM that Poland got from ICL on the Odra 1304.

**COMPUTER FACTORY IN KIEV makes both general-purpose computers and process-control computers, such as the Dnepr-2. Here workers are assembling electronic components on printed circuit boards, a technique characteristic of second-generation machines.**

In spite of being far behind in numbers of computers in service, the U.S.S.R. is nevertheless using computers in virtually every field in which they have been found useful outside eastern Europe, from construction and inventory control to medicine and space studies. There is considerable difference, however, in the Russian approach. Whereas business data processing in the U.S. and western Europe tends to be customer-oriented, in the U.S.S.R. the first priority is given to the needs of industry: management and production control.

The central planning network with its 800 computer centers is the apotheosis of this approach. The forecasting and simulation tasks that will fall to such a network are actually more suited to the capacities of high-speed scientific computers than to data-processing machines. It is doubtless for this reason that the U.S.S.R. is planning to use a stretched version of the BESM-6 as the top of the line in the RJAD series. One can envisage such machines being installed at major regional centers to perform simulation studies, while smaller computers at local branches would collect and collate data for transmission to the regional centers.

Two areas of technology in which the U.S.S.R. has had little experience will be crucial to the success of the project: the linking of computer systems and telecommunications. The Academy of Sciences in Moscow is experimenting with linked systems, using a BESM-6 and its smaller predecessors, the BESM-2, -3 and -4. A start has also been made in telecommunications with the recently introduced Minsk-32, the first Russian computer with a time-sharing capability. Contracts have already been placed with western European manufacturers for the installation of telecommunications equipment, including teletype terminals.

Accompanying these various hardware and software problems is the basic problem of providing the skilled technicians to implement the system. A major investment in training facilities will be required if the U.S.S.R. is to meet the computer manpower needs of the coming decade. If the U.S.S.R. gives the priority to the RJAD project that it has given in the past to other projects of great national importance, there is little doubt that it will meet its goals, and more or less on time.

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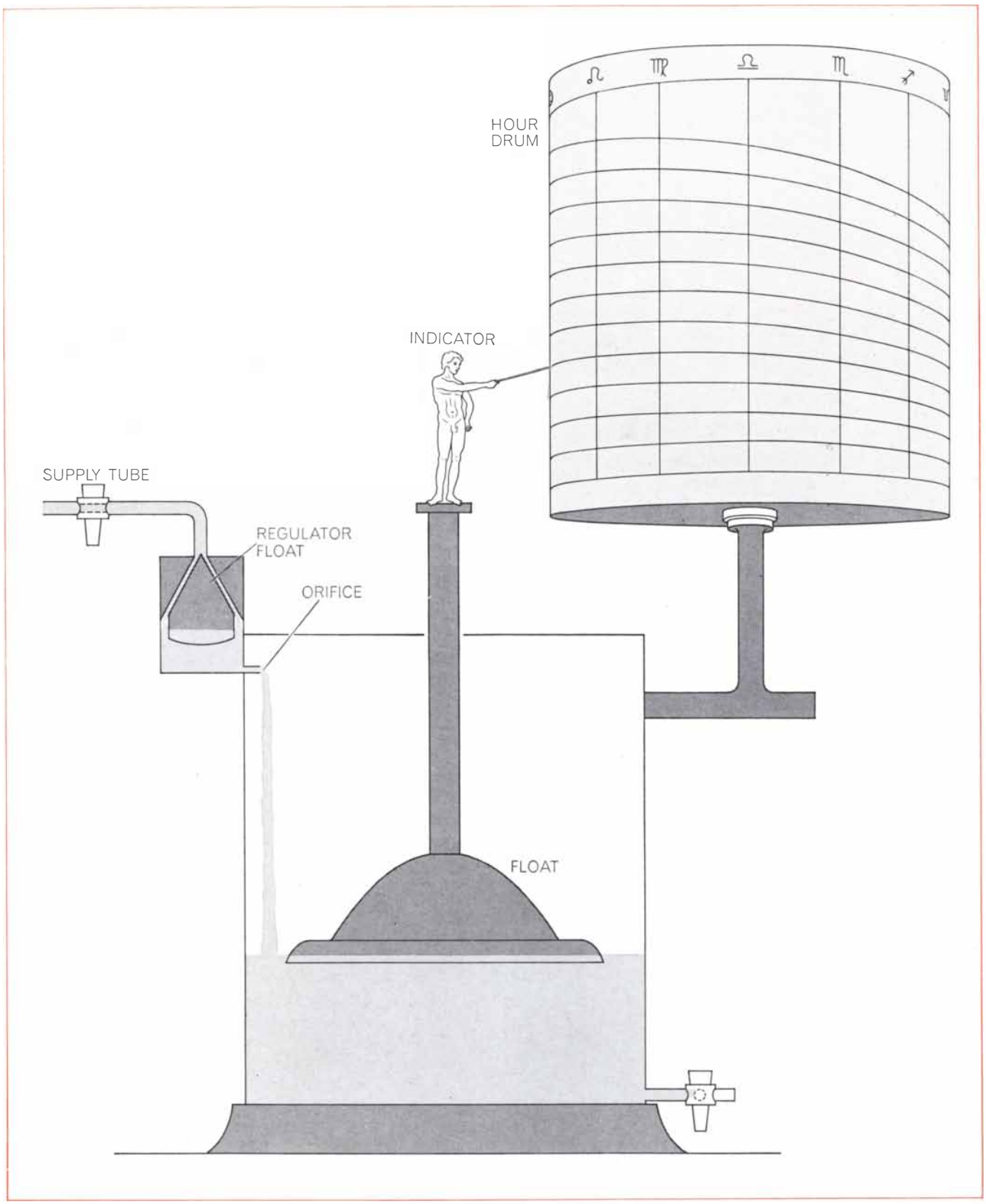



**ANCIENT WATER CLOCK** is the earliest known device for feedback control. It was invented in the third century B.C. by a Greek mechanician named Ktesibios, working in Alexandria. This drawing is based on a reconstruction by the German classicist Hermann Diels. The indicator figure is mounted on a large float (*bottom*), which rises inside a tank as a result of a slow trickle of water into the tank. The 12 hours, which vary in length with the seasons of the year, are indicated on the drum at top right. The change in the length of the hours can be represented by simply turning the drum to the proper month. The float regulator at top left controls the rate of water flowing into the main tank by maintaining a constant water level in the adjacent regulator vessel. If the level rises (as a result, say, of an increase of static pressure in the external supply line), the regulator float will rise, throttling the inflow into the regulator vessel. The device is remarkably similar in operation to the carburetor of a modern automobile.

# The Origins of Feedback Control

*The evolution of the concept of feedback can be traced through three separate ancestral lines: the water clock, the thermostat and mechanisms for controlling windmills*

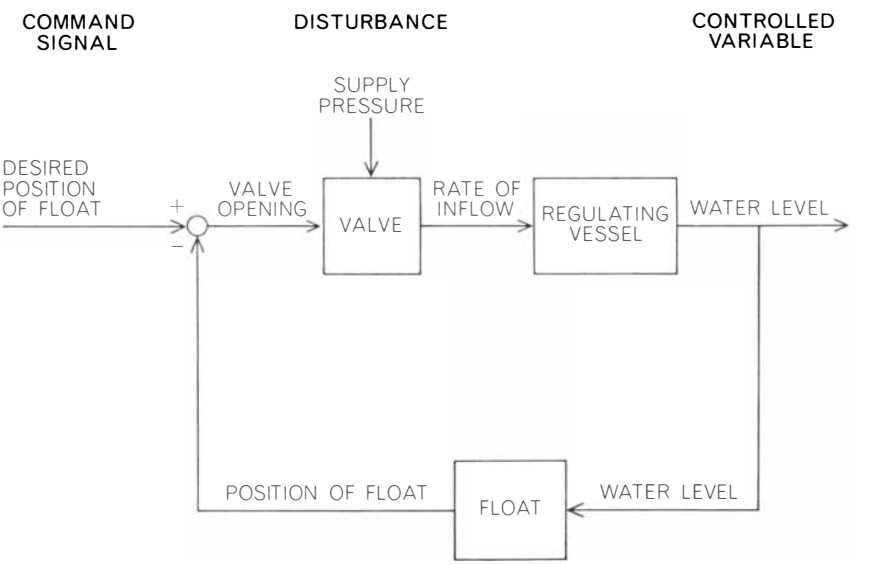
by Otto Mayr

Every animal is a self-regulating system owing its existence, its stability and most of its behavior to feedback controls. Considering the universality of this process and the fact that the operation of feedback can be seen in a great variety of phenomena, from the population cycles of predatory animals to the ups and downs of the stock market, it seems curious that theoretical study of the concept of feedback control came so late in the development of science and technology. The term "feedback" itself is a recent invention, coined by pioneers in radio around the beginning of this century. And the exploration of the implications of this principle is still younger: it received its main impetus from the work of the late Norbert Wiener and his colleagues in the 1940's.

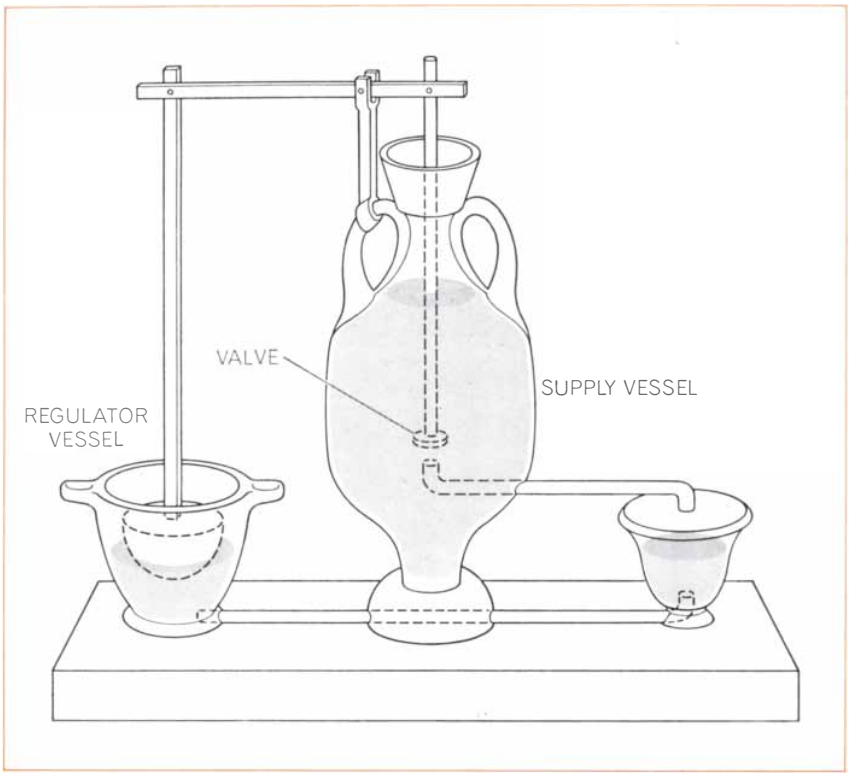
Feedback control is an instance of technology giving birth to science. Application of the feedback principle had its beginnings in simple machines and instruments, some of them going back 2,000 years or more. The thermostat and the flyball governor are well-known modern examples. Although the simple early inventions have been developed to a high order of sophistication, feedback control as an abstract concept did not receive much attention until the 1930's, when biologists and economists began to note striking parallels between their own objects of study and the feedback control devices of engineers. Certain regulatory processes in living organisms and in economic behavior showed the same cyclic structure of cause and effect and apparently obeyed the same laws. It became evident that the concept of feedback control could be a versatile and powerful tool for investigating many forms of dynamic behavior. Today the feedback control principle is not only widely embodied in hardware but also recognized as an important unifying concept in science.

The subject of this article is the historical growth of the concept. Its career can be traced with some assurance because feedback control can be rigorously defined. Wiener described it as "a method of controlling a system by reinserting into it the results of its past performance." A more formal definition, offered in 1951 by the American Institute of Electrical Engineers, states: "A Feedback Control System is a control system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control." The purpose of such a system is to carry out a command automatically, and it functions by maintaining the *controlled variable* (the output signal) at the same level as the *command variable* (the input) in spite of interference by any unpredictable disturbance. The command signal may be either constant, as it is in the case of the temperature setting on a thermostat, or continuously variable, as it is in the case of the steering wheel position in the power-steering system of an automobile. In all cases, if the feedback control system is to function effectively, it must be so designed that the controlled variable follows the command signal with the utmost fidelity.

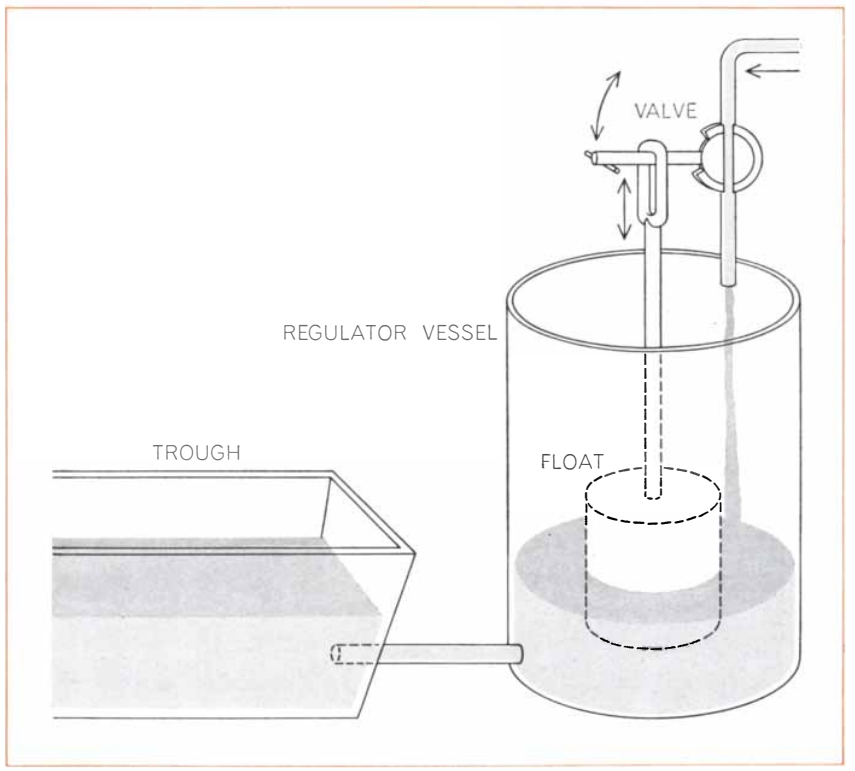
The main characteristic of a feedback control system is its closed-loop structure. The state of the output signal is




**TYPICAL CLOSED FEEDBACK LOOP is evident in this simplified block diagram depicting the operation of Ktesibios' water-clock flow regulator. The arrows represent signals and the blocks represent the physical components on which the signals operate. By expressing the signals as mathematical variables and the blocks as functions, the diagram can be reduced to a differential equation describing the dynamic behavior of the system.**




**"WINE DISPENSER" designed by Hero of Alexandria around A.D. 50 incorporated an improved float regulator in which the valve (the control element) was not directly attached to the float (the sensing element). The level in the communicating vessels was maintained by the float in one of the vessels (*left*) acting on the valve in the supply vessel (*center*).**




**FLOAT REGULATOR for an animal drinking trough was described in a ninth-century book titled *Kitāb al-Ḥiyal* (*On Ingenious Mechanisms*) by three brothers from Baghdad named Banū Mūsā. Water was drawn from a river through a pipe into two communicating vessels. The float in the regulating vessel controlled a stopcock valve in the intake pipe.**

monitored by some sensing device that feeds the signal back to the input side. There it is subtracted from the command signal; if the result is not zero, the system responds with a corrective action whose size and direction depend on the magnitude of the deviation, or "error signal." In the case of a home thermostat, for example, if the room temperature has dropped below the desired temperature, the system responds with an increased supply of heat, that is, a negative change in the output signal evokes a positive corrective action. In general a signal that has traveled around the loop of a feedback system returns with a reversed sign. The change of sign is essential for the stability of the system; if the signal were not changed in sign, it would create a vicious circle, building up the deviation of the output from the desired level.

The origin and main lines of development of the feedback concept are illustrated by three devices: the ancient water clock, the thermostat and mechanisms for controlling windmills. Let us trace the history of each of these applications and see where they led.

The earliest known construction of a device for feedback control was a water clock invented in the third century B.C. by a Greek mechanician named Ktesibios, working in the service of the Egyptian King Ptolemy II in Alexandria. He was probably associated with the illustrious museum that was then the principal cultural center of the Mediterranean world and attracted Greece's foremost scholars. Ktesibios' own descriptions of his inventions (which in addition to the water clock included a force pump, a water organ and several catapults) are now lost, but fortunately an account of them is preserved in *De Architectura*, the great work of the Roman architect and engineer Vitruvius.

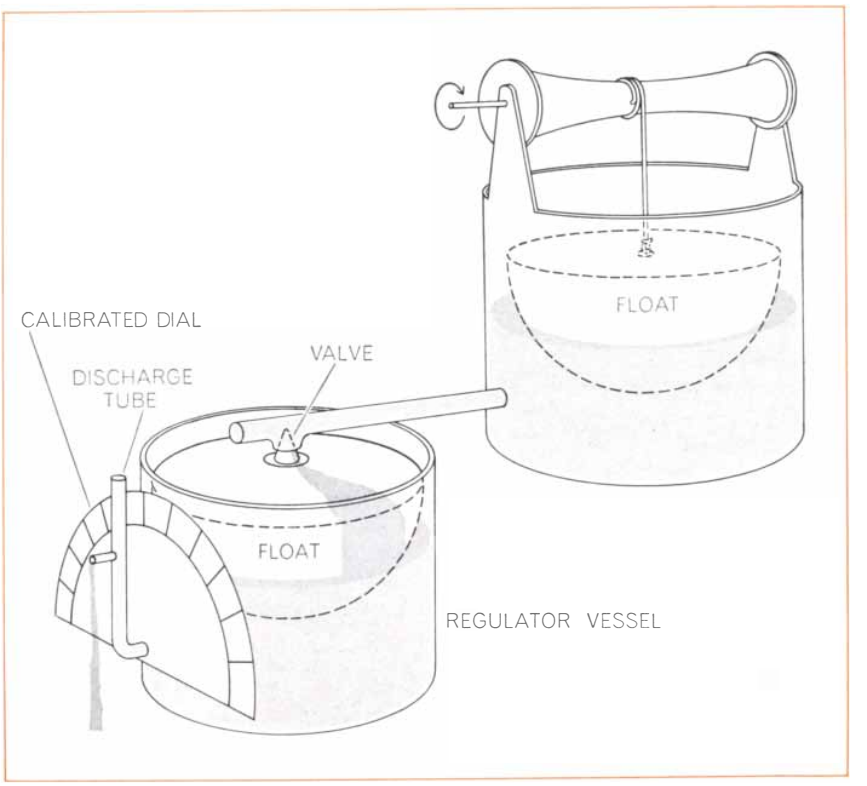
Vitruvius' description of Ktesibios' water clock is not clear; however, the German classicist Hermann Diels translated its obscurities into a plausible reconstruction of the device. The water clock measures the passage of time by means of a slow trickle of water, flowing at a constant rate into a tank where an indicator riding on the water tells the time as the water level rises [*see illustration on page 110*]. Ktesibios solved the problem of maintaining the trickle at a constant rate by inventing a device resembling the modern automobile carburetor. Interposed between the source of the water supply and the receiving tank, this structure regulates the water

flow by means of a float valve. When the float is at a certain level, the valve attached to it is open just far enough to feed water into the timekeeping tank at the desired rate. If for some reason the water in the regulator falls below or rises above that level, the float responds by opening or closing off the water supply until the float returns to the specified level.

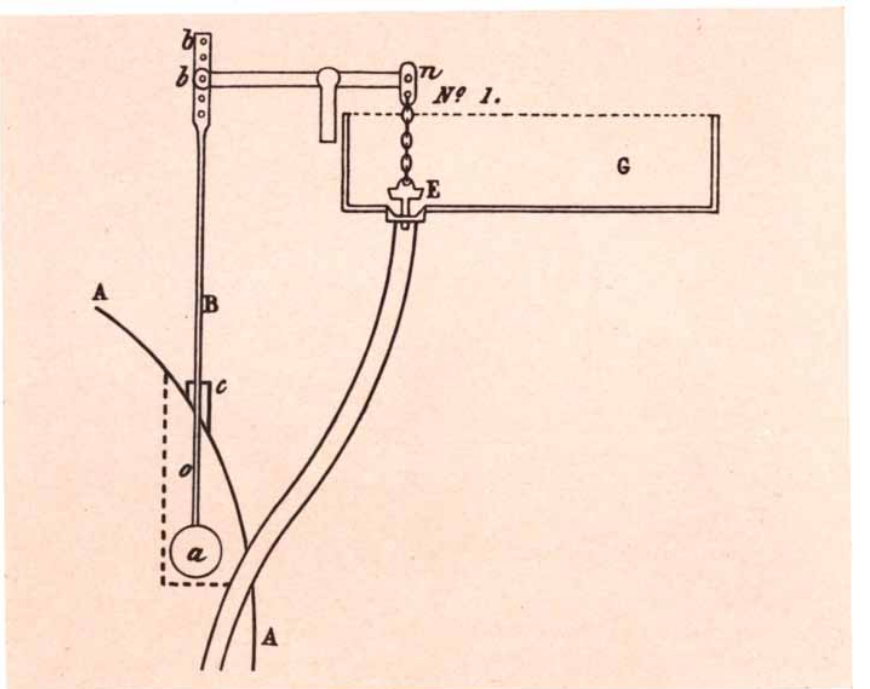
About three centuries after Ktesibios we again encounter automatic regulators of the float type in the *Pneumatica* of Hero of Alexandria. Hero was a prolific author of books on mathematics, surveying, optics, mechanics, pneumatics, automatons and military engineering, and his *Pneumatica* contains a number of amazing anticipations of modern inventions. Among other things, it describes several float regulators considerably more refined than that of Ktesibios. In one, called a "wine dispenser," the valve is not directly attached to the float, thus demonstrating that in a feedback control device the sensing element and the control element can be widely separated from each other [*see top illustration on opposite page*]. The playful applications Hero suggested for his devices are frowned on by some scholars; it is clear, however, that he was a serious scientist who was primarily interested in describing principles and used trivial but readily understandable examples the better to make his points.

In the ninth century, some 800 years after Hero, we find the float regulator cropping up again, this time in Arabic. In a book called *Kitāb al-Ḥiyal* (*On Ingenious Mechanisms*), evidently inspired by Hero's *Pneumatica,* a trio of authors in Baghdad presented eight applications of the float valve for feedback control. The authors were three brothers, Banū Mūsā, who were high officials at the court of the Abbaside caliphs. Their devices added a few refinements to the float-valve system. One was the use of a proper stopcock as the regulating valve instead of the primitive contrivance of a plate held against the end of a pipe [*see bottom illustration on opposite page*].

The float valve inspired some of the proudest achievements of Islamic technology in the period preceding the Middle Ages. Its artisans built monumental water clocks in which the time was told by elaborate theatrical displays performed by automatons. These are described in detail in three surviving books on water clocks. The first, probably written in the ninth century, is by an anonymous author usually called "Pseudo-




**NINTH-CENTURY WATER CLOCK was described by the Islamic author known as "Pseudo-Archimedes." The time-indicating mechanism (*not shown*) was driven by the constantly falling water level in the main float chamber. A constant discharge from this chamber was maintained by means of a float valve in the regulating vessel. The outflow from this vessel could in turn be calibrated by turning the discharge tube around its axis, thereby making it possible to adjust the clock for seasonal variations in the length of the hour.**

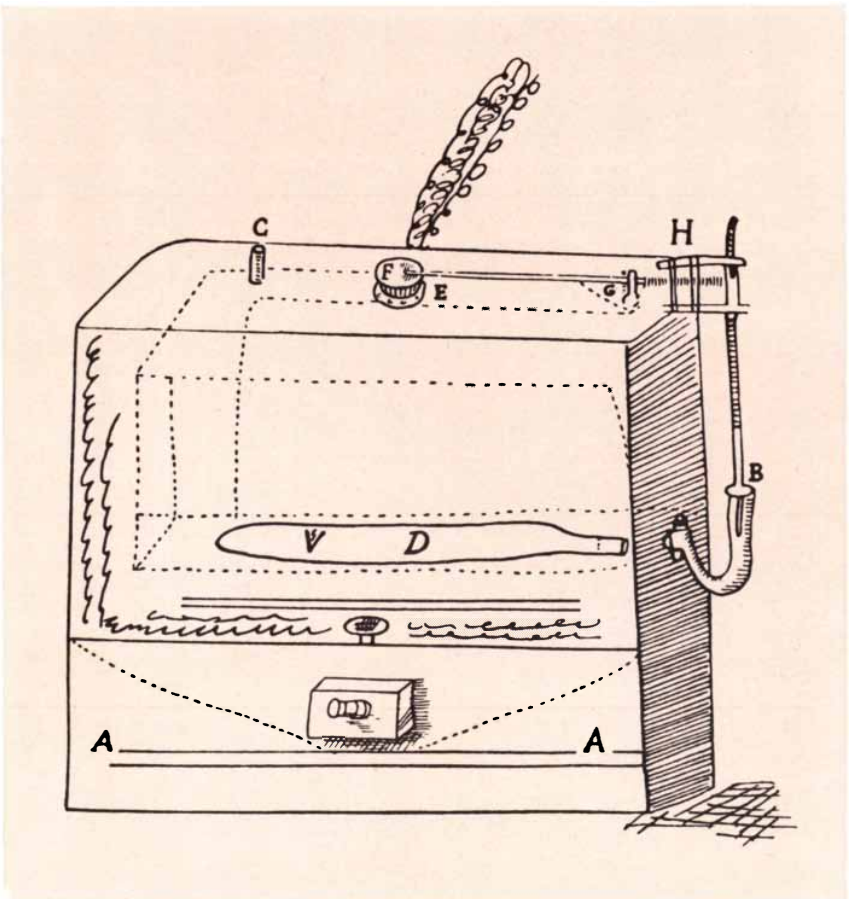



**FLOAT REGULATOR WAS REINVENTED in 18th-century England, apparently without knowledge of its earlier career. This drawing, showing a water-level regulator for steam boilers, is from a British patent awarded to Sutton Thomas Wood in 1784. The level in the boiler (*A*) was sensed by a float (*a*) that controlled the water supply through a valve (*E*).**

Archimedes"; the other two, based on that work, are by 13th-century writers named Ibn al-Sā'ātī and al-Jazarī. The clocks described in these three books employ the float-level regulator of Ktesibios, but it now regulates the *outflow* from the main float chamber instead of the flow into the chamber. Hence time is measured by the sinking, rather than the rise, of the water level [*see top illustration on preceding page*].

After these accounts in the early 13th century the float valve drops out of sight. No references to the employment of the device for water-level regulation have been found in the technological literature of the Middle Ages or the Renaissance or Baroque periods. Even a beautifully illustrated Latin translation of Hero's *Pneumatica*, which was published in 1575 and had a powerful impact on the development of technology, failed to induce engineers to take up the float regulator as a method of feedback control.

In the middle of the 18th century the device was reinvented in England, apparently without knowledge of its earlier career. The float regulator's rebirth was first mentioned in a 1746 building manual, *The Country Builder's Estimator*, by William Salmon, as a device for regulating the water level in domestic cisterns. In 1758 the British bridge and canal builder James Brindley obtained a patent for a steam engine that incorporated a float valve to regulate the water level in the steam boilers. A few years later I. I. Polzunov, a Russian pioneer in the development of the steam engine, designed such a device for the same purpose. In 1784 Sutton Thomas Wood in England patented the same invention once more in a design strikingly similar to Hero's 17-centuries-old system [*see bottom illustration on preceding page*]. The float regulator soon won general acceptance as a method of feeding water to boilers. Today it is widely used for many purposes.

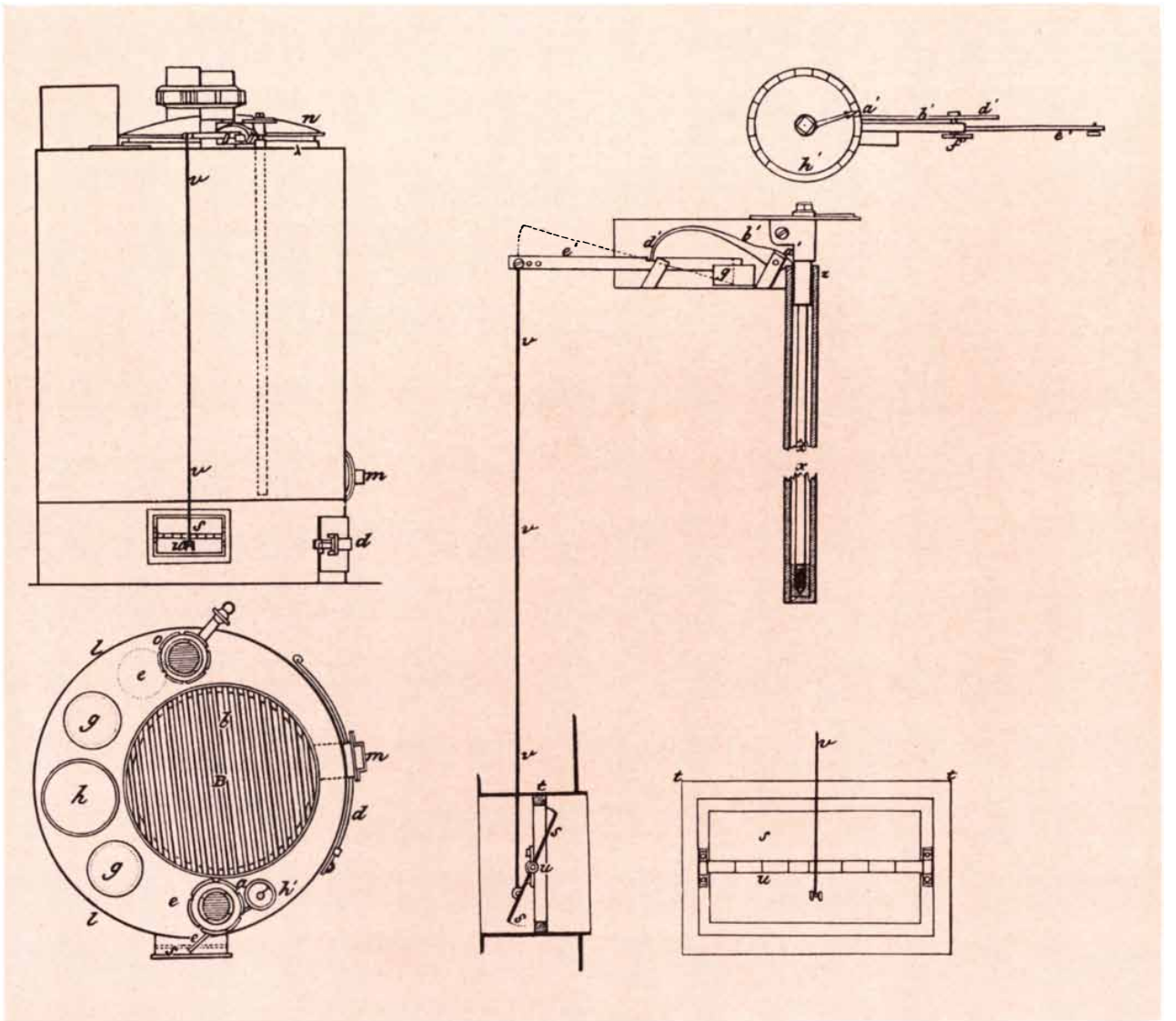



**FIRST THERMOSTAT** was invented early in the 17th century by Cornelis Drebbel. In this drawing, made by Drebbel's grandson, the device is shown adapted as a temperature regulator for an incubator. Smoke rising from the fire (*A–A*) passes by the water-jacketed incubator box (*dotted lines*) and escapes at the top through an opening (*E*). A glass vessel (*D*) containing alcohol is inserted into the water jacket and is sealed by mercury contained in a *U*-shaped portion of the vessel (*right*). As the temperature rises the increasing volume of the evaporating alcohol forces the mercury to rise in the right leg of the vessel, raising a float (*B*) and, through a linkage (*H*) pivoted at a point (*G*), closing a damper (*F*).

The thermostat does not have so ancient a history. Its first prototype was invented early in the 17th century by Cornelis Drebbel, a Dutch engineer who had migrated to England and worked in the service of James I and Charles I. A highly original inventor, Drebbel would be much better known today if he had committed his inventions to writing. According to an account by Francis Bacon, Drebbel devised his temperature regulator only incidentally, as an instrument to serve another purpose: alchemy. He believed he could transmute base metals to gold if he could keep the temperature of the process constant for a long time.

Drebbel's apparatus consisted basically of a box with a fire at the bottom and above this an inner compartment containing air or alcohol with a *U*-shaped neck topped by mercury [*see illustration at left*]. As the temperature in the box rose, the increased pressure of the heated air or alcohol vapor pushed up the mercury, which in turn pushed up a rod; this mechanical force was applied to close a damper and throttle down the fire. Conversely, if the temperature in the box fell below the desired level, the gas pressure was reduced, the mercury dropped and the mechanical linkage opened the damper.

Drebbel used his contrivance not only for smelting experiments but also to maintain an even temperature in incubators. His regulator seems to have worked with some success; members of the Royal Society of London, including Robert Boyle, Christopher Wren and in the following generation Robert Hooke, showed interest in it. Detailed descriptions of the device were given in a laboratory book by Drebbel's grandson (whose manuscript is preserved in the University of Cambridge library) and in the journals of a French devotee of science, Balthasar de Monconys, who investigated Drebbel's furnaces. Over the following century there were occasional reports of similar furnaces, evidently inspired by Drebbel's, that were built in Germany, France and America. None of these reports gave credit to Drebbel. The French natural philosopher and inventor René-Antoine de Réaumur described such a furnace for the artificial hatching of chickens and attributed its invention to a member of the French royal family, the Prince de Conti.

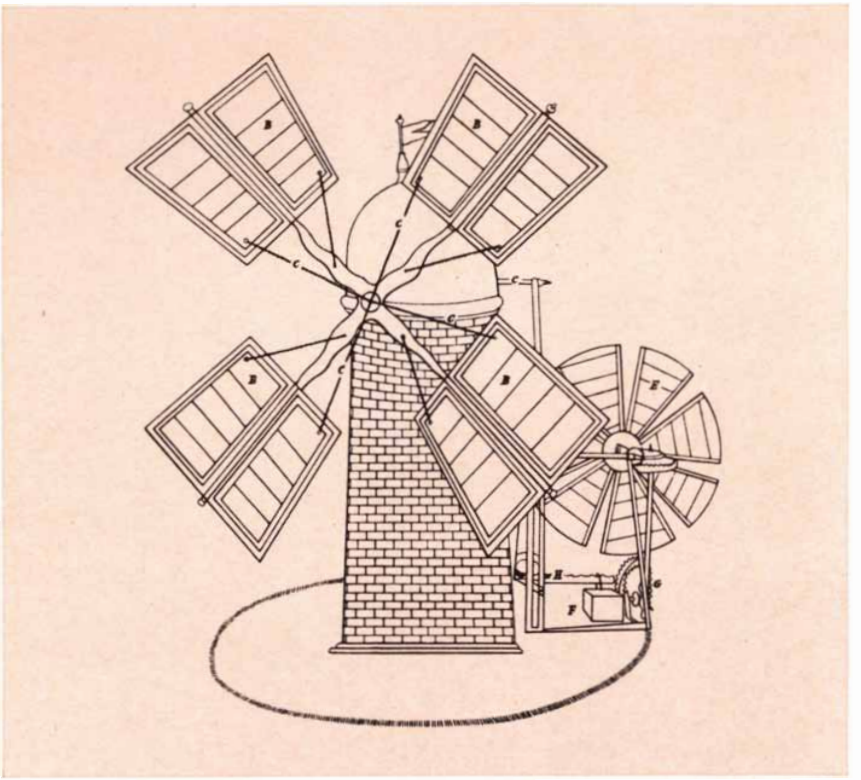


**IMPROVED THERMOSTAT, shown here as it was applied to regulate the temperature in a hot-water furnace, was designed in 1783 by a Parisian inventor named Bonnemain. A sensitive two-metal temperature feeler, consisting of an iron rod (*x*) surrounded by a lead tube (*z*), was immersed in the water to be heated. The motion of the upper rim of the lead tube caused by thermal expansion was then employed to adjust the air damper (*s*). The desired temperature inside the furnace could be set on a dial (*h*).**

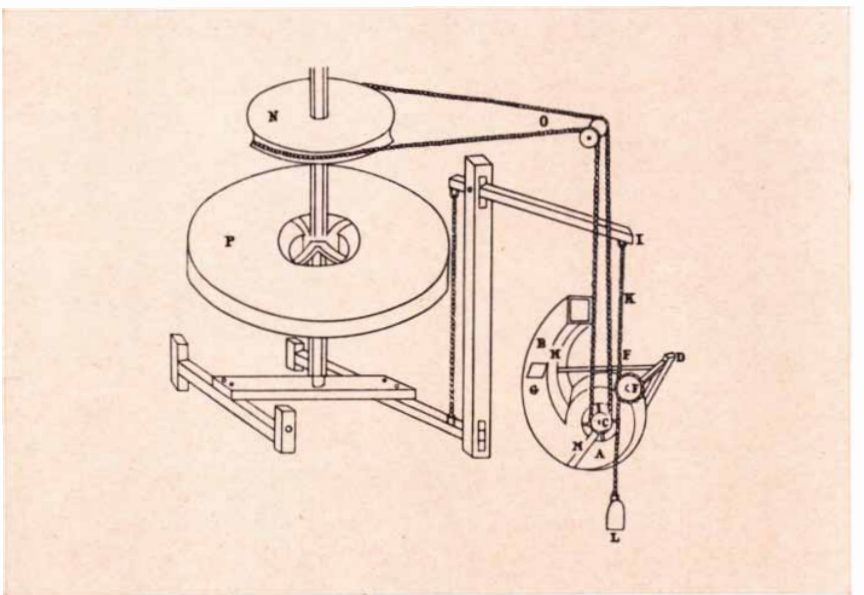
For two centuries Drebbel's idea of temperature regulation by feedback drew little notice apart from these few sporadic reports. Then the idea suddenly aroused the interest of the entire engineering community. Credit for this achievement belongs to a Parisian inventor named Bonnemain. In 1783 Bonnemain, presumably having got the idea from reading of Réaumur's success in hatching chickens with an artificial incubator, built a *régulateur de feu* himself and obtained a French patent for it. He proceeded to employ his self-regulating incubator with success in a large farm supplying chickens to the royal court and the Paris markets. Bonnemain's apparatus was far superior to the earlier temperature regulators: it had a sensitive temperature feeler made of two metals (an iron rod encased in a lead tube) and several refinements in design [*see illustration above*]. Bonnemain refrained from sharing the details of his apparatus with the world at large until he was over 80; in 1824 the French Society for the Encouragement of National Industry finally prevailed on him to publish a detailed description of his system of temperature regulation. The leading technical journals in Britain and Germany promptly published translations of this account, and Bonnemain's temperature regulator soon found its way into encyclopedias. The author of one of these, the Scottish chemist Andrew Ure, coined the term "thermostat" in his *Dictionary of Arts, Manufactures, and Mines,* which in 1839 described Bonnemain's regulator and some that Ure himself had designed.

The third ancestral line of feedback mechanisms originated in the invention of devices for the automatic control of windmills. They were devised in the 18th century by millwrights in England and Scotland, a resourceful group who combined craft skills with the beginning of a scientific attitude. Many of the famous British mechanical engineers of the 18th and 19th centuries began their careers as millwrights.

The first of the millwrights' feedback devices, patented in 1745 by Edmund



**EARLY WINDMILL CONTROLS** are shown in this drawing, from a British patent awarded to Edmund Lee in 1745. The regulatory devices consisted of a fantail designed to keep the windmill facing the wind and a mechanism to control the speed of the mill in spite of changes in the wind velocity. The tail wheel (*E*) attached to the movable cap of the mill drove a chain of gears that engaged a circular rack on the ground. If the mill was not facing the wind, the fantail would rotate, turning the main wheel into the wind. The main sails (*B*) of the mill were pivoted along the crossbeams and were held forward by means of a counterweight (*F*), to which they were attached by chains (*C*) running through the hollow main shaft.



**"LIFT-TENTER"** was a control device designed by the 18th-century British millwrights to counteract the tendency of millstones to move apart as their speed of rotation increased. In this drawing of a lift-tenter invented by Robert Hilton in 1785 the "runner" millstone (*P*) was lowered in proportion to the speed of the mill. The speed was measured by means of the displacement of a baffle (*B*) in the discharge shroud of a centrifugal fan (*A*).

Lee, was a fantail designed to keep the windmill facing the wind [*see top illustration at left*]. The fantail is a small windwheel mounted at right angles to the main wheel. It is attached to the rear side of the movable cap that turns the big wheel into the wind. Through a train of gears the fantail controls the turning of the cap, so that any rotation of the fantail will cause the cap to turn. When the main wheel squarely faces the wind, the fantail, at right angles, is aligned parallel to the wind direction and does not rotate. Whenever the wind shifts so that the main wheel no longer faces it squarely, the wind will strike the tail wheel, causing it to rotate and slowly turn the mill cap until the fantail again is parallel to the wind and the main wheel faces it. In short, the system forms a closed loop. Under actual conditions, with the wind direction constantly changing, the fantail can be considered a rudimentary servo system.

Lee's windmill also contained an invention that was designed to control the speed of the mill in spite of changes in the wind velocity. Regulation of the speed of rotation was needed to protect the millstones from excessive wear and to produce flour of uniformly fine quality. Lee attacked this problem by allowing the windmill sails to pivot around the arms that held them. The sails were connected to a counterweight that pitched their leading edge forward in moderate winds. When the wind rose to excessive velocities, so that its force on the sails was greater than that of the counterweight, the tilt of the sails was reversed and the wheel's rotation velocity was checked.

This system was not a case of feedback control, because it does not try to sense the controlled variable: speed. For genuine feedback control of a windmill's speed a method of measuring the speed with some sensitivity had to be found.

An approach to meeting that need was discovered in a mechanism known as the "lift-tenter." This device was designed to counteract the tendency of millstones to move apart as their speed of rotation increased. The lift-tenter operated to press the millstones together with a force proportional to the rotation speed [*see bottom illustration at left*]. In 1787 Thomas Mead, an English millwright and inventor, combined the lift-tenter idea with the use of a centrifugal pendulum to produce a speed-control system that genuinely embodied the feedback principle. The whirling pendulum measured the speed of the millstones' rotation, and through appropriate mechani-

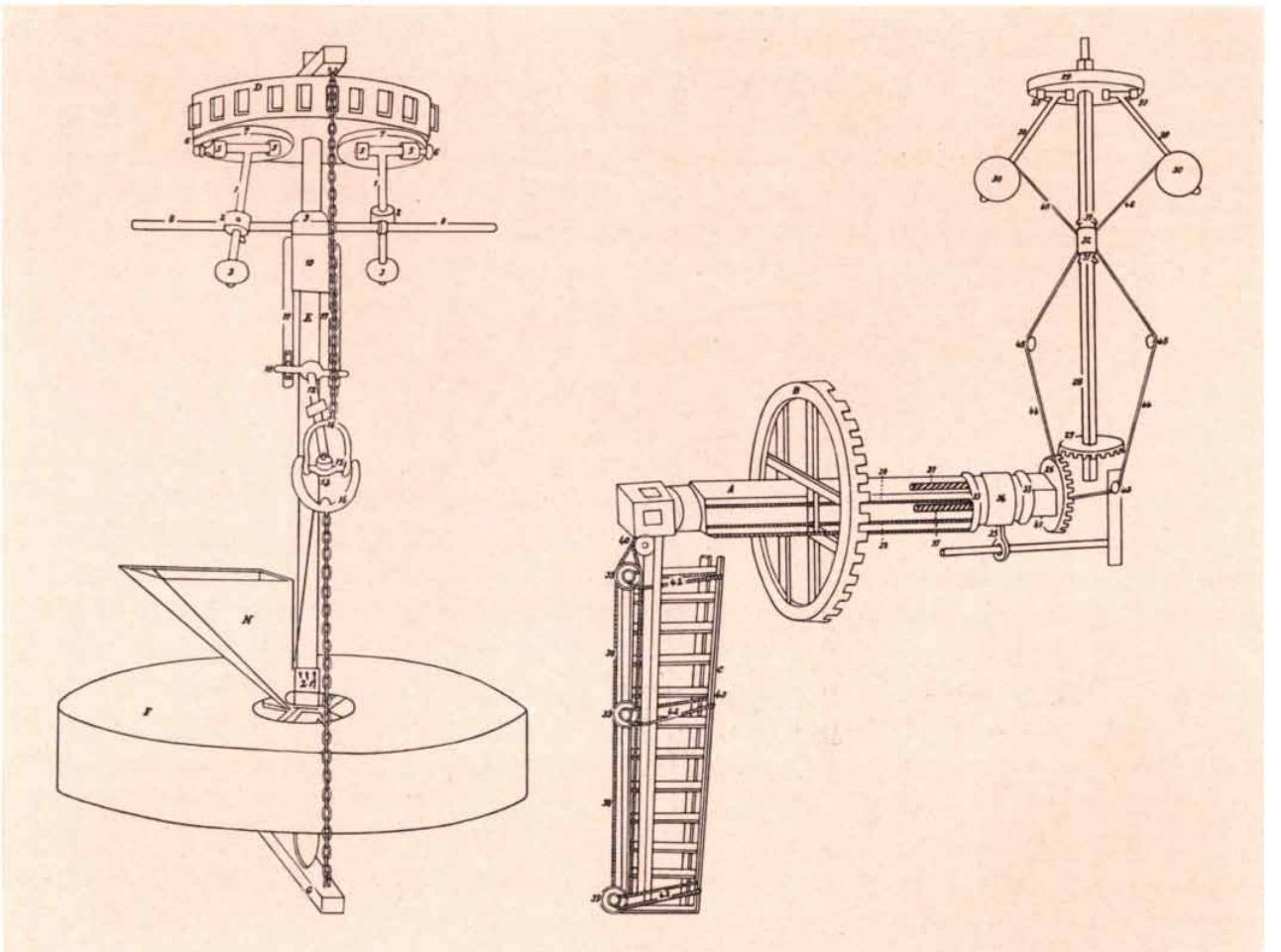
cal connections it adjusted the area of the windmill sails to keep the wheel rotating at the desired speed [*see illustration below*].

The idea of the centrifugal pendulum was immediately greeted with gratitude by the pioneers in the new technology of the steam engine, just then emerging. James Watt and his partner Matthew Boulton were building a large mill (later to be named the Albion Mill) where the capabilities of Watt's new rotary engine were to be demonstrated. The new engine presented totally new requirements for its regulatory system. There was no way to adapt the existing devices to the continuously operating rotary engine.

Watt and Boulton hired John Rennie, then a young man of 23, to supervise the construction and operation of the Albion Mill. Rennie (who was later to become one of Britain's most famous builders of bridges) had just finished his apprenticeship under the noted Scottish millwright Andrew Meikle. In a visit to the Albion Mill in May of 1788 Boulton found that a lift-tenter had been installed, presumably by Rennie. Boulton promptly sent a detailed and enthusiastic description of it to Watt. The idea fell on prepared ground. By November, Watt and his colleagues had designed a "centrifugal speed regulator," and around the end of the year the first governor was installed on the "Lap" engine. The picture of Watt's governor was to become perhaps the most familiar one in the entire history of technology.

Watt did not take out a patent for the governor. He considered the device merely an adaptation of the centrifugal pendulum to a new use. He and Boulton tried to protect it from competitors by keeping its existence secret; the first customers who ordered it were asked to hide the governor from public view. The device soon became known, however. Within a few years after its invention it was recognized everywhere as a symbol of the steam engine. Rotating dramatically at the top of every steam engine, it demonstrated the action of feedback control more widely and more forcefully than words could have done. The governor soon entered the textbooks and handbooks of engineering, and inventors began to develop feedback devices in other areas of technology.

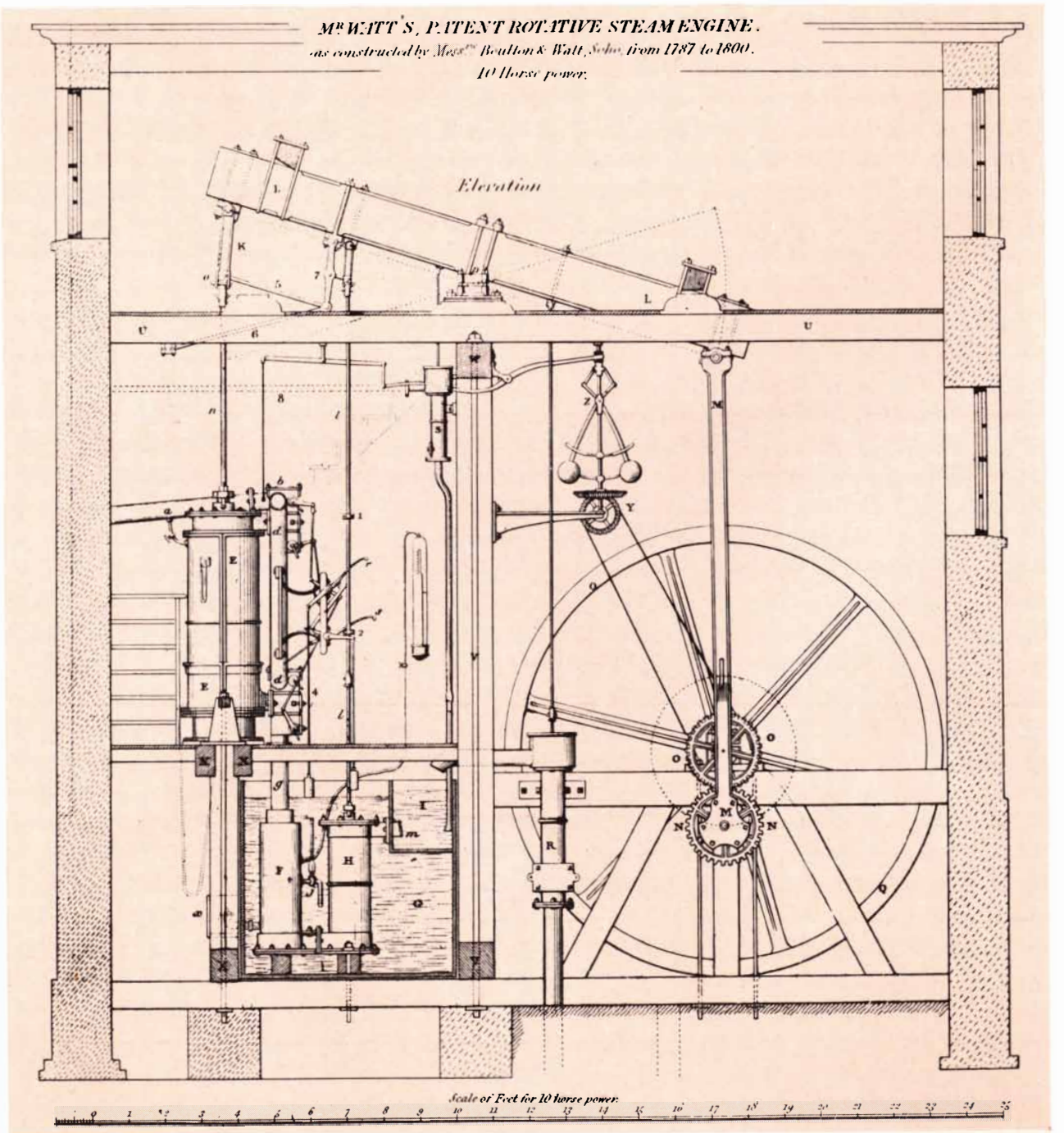
It is curious that all the inventions of feedback devices that came in with the beginning of the Industrial Revolution originated in Britain. Even those inventors who were not British-born, notably Drebbel and Denis Papin (the Frenchman who invented the safety valve, a rudimentary feedback device), presented their inventions while working in England. Why was the Continent so backward? Why was it, for instance,



**CENTRIFUGAL PENDULUMS** were employed as feedback control devices by the English millwright Thomas Mead in his 1787 windmill patent. The speed of rotation of the mill sensed by one set of centrifugal pendulums drove the mill's lift-tenter mechanism (*left*). The motion of another set of pendulums in turn regulated the speed of the mill by reducing the area of the sails (*right*).

that engineers and inventors on the Continent ignored the float valve presented in the widely read translations of Hero's *Pneumatica* in 1575 and took serious notice of it only after the device was rediscovered in Britain two centuries later?

One can speculate plausibly that in the 16th to 18th centuries the Continental mind rejected feedback control because it was preoccupied with a different conception of control: control by rigidly predetermined program. In technology this was evidenced by almost countless inventions of automatons, monumental clocks, music boxes and clock-driven planetariums. The fascination with ordered programs was reflected in the Continent's prevailing attitude toward the state (absolute government) and in the economic system (mercantilism). In Britain, on the other hand, scientists, inventors and philosophers early in the 18th century began to turn to a different concept of control, one in which the system was truly autonomous, containing inherent mechanisms that maintained its equilibrium and viability. In technology such thinking led to the creation of feedback devices, in economics to the free-market system of Adam Smith and in political science to the division of powers and constitutional government.




**FLYBALL GOVERNOR incorporated into the first continuously operating rotary steam engines in the 1790's by James Watt and Matthew Boulton was based directly on the windmill lift-tenter. In this 1826 drawing the centrifugal pendulum (*top center*), driven by a pulley, is linked to a throttle valve in the engine's steam line, enabling it to throttle the steam supply with increasing speed.**

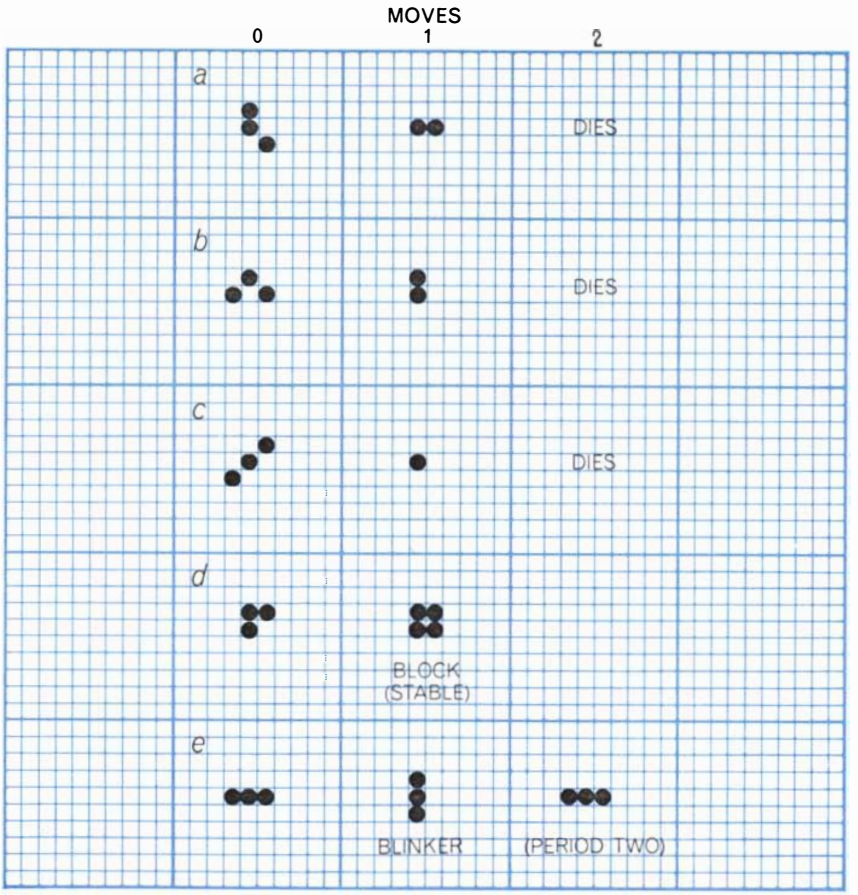
# MATHEMATICAL GAMES

## *The fantastic combinations of John Conway's new solitaire game "life"*

by Martin Gardner

Most of the work of John Horton Conway, a mathematician at Gonville and Caius College of the University of Cambridge, has been in pure mathematics. For instance, in 1967 he discovered a new group—some call it "Conway's constellation"—that includes all but two of the then known sporadic groups. (They are called "sporadic" because they fail to fit any classification scheme.) It is a breakthrough that has had exciting repercussions in both group theory and number theory. It ties in closely with an earlier discovery by John Leech of an extremely dense packing of unit spheres in a space of 24 dimensions where each sphere touches 196,560 others. As Conway has remarked, "There is a lot of room up there."

In addition to such serious work Conway also enjoys recreational mathematics. Although he is highly productive in this field, he seldom publishes his discoveries. One exception was his paper on "Mrs. Perkins' Quilt," a dissection problem discussed in "Mathematical Games" for September, 1966. My topic for July, 1967, was sprouts, a topological pencil-and-paper game invented by Conway and M. S. Paterson. Conway has been mentioned here several other times.




*The fate of five triplets in "life"*

This month we consider Conway's latest brainchild, a fantastic solitaire pastime he calls "life." Because of its analogies with the rise, fall and alterations of a society of living organisms, it belongs to a growing class of what are called "simulation games"—games that resemble real-life processes. To play life you must have a fairly large checkerboard and a plentiful supply of flat counters of two colors. (Small checkers or poker chips do nicely.) An Oriental "go" board can be used if you can find flat counters that are small enough to fit within its cells. (Go stones are unusable because they are not flat.) It is possible to work with pencil and graph paper but it is much easier, particularly for beginners, to use counters and a board.

The basic idea is to start with a simple configuration of counters (organisms), one to a cell, then observe how it changes as you apply Conway's "genetic laws" for births, deaths and survivals. Conway chose his rules carefully, after a long period of experimentation, to meet three desiderata:

1. There should be no initial pattern for which there is a simple proof that the population can grow without limit.

2. There should be initial patterns that *apparently* do grow without limit.

3. There should be simple initial patterns that grow and change for a considerable period of time before coming to an end in three possible ways: fading away completely (from overcrowding or from becoming too sparse), settling into a stable configuration that remains unchanged thereafter, or entering an oscillating phase in which they repeat an endless cycle of two or more periods.

In brief, the rules should be such as to make the behavior of the population unpredictable.

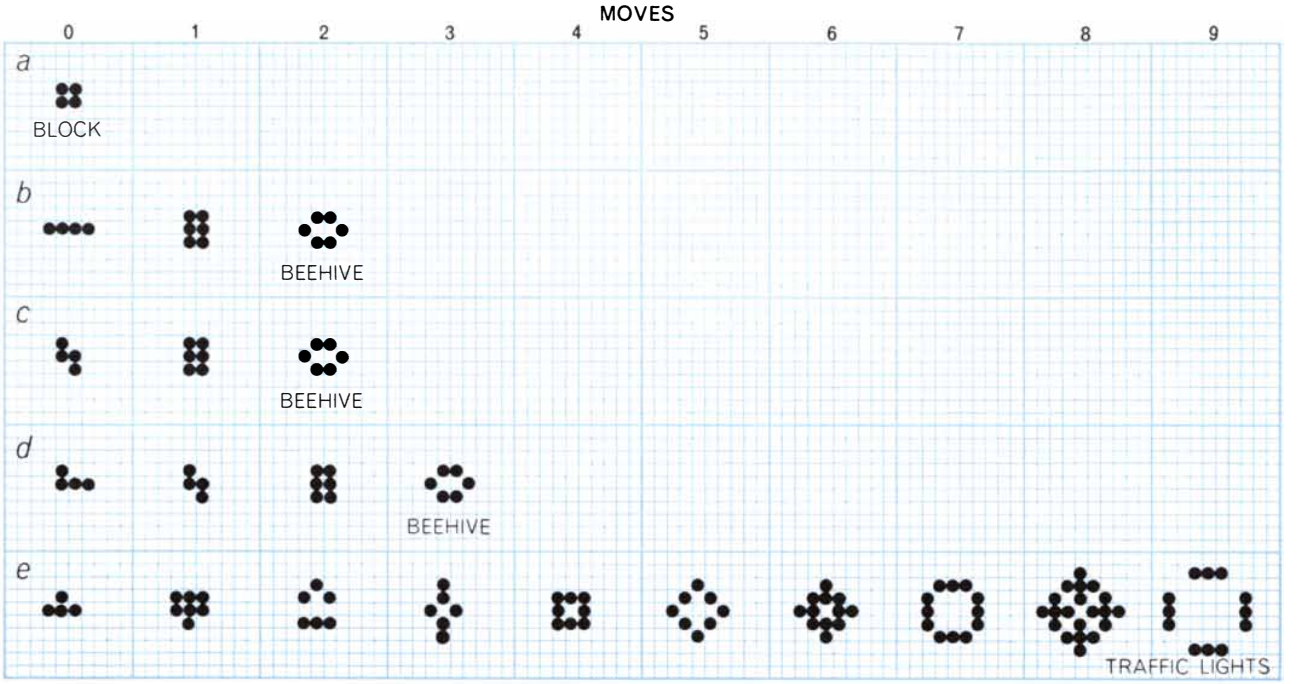
Conway's genetic laws are delightfully simple. First note that each cell of the checkerboard (assumed to be an infinite plane) has eight neighboring cells, four adjacent orthogonally, four adjacent diagonally. The rules are:

1. Survivals. Every counter with two or three neighboring counters survives for the next generation.

2. Deaths. Each counter with four or more neighbors dies (is removed) from overpopulation. Every counter with one neighbor or none dies from isolation.

3. Births. Each empty cell adjacent to exactly three neighbors—no more, no fewer—is a birth cell. A counter is placed on it at the next move.

It is important to understand that all births and deaths occur *simultaneously.* Together they constitute a single genera-




*The life histories of the five tetrominoes*

tion or, as we shall call it, a "move" in the complete "life history" of the initial configuration. Conway recommends the following procedure for making the moves:

1. Start with a pattern consisting of black counters.

2. Locate all counters that will die. Identify them by putting a black counter on top of each.

3. Locate all vacant cells where births will occur. Put a white counter on each birth cell.

4. After the pattern has been checked and double-checked to make sure no mistakes have been made, remove all the dead counters (piles of two) and replace all newborn white organisms with black counters.

You will now have the first generation in the life history of your initial pattern. The same procedure is repeated to produce subsequent generations. It should be clear why counters of two colors are needed. Because births and deaths occur simultaneously, newborn counters play no role in causing other deaths or births. It is essential, therefore, to be able to distinguish them from live counters of the previous generation while you check the pattern to be sure no errors have been made. Mistakes are very easy to make, particularly when first playing the game. After playing it for a while you will gradually make fewer mistakes, but even experienced players must exercise great care in checking every new generation before removing the dead counters and replacing newborn white counters with black.

You will find the population constantly undergoing unusual, sometimes beautiful and always unexpected change. In a few cases the society eventually dies out (all counters vanishing), although this may not happen until after a great many generations. Most starting patterns either reach stable figures—Conway calls them "still lifes"—that cannot change or patterns that oscillate forever. Patterns with no initial symmetry tend to become symmetrical. Once this happens the symmetry cannot be lost, although it may increase in richness.

Conway conjectures that no pattern can grow without limit. Put another way, any configuration with a finite number of counters cannot grow beyond a finite upper limit to the number of counters on the field. This is probably the deepest and most difficult question posed by the game. Conway has offered a prize of $50 to the first person who can prove or disprove the conjecture before the end of the year. One way to disprove it would be to discover patterns that keep adding counters to the field: a "gun" (a configuration that repeatedly shoots out moving objects such as the "glider," to be explained below) or a "puffer train" (a configuration that moves but leaves behind a trail of "smoke"). I shall forward all proofs to Conway, who will act as the final arbiter of the contest.

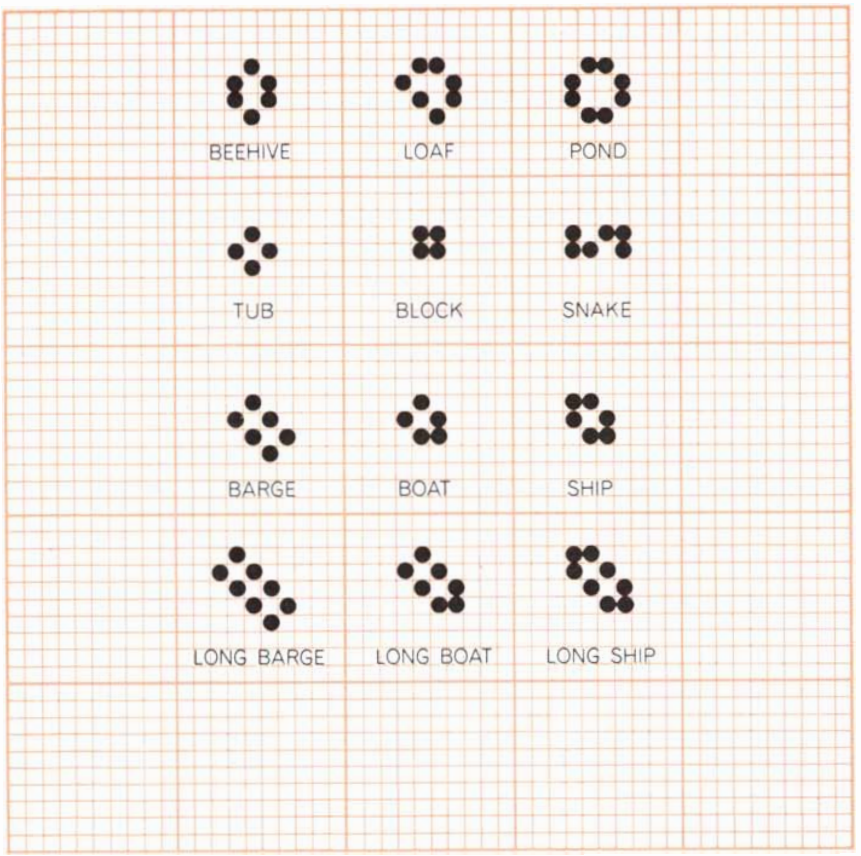
Let us see what happens to a variety of simple patterns.

A single organism or any pair of counters, wherever placed, will obviously vanish on the first move.

A beginning pattern of three counters also dies immediately unless at least one counter has two neighbors. The illustration on the opposite page shows the five triplets that do not fade on the first move. (Their orientation is of course irrelevant.) The first three [*a*, *b*, *c*] vanish on the second move. In connection with *c* it is worth noting that a single diagonal chain of counters, however long, loses its end counters on each move until the chain finally disappears. The speed a chess king moves in any direction is called by Conway (for reasons to be made clear later) the "speed of light." We say, therefore, that a diagonal chain decays at each end with the speed of light.

Pattern *d* becomes a stable "block" (two-by-two square) on the second move. Pattern *e* is the simplest of what are called "flip-flops" (oscillating figures of period 2). It alternates between horizontal and vertical rows of three. Conway calls it a "blinker."

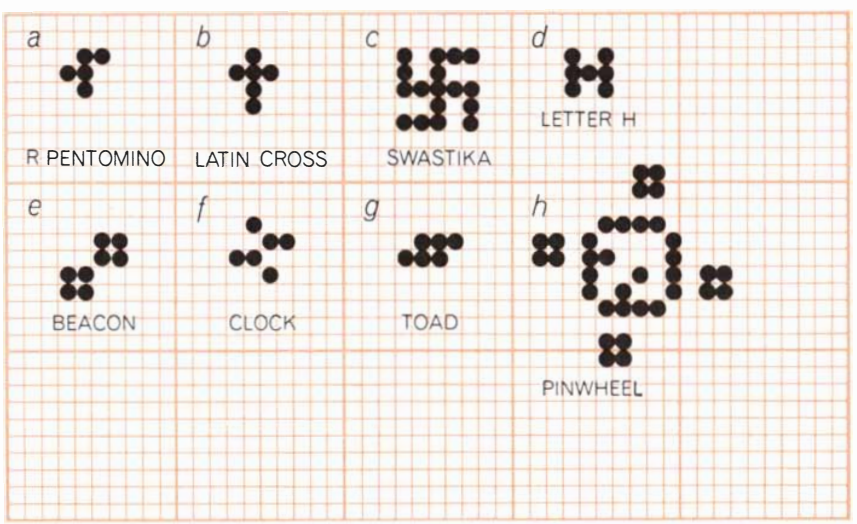
The illustration above shows the life histories of the five tetrominoes (four rookwise-connected counters). The square [*a*] is, as we have seen, a still-life figure. Tetrominoes *b* and *c* reach a stable figure, called a "beehive," on the second move. Beehives are frequently produced patterns. Tetromino *d* becomes a




*The commonest stable forms*

beehive on the third move. Tetromino *e* is the most interesting of the lot. After nine moves it becomes four isolated blinkers, a flip-flop called "traffic lights." It too is a common configuration. The illustration above shows the 12 commonest forms of still life.

The reader may enjoy experimenting with the 12 pentominoes (all patterns of five rookwise-connected counters) to see what happens to each. He will find that six vanish before the fifth move, two quickly reach a stable pattern of seven counters and three in a short time become traffic lights. The only pentomino that does not end quickly (by vanishing, becoming stable or oscillating) is the *R* pentomino [*"a" in the illustration at the bottom of this page*]. Its fate is not yet known. Conway has tracked it for 460 moves. By then it has thrown off a number of gliders. Conway remarks: "It has left a lot of miscellaneous junk stagnating around, and has only a few small active regions, so it is not at all obvious that it will continue indefinitely. After 48 moves it has become a figure of seven counters on the left and two symmetric regions on the right which, if undisturbed, would grow into a honey farm (four beehives) and traffic lights. However, the honey farm gets eaten into pretty quickly and the four blinkers forming the traffic lights disappear one by one into the rest of a rather blotchy population."




*The* R *pentomino* (a) *and exercises for the reader*

For long-lived populations such as this one Conway sometimes uses a PDP 7 computer with a screen on which he can observe the changes. The program was written by M. J. T. Guy and S. R. Bourne. Without its help some discoveries about the game would have been difficult to make.

As easy exercises to be answered next month the reader is invited to discover the fate of the Latin cross [*"b" in the illustration at the bottom of this page*], the swastika [*c*], the letter *H* [*d*], the beacon [*e*], the clock [*f*], the toad [*g*] and the pinwheel [*h*]. The last three figures were discovered by Simon Norton. If the center counter of the *H* is moved up one cell to make an arch (Conway calls it "pi"), the change is unexpectedly drastic. The *H* quickly ends but pi has a long history. Not until after 173 moves has it settled down to five blinkers, six blocks and two ponds. Conway also has tracked the life histories of all the hexominoes, and all but seven of the heptominoes.

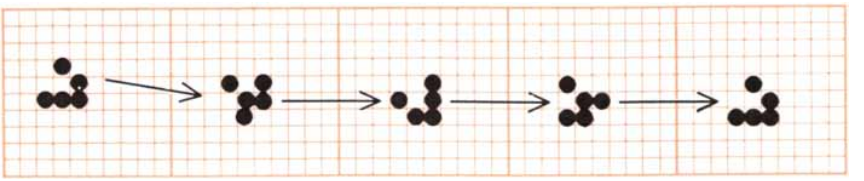
One of the most remarkable of Conway's discoveries is the five-counter glider shown in the top illustration on the opposite page. After two moves it has shifted slightly and been reflected in a diagonal line. Geometers call this a "glide reflection"; hence the figure's name. After two more moves the glider has righted itself and moved one cell diagonally down and to the right from its initial position. We mentioned above that the speed of a chess king is called the speed of light. Conway chose the phrase because it is the highest speed at which any kind of movement can occur on the board. No pattern can replicate itself rapidly enough to move at such speed. Conway has proved that the maximum speed diagonally is a fourth the

speed of light. Since the glider replicates itself in the same orientation after four moves, and has traveled one cell diagonally, one says that it glides across the field at a fourth the speed of light.

Movement of a finite figure horizontally or vertically into empty space, Conway has also shown, cannot exceed half the speed of light. Can any reader find a relatively simple figure that travels at such a speed? Remember, the speed is obtained by dividing the number of moves required to replicate a figure by the number of cells it has shifted. If a figure replicates in four moves in the same orientation after traveling two unit squares horizontally or vertically, its speed will be half that of light. I shall report later on any discoveries by readers of any figures that crawl across the board in any direction at any speed, however low. Figures that move in this way are extremely hard to find. Conway knows of only four, including the glider, which he calls "spaceships" (the glider is a "featherweight spaceship"; the others have more counters). He has asked me to keep the three heavier spaceships secret as a challenge to readers. Readers are also urged to search for periodic figures other than the ones given here.

The bottom illustration on this page depicts three beautiful discoveries by Conway and his collaborators. The stable honey farm [*"a" in the illustration*] results after 14 moves from a horizontal row of seven counters. Since a five-by-five block in one move produces the fourth generation of this life history, it becomes a honey farm after 11 moves. The "figure 8" [*b*], an oscillator found by Norton, both resembles an 8 and has a period of 8. The form *c*, called "pulsar *CP* 48–56–72," is an oscillator with a life cycle of period 3. The state shown here has 48 counters, state two has 56 and state three has 72, after which the pulsar returns to 48 again. It is generated in 32 moves by a heptomino consisting of a horizontal row of five counters with one counter directly below each end counter of the row.

Conway has tracked the life histories of a row of $n$ counters through $n = 20$. We have already disclosed what happens through $n = 4$. Five counters result in traffic lights, six fade away, seven produce the honey farm, eight end with four blinkers and four blocks, nine produce two sets of traffic lights, and 10 lead to the "pentadecathlon," with a life cycle of period 15. Eleven counters produce two blinkers, 12 end with two beehives, 13 with two blinkers, 14 and 15 vanish, 16 give "big traffic lights" (eight blinkers), 17 end with four blocks, 18 and 19 fade away and 20 generate two blocks.



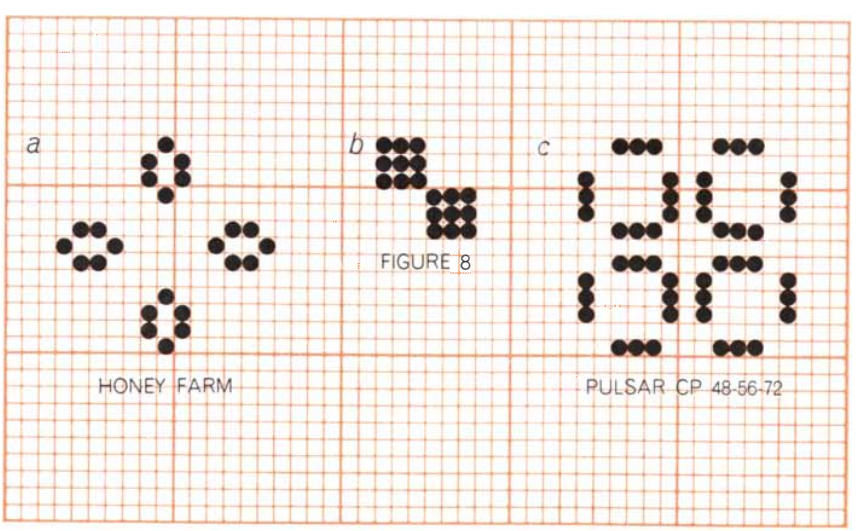
*The "glider"*

Rows consisting of sets of five counters, an empty cell separating adjacent sets, have also been tracked by Conway. The 5–5 row generates the pulsar *CP* 48–56–72 in 21 moves, 5–5–5 ends with four blocks, 5–5–5–5 ends with four honey farms and four blinkers, 5–5–5–5–5 terminates with a "spectacular display of eight gliders and eight blinkers. Then the gliders crash in pairs to become eight blocks." The form 5–5–5–5–5–5 ends with four blinkers, and 5–5–5–5–5–5–5, Conway remarks, "is marvelous to sit watching on the computer screen." He has yet to track it to its ultimate destiny, however.

Last month's main problem was to describe the track that allows a square wheel to roll along it so that its center travels a straight horizontal line. The track is a series of catenary arcs. This applies to all wheels that are regular polygons. (If a wheel is an irregular convex polygon, the track must have arcs that are differently shaped catenaries, one for each side of the wheel.) If the wheel turns with a constant speed, its horizontal speed will vary. For details of the proof I must refer readers to "Rockers and Rollers," by Gerson B. Robison, in *Mathematics Magazine* for January, 1960, pages 139–144, and the solution to Problem *E*1668 in *The American Mathematical Monthly* for January, 1965, pages 82–83. The riddle's answer is a pair of roller skates.

In July's column on Diophantine analysis I incorrectly said that Fermat's last theorem had been proved for all exponents except primes greater than 2. I should have said that, if the theorem is true for all prime exponents greater than 2, the general theorem holds. This is quite a different matter, since it allows counterexamples with composite exponents.

Several readers generalized the Diophantine problem, of the rectangle with the border, to three dimensions, seeking integral edges for a brick composed of unit cubes equal to the number of unit cubes required to cover it on all sides with a one-unit layer of cubes. Daniel Sleator of the University of Illinois used a computer to find the complete solution, a total of 20 bricks. The smallest-volume brick has edges of 8, 10, 12; the largest, 5, 13, 132. This confirms a guess made by M. H. Greenblatt in *Mathematical Entertainments* (Crowell, 1965), page 11, that the problem has "about" 20 solutions.




*Three remarkable patterns, one stable and two oscillating*

# THE AMATEUR SCIENTIST

## *The color vision of pigeons is tested in a Skinner box*

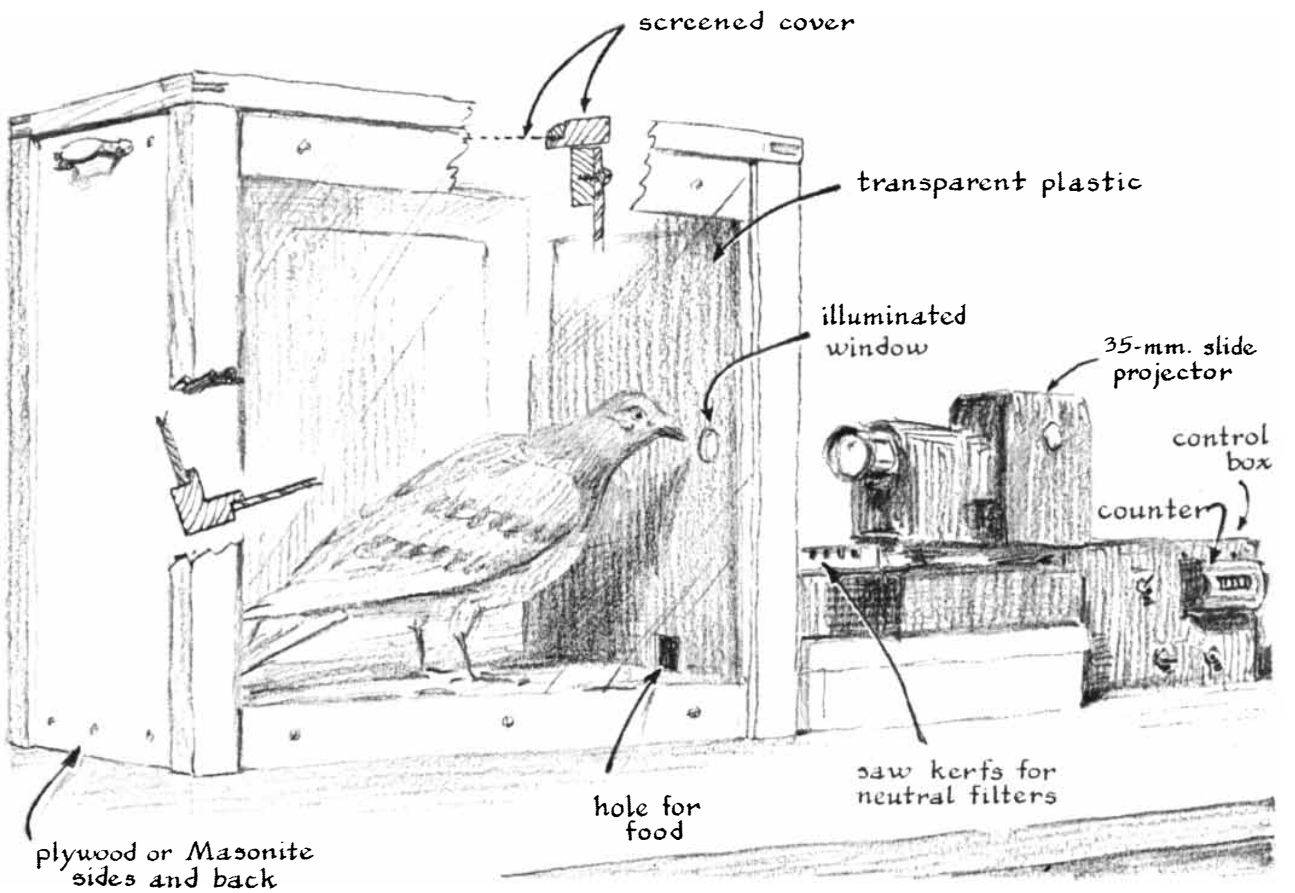
Conducted by C. L. Stong

Animals learn largely by trial and error, but an experimenter can make it easy for an animal to acquire a desired pattern of behavior by modifying its environment and subjecting it to the appropriate kinds of experience. The pattern of behavior thus acquired may disclose significant facts about the animal that would otherwise remain obscure. An experiment that illustrates this powerful technique for exploring animal capacities was made last year by James S. Moran, a high school student of Bridgeton, Mo.

Moran set out to investigate visual perception in pigeons and in particular to compare their color vision with that of humans. He succeeded so well that his project was numbered among the top winners at the 1970 International Science Fair. Moran describes his experiment as follows:

"The eyes of mammals contain photosensitive cells of two kinds: rods, which are extremely sensitive to light but insensitive to differences in color, and cones, which are less sensitive to light but instrumental in the perception of color. Investigators have learned by dissection that the eyes of nocturnal animals, including mice and dogs, are deficient in cones [see "Visual Cells," by Richard W. Young, page 80]. Presumably these animals see the world largely in monochrome. In contrast, the eyes of numerous fishes, reptiles and birds have many cones. The retina of the land tortoise has no rods. These animals should perceive color at least as vividly as people do.

"I should have enjoyed experimenting with tortoises to check this assumption, but they are difficult to train, and so I settled for pigeons. A friend who makes a hobby of racing pigeons gave me two males and two females, together with

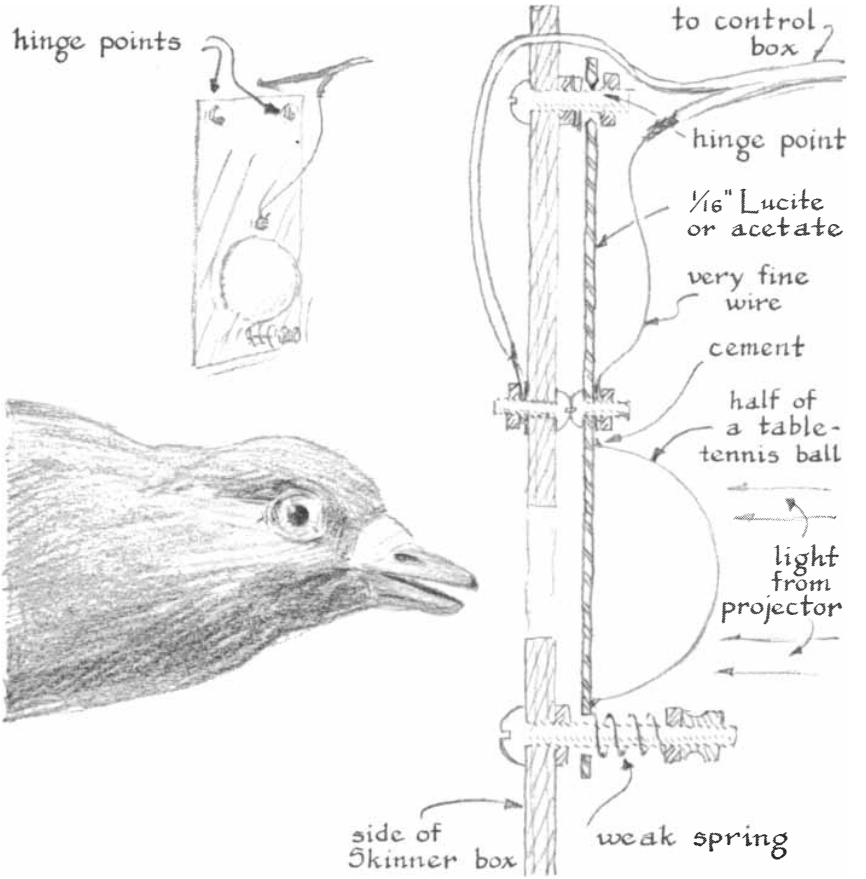



*Arrangement of James S. Moran's homemade Skinner box*

basic instruction in the care of pigeons. I took the birds home in small cages made of wire screen on a wood frame with a plywood floor. Larger quarters were then built with similar materials. The permanent cage consisted of three interconnecting compartments. Two of the compartments are 10 feet long, two feet wide and two feet high. They were stacked one on top of the other and connected at one end to the third compartment, a four-foot cube. Openings about 12 inches square near the floor enabled the birds to move at will among the three compartments. Open boxes at floor level extended from the outside into the cube for providing feed, grit and water. A layer of sand on the floor absorbed droppings and kept the cage reasonably decent between cleanings. No experiments were made until the birds became accustomed to their new surroundings and began to breed.

"The contrived environment to which the birds were ultimately subjected was provided by a version of an apparatus developed by B. F. Skinner of Harvard University. The apparatus essentially consists of an 18-inch cubical box. In it a pigeon is exposed to a small window that admits light of a selected color to the compartment [*see illustration on opposite page*]. When the bird pecks the window, an electrical mechanism drops a measured quantity of food into the box, provided that certain switches have been placed in the correct position. The bird can thus learn to reward itself for pecking at light of a predetermined color. Conversely, it can also learn that no reward will follow the pecking at light of other colors. Skinner developed the apparatus primarily for measuring the rewarding effect of a stimulus by counting the number of times an animal would perform an act leading to a reward compared with the number of times it would perform an unrewarded act.

"The electrical circuit of my box includes an inexpensive digital counter that is actuated when the bird pecks the window, if a switch is in the proper position. The apparatus can be altered in many ways for making other experiments. For example, one interesting variation that illustrates the versatility of the apparatus consists of a box equipped with a lever at one end that causes food to be deposited at the opposite end. Two cats were put in the box, one at a time, until each had learned by trial and error to operate the lever and so obtain food. After the cats had mastered the operation both were put in the box. Thereafter one cat spent the entire time patiently working the lever until the freeloader at the other end had gorged itself!

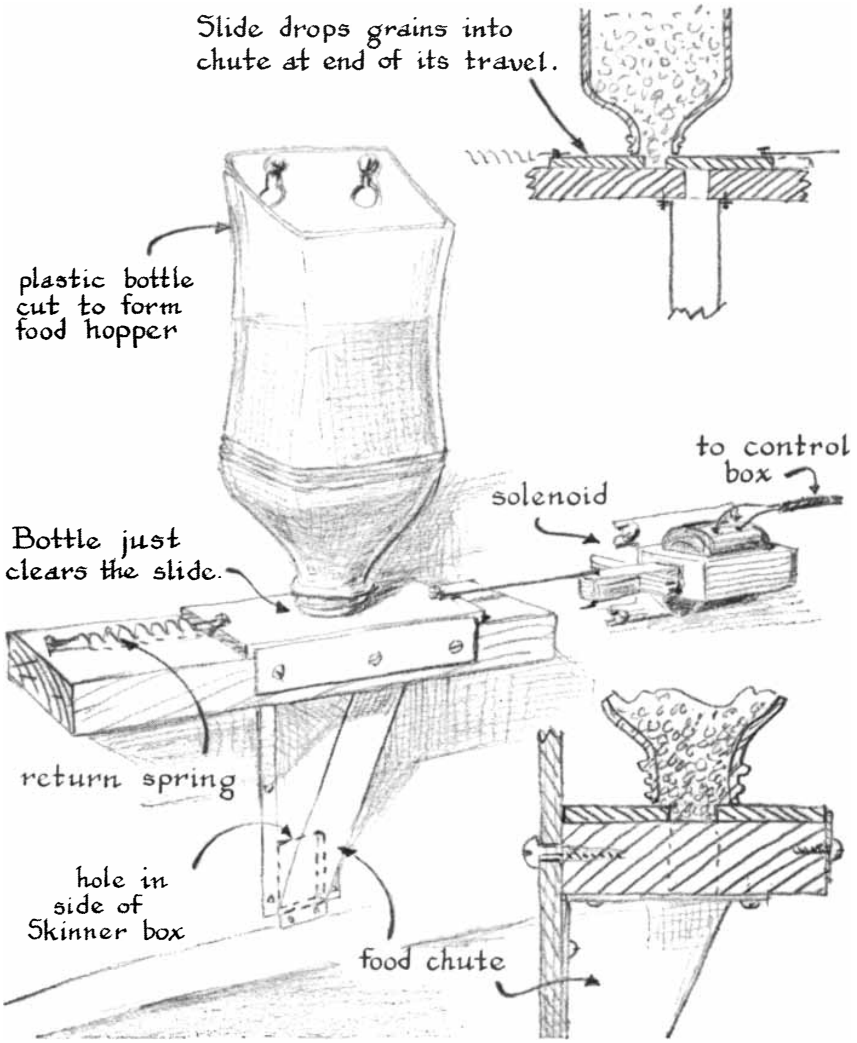



***Construction of the window switch***

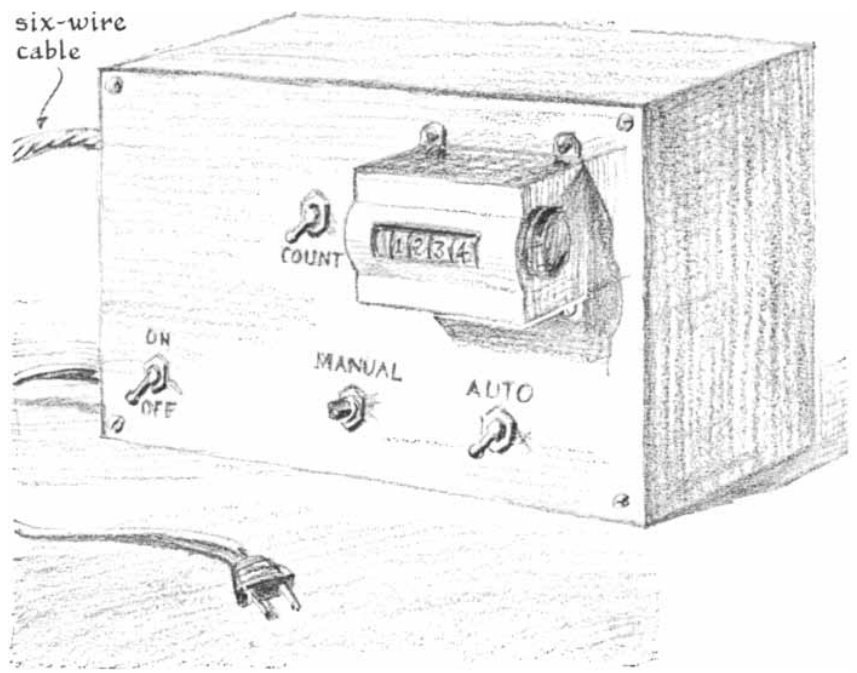
"The Skinner box I made had been modified several times. The version I shall describe requires relatively few parts and is adequate for investigating the color perception of pigeons. The top and bottom and three of the sides of the 18-inch cube are quarter-inch plywood. I install one side of transparent plastic when I want to demonstrate the experiment, but otherwise I use a white opaque material and shine a bright light into the box. Another side of the box has a circular window an inch in diameter located seven inches above the floor. A square opening of the same size is made below the window, three inches above the floor. A rectangular tube that slants downward enters the box through the lower opening. The tube serves as a chute for admitting food to the box from an automatic dispenser. The upper opening is the window that admits colored light to the box. When the bird pecks the window, food drops through the chute at its feet, if the experimenter has preset the appropriate switch.

"The window assembly [*see illustration above*] functions as an electrical switch. Its contacts are normally closed. The assembly includes a strip of quarter-inch pine about two inches wide and four inches long hinged at one end to a similar strip of transparent plastic; together they close like a book. A hole near the bottom end of the pine strip matches the window in the box. The strip is mounted to the box so that the holes coincide. The bird can momentarily knock the plastic away from the window by pecking through the opening, thereby separating the heads of a pair of brass machine screws that serve as electrical contacts. One of the screws passes through the wood just above the window; the other goes through the plastic. The force of a weak compression spring restores the circuit. The spring is held in place by a third machine screw that is fastened to the wood just below the window and passes through an oversize hole in the plastic. To diffuse the light that enters the box I cemented to the outer surface of the plastic half of a table-tennis ball positioned to cover the opening. Light scattered by the translucent ball can be seen easily from most positions inside the box.

"The light source is a 35-millimeter




*Details of the food dispenser*




*The control cabinet*

slide projector. Its beam is focused on the table-tennis ball. Colors can be provided by inserting Wratten filters in the slide holder of the projector. My experiments were made with red, with a dominant wavelength of 6,055 angstroms; yellow-green, at 5,013 angstroms, and blue, at 4,711 angstroms. When the filters are flooded by white light of constant intensity, yellow-green appears brightest and red appears brighter than blue. I equalized the apparent intensity by inserting neutral-density filters between the projection lens and the Wratten filters. The neutral-density filters are supported at right angles to the beam by saw kerfs made in a block of wood two inches square mounted in front of and just below the projection lens.

"The food dispenser is attached to the side of the box that contains the window. Pigeon food consists typically of oats, cracked corn or another grain. The dispenser operates on the same principle as a penny candy machine. Food from a reservoir drops into a hole in a slab of plastic that can be slid back and forth [*see top illustration at left*]. The bottom of the hole is closed by a fixed slab of plywood that supports the movable piece, thereby trapping food in the hole. When the sliding member is moved to the outer extreme of its travel, the food drops through a matching hole in the fixed slab and into a chute that carries it to the box.

"A solenoid operates the slide to deliver food. After the delivery a helical spring returns the sliding member to its former position. Solenoids that operate on house current are inexpensive at military-surplus stores. The solenoid is energized by a relay that forms part of the food-dispenser assembly.

"The remaining parts of the apparatus were assembled in a separate control box eight inches long, six inches high and four inches deep. This box contains a 24-volt direct-current power supply; a relay with two normally closed contacts that are electrically independent; a digital counter of the ratchet type capable of registering a minimum of 500 counts per minute; three single-pole, single-throw toggle switches; a push button, and a fuse. The relays are designed for operation on direct current at 28 volts. The digital counter operates on 24 volts at 60 cycles [*see illustration on opposite page*]. The control cabinet is connected to the Skinner box by a six-wire cable.

"The operation is fairly simple. When the circuit is energized by closing the on-off switch, the armature of the relay in the control cabinet pulls up. In this

position the energizing circuit is broken to both the digital counter and the relay that operates the food dispenser.

"Assume that the automatic feed switch and the counting switch are turned on. A bird that pecks the window will then break the circuit that energizes the relay in the control box. The armature of this relay will return to its normal position, and its contacts will close the circuit of both the food dispenser and the digital counter.

"Food is dispensed at once, but a time-delay relay prevents the dispenser from operating oftener than once every three seconds. Every peck is counted, even though all pecks are not necessarily rewarded. The delayed action prevents the birds from gorging themselves too quickly after they have become proficient in operating the apparatus.

"Either the food dispenser or the digital counter can be inactivated by opening the appropriate switch. The manual food switch is a push button of the kind with normally closed contacts. It is connected in series with the window switch and is normally used for testing the apparatus.

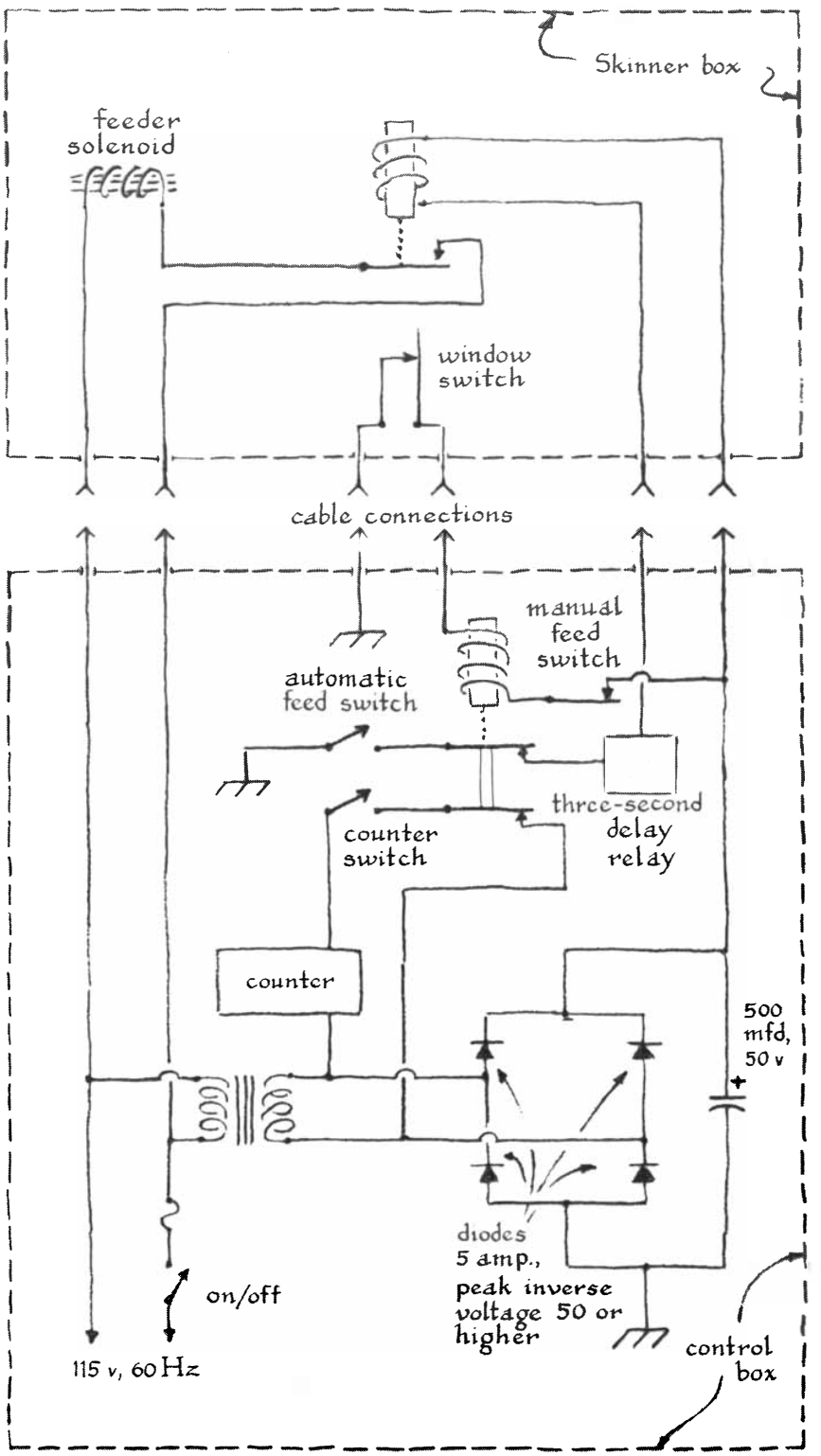
"The circuitry I have described can be modified. I happened to have access to direct-current relays with this contact configuration and to a digital counter that operates on alternating current at this voltage, and so I made a power supply to match these parts. Other components can be substituted by modifying the power supply. My present apparatus contains two windows, so that a bird can select either of two colors.

"Three pairs of birds were selected for the experiments. Each bird was weighed at the same hour every day for two weeks while being fed normally. The results (ignoring excessively low or high weights) were averaged and recorded as the normal weight of each individual. During the next two weeks all the birds were put on a restricted diet to reduce their weight to 80 percent of normal. Thus prepared, my birds were ready to learn how to operate the Skinner box.

"I made up a list of rules to govern the experiments. Birds were tested only if their weight exceeded 75 percent of normal. A bird that fell below 75 percent of its normal weight was given extra rations until it regained minimum weight. All the birds were weighed immediately before and after tests. Considerable effort was made to maintain a daily schedule of testing at a predetermined hour. On the few occasions when the schedule was inadvertently interrupted, the performance of the birds was recorded on the day that tests were resumed but was not included in the final results.

"During all tests the birds were subjected to 'white noise,' the hissing signal generated by an amplifier when the button of a carbon microphone or a similar noise generator is connected to the input terminals. The electrical noise was reproduced as sound by a loudspeaker placed near the Skinner box. My aim was to drown out audible distractions.

"The birds were rewarded with food only when they pecked at red. Their exposure to each color was limited to one




*Circuitry of the apparatus*

minute. The color filters were put in the projector in random order, as determined by a book of random numbers. If the last color in a series of tests happened to be other than red, and if the bird had failed to peck at the last color, it was exposed to red for an additional minute to determine whether the failure to peck was in fact due to the nonred color or merely to the fact that the bird had satisfied its hunger.

"For the first series of tests the birds were exposed to red and blue because these colors are at opposite ends of the spectrum. I assumed that if the birds could not discriminate between red and blue, there would be no point in continuing the experiment with more closely related colors. A good way to train a naïve bird is to fasten a bit of food to a piece of tape and attach it to the window. With the red light on, push the manual feed switch to reward the bird every time it hits the switch. Continue to reinforce only as the bird pecks closer to the red light, and stop using the manual switch once the bird has activated the window. A pigeon can be trained in this way in as little as 15 minutes.

"In the first tests a response (peck) to any color other than red yielded no food. Each color was presented for one minute. At the end of this interval the light was turned off and the number of responses indicated by the digital counter was recorded. The next color, as determined by random selection, was similarly presented to the bird for one minute, and so on for a series of 20 one-minute periods. The number of responses to each color was tabulated for the session and carried forward cumulatively on succeeding days. Each bird was subjected to only one 20-minute test session a day.

"A marked trend in favor of response to red became evident in the tabulated results of all birds within five days and increased thereafter. When the results are plotted, the graph that represents response to red rises steeply, whereas the one representing blue rises somewhat less at first and then levels off. After 15 test sessions the average response of all the birds during each test session, as adjusted for 10 periods of exposure to red and 10 to blue, was 194 responses to red and six to blue [*see upper illustration at left*]. This result, it seems to me, can be explained only by the assumption that pigeons easily discriminate between these colors, which differ in their dominant wavelength by 1,344 angstroms.

"A similar series of experiments was conducted in which the birds were exposed to red and yellow-green. The dominant wavelengths differ by only 509 angstroms and there is an overlap of more than 400 angstroms. The average results for all the birds after 15 test sessions, as adjusted for 10 exposures to red and 10 to green, were 144 responses to red and one response to green [*see lower illustration at left*]. The likelihood that these results are the product of random response is $2^{20}$, or one chance in a million.

"Currently I am continuing the experiment with a series of filters of better quality that transmit a narrower band of color and that progressively approach

| NAME OF BIRD | ALL TEST SESSIONS EXCEPT LAST FIVE | | LAST FIVE TEST SESSIONS | |
|---|---|---|---|---|
| | RED | BLUE | RED | BLUE |
| ATTILA | 205 | 40 | 174 | 9 |
| OPHELIA | 193 | 18 | 229 | 2 |
| HERMIONE | 196 | 23 | 177 | 2 |
| SARGON | 212 | 37 | 240 | 11 |
| PORTIA | 140 | 14 | 152 | 6 |
| MEAN | 190 | 26 | 194 | 6 |

*Summary of responses to red and blue*

| NAME OF BIRD | ALL TEST SESSIONS EXCEPT LAST FIVE | | LAST FIVE TEST SESSIONS | |
|---|---|---|---|---|
| | RED | GREEN | RED | GREEN |
| ATTILA | 185 | 8 | 114 | 0 |
| OPHELIA | 194 | 3 | 154 | 0 |
| HERMIONE | 157 | 7 | 139 | 1 |
| SARGON | 208 | 32 | 167 | 1 |
| PORTIA | 208 | 8 | – | – |
| MEAN | 190 | 12 | 144 | 1 |

*The responses to red and green*

red. The birds should find it increasingly difficult to distinguish between hues, and at some point discrimination may become impossible. The result should provide an approximate measure of the limit of the bird's color perception, information acquired indirectly by the ability of the pigeon to learn."

Last month this department described a simple oscillator in the form of a hairpin loop of wire that vibrates like a child's swing when the wire is heated by an electric current. The origin of the oscillator and the explanation of how it works is now provided by A. D. Moore, professor emeritus of electrical engineering of the University of Michigan. Moore writes as follows:

"The oscillator was discovered accidentally in 1928 by P. C. Clarke of Lansdale, Pa. Clarke spent a lot of time trying to find out what made the gadget go, and within a year or so people at various institutions went to work on it. I came across the oscillator during a visit to the University of Illinois and could scarcely wait until I got home to make one of my own.

"A number of experimenters had reached the conclusion that still air is necessary for the oscillator's operation. When you put the wire in a vessel and pump out the air, you get no action. On the other hand, the wire will not vibrate in a wind. You can stop the action by fanning the wire with a piece of cardboard. I finally hit on the idea that perhaps the motion is generated by alternating differences in temperature between the windward and leeward sides of the moving wire. When the wire is moving in one direction, the windward side cools. As a result of the cooling that side contracts. The leeward side also cools, but not as much, nor does it contract as much. The net difference in contraction causes the wire to bend in the direction of the motion and thus generates a force that increases the amplitude of the swing.

"It is well known that when a cooling fluid moves past a cylinder, heat transfer is greatest on the windward side and least on the leeward side. According to my theory, the dimensions of the wire must be such that the hot and cold sides have sufficient time to reverse when the loop reaches the limit of its excursion and starts back. The temperature cannot reverse instantly, but it must do so soon enough for the expansion-contraction effect to operate over a large part of the swing.

"It is always good fun to cook up theories and even more fun to contrive experiments for testing them. To check my theory I constructed a loop of adjustable length with No. 24 Nichrome wire. At a length of approximately 10 inches and a current of 2.75 amperes the amplitude of vibration was about an inch. At greater or lesser current the amplitude decreased. Maintaining the optimum current, I gradually shortened the loop. The natural frequency of vibration increased and the amplitude decreased. At a length of six inches the wire came to rest. The frequency of vibration was too high for effective reversals of temperature. I then added mass to the bottom of the loop to reduce the frequency. The short, loaded loop promptly resumed oscillation. This result agreed with my theory.

"On the other hand, different theories have been advanced. For example, Roger Hayward, who illustrates 'The Amateur Scientist,' recently suggested that perhaps the overall expansion and contraction of the wire causes the vibrations, much the same effect that children exploit when they pump a swing. According to this theory, the full length of the loop cools and contracts during each vibration. The contraction raises the mass toward the point of suspension, just as the child raises his mass when he pumps a swing. In such a situation the driving force arises from the conservation of angular momentum.

"To further check what happens I made another oscillator of the same type but of a different design. I called the new oscillator a 'one-legged' loop. I was certain that it would work, and it did.

"The apparatus consisted of a brass tube of thin-wall stock about a yard long with an outer diameter of 1/8 inch. The upper end of the tube was rigidly anchored to a support. Through the bore of the tube I ran a length of No. 30 Nichrome wire and insulated it from the brass with short lengths of glass tubing that were strung on the wire like beads. The bottom of the wire was attached to the bottom of the tube to complete the circuit.

"When current was applied, the tube behaved just as I thought it would: the free end rotated in a circle about three inches in diameter! It may be possible for pumping action to make a contribution to the motion of oscillators of the hairpin-loop type, although I doubt it. On the other hand, pumping action could not possibly drive the 'one-legged oscillator.' Its motion can be maintained only by a bending action that continuously circles the tube."

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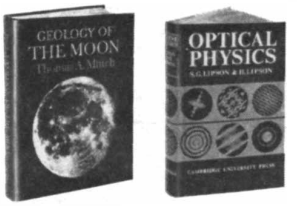


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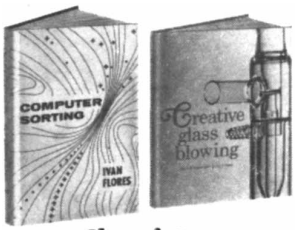


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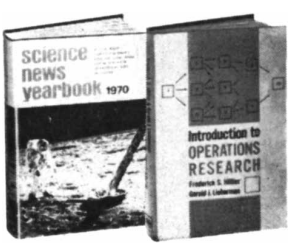


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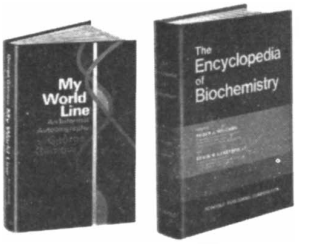


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# BOOKS

## *The findings of modern biology and their implications for man*

by Alfred E. Mirsky

BIOLOGY AND THE FUTURE OF MAN, edited by Philip Handler. Oxford University Press ($12.50).

Being a biologist, I picked up this book with alacrity. Its 20 chapters and 900 pages present the reader with a survey of virtually the entire sweep of biology. The scope of the presentation is exciting and the sequence in which the topics are ordered is logical. The book begins with a chapter on molecular biology, basic to modern biology. Early chapters take up biochemistry ("The Materials of Life and Their Transformations"), cells and the origins of life. The succeeding chapters, dealing with life at higher levels of biological organization, are concerned with development, physiology, the nervous system, behavior, ecology, heredity and evolution and systematics ("The Diversity of Life"). In all the chapters I have mentioned there are frequent comments on the significance of various lines of investigation for man. The final six chapters are on phases of biology that are directed explicitly to the service of man.

It is fitting that this book should be sponsored by the National Academy of Sciences. The academy is an adviser on science to the Government, and the first step in advising is to inform. The book is accordingly addressed not "to the cognoscenti of the sub-disciplines concerned" but to "reasonably well-read scientists and laymen"—to the "interested non-scientist." To write for such readers was a difficult challenge for the 175 experts who contributed to the book. The challenge must have been equally difficult for Philip Handler, the editor of the book and now the president of the academy.

I found almost every chapter so absorbing that I was impelled to read the book without pausing. This was true even when there were passages that I could not understand, because even the mirage was enticing. There are examples of such passages in the chapter on the nervous system, particularly the sections on the brain. For anyone but a neurophysiologist far better illustrations are needed for effective communication. Indeed, the illustrations are inadequate in many other chapters. In the section on the kidney the text is excellent but the absence of illustrations makes it just about unintelligible to a reader who does not already know about kidney function. Appropriate illustrations might have doubled or even tripled the cost of the book, but for such a book they would have been worth the cost. An index would also have been well worth the effort.

There are many chapters (for example those on ecology, the diversity of life, digital computers and medicine) that are well suited for the "interested non-scientist" because they are written with enthusiasm and succeed in communicating this enthusiasm along with much fascinating information. Looking for such information, the reader is tempted to browse. If he opens the book at random, he has a fair chance of finding a rewarding section.

One such section deals with the population problem. "The upsurge in the growth of human populations" is described as a major hazard in the future of mankind. I doubt whether any reader of the book will hold a contrary opinion. In this case, however, enthusiasm has led to the following overstatement: "... many of the most tragic ills of human existence *find their origin* in population growth. Hunger, pollution, crime, despoliation of the natural beauty of the planet, irreversible extermination of countless species of plants and animals, overlarge, dirty, overcrowded cities with their paradoxical loneliness, continual erosion of limited natural resources, and the seething unrest which creates the political instability that leads to international conflict and war, *all derive from* the unbridled growth of human populations." (The italics are mine.) The war in Southeast Asia is surely not due to an upsurge in population. Indeed, it would be difficult to point to wars for which overpopulation was a major cause. Although the other social ills mentioned in the quotation have some connection with the rate of population growth, the connection is only partial. It has been pointed out by Herman Miller, the demographer who heads the population division of the Census Bureau, that "pollution, traffic jams, delinquency and crime are no worse in France, England and Holland than in the United States despite the fact that population density in those countries is between 5 times and 30 times as great as in the United States." What we need, Miller remarks, is a national commitment to use our growing affluence to attack our domestic problems. There is no upsurge of population in Sweden, but there is a water-pollution crisis. Sweden is using its affluence to solve the problem.

The reader is presented with another overstatement concerning population when he is asked in connection with population expansion in the U.S.: "Further, consider the *seemingly impossible burden* of coping with the demand for college education: college enrollments which were 6 million in 1965, will be 8 million in 1970, 10 million in 1975...." (Italics are mine.) Such a reader may know that in Israel, a country far less affluent than the U.S., the number of students in universities rose from 28,520 in 1966 to 40,000 in 1970. The upsurge of population is a hazard, but it must be faced rationally.

If a stationary population is achieved, such a population would be much older than the present one. It would, according to Miller, have an equal number of people under 15 and over 60. There are numerous references to age and population in *Biology and the Future of Man.* (Without an index, of course, it takes a bit of luck to locate them.) On page 631 one reads: "The reduction in death rate since 1900 has been greatest for relatively young people." On page 763 it is said: "But, life expectancy past the age of 45 has increased only slightly...." On page 912 it is stated: "Increases in life expectancy past the age of 45 have remained

smaller...." On page 631, however, there is a table (taken from U.S. Public Health Service Publication No. 600, "The Facts of Life and Death") giving the average remaining lifetime in years at specified ages between 1900–1902 and 1963. Inspection of the table shows that the statements I have just quoted are incorrect. For those of age five the expectancy in 1900–1902 was 82 percent of what it became in 1963. For people of age 45 the corresponding figure is 84 percent; for those of age 60 it is 83.7 percent; age 65, 82.8 percent; age 70, 81.5 percent; age 75, 80.5 percent, and age 80, 82.8 percent. The significance of these figures for the future of man calls for an extended discussion, particularly if there is to be a change in the age structure of the population when a stationary state is achieved.

This brings up another passage (page 917): "...the need for support of research which will benefit the health of the newborn and of young productive people in general competes for the personnel and material resources required for research on aging." This may well be the present state of affairs when our affluent society is expending so much of its resources on war and preparation for war, but if research on early environmental influences and research on the aging process must "compete" with each other for funds, the future is surely dim even for an affluent society.

Throughout the book there are, as there should be, references to genetics. Halfway through the book, in the chapter "Heredity and Evolution," there is this perceptive statement: "Transmission genetics [the genetics of heredity] is no longer the most exciting or the central part of genetics. That role is now played by molecular, cellular, and developmental genetics." These aspects of genetics are presented in the early chapters. Some of the topics covered are the chemical structure of genes, how genes are replicated, the nature of gene action, the way genes determine the synthesis of enzymes and other proteins, the control and regulation of gene activity by what are in the broadest sense environmental factors, and the role of variable patterns of gene activity in development and differentiation. An acquaintance with these topics is required for a discussion of the interaction of heredity and environment—a major theme of the book.

I found these four chapters to be clearly written and on the whole excellent. Since my own scientific background lies in this field, I asked several "reasonably well-read scientists [nonbiologists] and laymen" to read these chapters. The report I received was that they were difficult and not fully understandable. I then went over the chapters again, and I could see why there was a failure to communicate some of the fundamentals of modern biology. Chapter 2 and Chapter 3 "are...presented in the language of chemistry," which is obviously difficult for many readers, and in Chapter 4 and Chapter 6 some assumptions are made about what was covered in the preceding chapters.

As we come to the succeeding chapters, let us see something of the role played by genetics. In the chapter on physiology there is an excellent section on insect endocrinology. Here is an account of how cells in the insect brain, which responds to changing conditions inside and outside the animal, secrete a hormone that stimulates a second endocrine organ, the prothoracic gland, to release a steroid hormone, ecdysone, that acts on various tissues of the body. Ecdysone is effective because it activates certain genes. This well-studied case shows how gene activation enables the organism to adapt to a change in the environment. In a later chapter, on the nervous system, genetics enters in quite a different way as the following pertinent questions are raised: "If the connections of the nervous system are largely specified genetically, how do functional modifications occur in the brain? The environment continuously produces modifications in the behavior of the organism. How is the modifiability of behavior consistent with a rigidly wired brain?" The genetics referred to here is transmission genetics, which tends to be rigid. In cellular and developmental genetics, on the other hand, the constellation of genes is regarded as plastic, and as the environment changes, batteries of genes are activated or repressed. Beginnings have already been made in the application of this kind of genetics to the investigation of the nervous system of higher animals.

Following the chapter on the nervous system comes one on the biology of behavior. Reading it goes far to explain why this branch of biology has attracted so many new workers in recent years and also the interest of many reasonably well-read scientists and laymen. It seems likely that many of the older biological disciplines will in time focus more definitely on behavior, particularly on human behavior. The genetics of behavior was founded about 1925; by 1940 Robert C. Tryon's classical work on the inheritance of maze-learning ability in rats was published, and in 1960 there appeared John L. Fuller and W. Robert Thompson's *Behavior Genetics.* Throughout this period transmission genetics was "the central part of genetics," and it was accordingly central for behavior genetics. The inheritance of behavior is well reported in this chapter.

The more recent cellular and developmental genetics, however, are not adequately presented, so that the reader is unable to appreciate the significance for behavior of the newer genetics. Thus one would not know by reading the interesting section on the endocrine system and behavior that the remarkable behavioral effects of estrogenic and androgenic hormones are in many, if not all, instances due to the activation of genes by these steroid hormones. The section on the development of behavior gives some striking examples of the importance of early experience in the development of later behavioral capacities, a field that has been "the subject of a massive experimental assault in recent years." The experiments described will whet the appetite of the reader for further information, and more information along these lines is in fact given in the final chapter. Nonetheless, a reader of the accounts in both chapters would have been greatly helped if the discussion had been linked to what had been presented in the chapter on the biology of development, because there it was shown that "early experience" is responsible for the pattern of gene activation that occurs in development.

In the final chapter ("Biology and the Future of Man") there are several discussions concerning the future of genetic systems. The section on "guarding the genetic quality of man" deals with defective genes: how to recognize them before birth, the ways of coping with them medically and the role of genetic counseling. In the final section of this chapter there is a discussion of the genetic factors concerned with man's mental and behavioral traits, and some proposals for the future are made.

It is interesting that this section begins in the same way that Plato introduces the idea of eugenics in *The Republic.* Plato proposed, and it is also proposed here, that there should be selective breeding of man. The following passage is from Francis Macdonald Cornford's translation:

*How are we to get the best results? You must tell me, Glaucon, because I see you keep sporting dogs and a great many game birds at your house; and there is something about their mating and breeding that you must have noticed.*

*What is that?*

*In the first place, though they may all be of good stock, are there not some that turn out to be better than the rest?*

*There are.*

*And do you breed from all indiscriminately? Are you not careful to breed from the best so far as you can?*

*Yes.*

*And from those in their prime, rather than the very young or the very old?*

*Yes.*

*Otherwise, the stock of your birds or dogs would deteriorate very much, wouldn't it?*

*It would.*

*And the same is true of horses or of any animal?*

*It would be very strange if it were not.*

*Dear me, said I; we shall need consummate skill in our Rulers, if it is also true of the human race.*

The corresponding passage in *Biology and the Future of Man* is: "Even without scientific knowledge of genetics, man created a great variety of genetically different strains of domesticated animals and plants by selecting for desired types and breeding." And later it is said: "Presumably, we could also breed for mental performance, for special properties like spatial perception or verbal capacity, perhaps even for cooperativeness or disruptive behavior, even, conceivably, for high scores in intelligence tests."

Between Plato and *Biology and the Future of Man* the most important writer on eugenics was that remarkable Victorian Francis Galton. His presentation of eugenics and the presentation in this book are markedly similar (although the word eugenics is not used in the book). Galton linked eugenics and evolution in what became virtually a religion for him and his followers in the eugenic societies of Britain and America. The final sentences of *Biology and the Future of Man* are: "[Man] influences the numbers and genetic constitution of virtually all other living species. Now he can guide his own evolution. In him, Nature has reached beyond the hard regularities of physical phenomena. *Homo sapiens*, the creation of Nature, has transcended her. From a product of circumstances, he has risen to responsibility. At last, he is Man. May he behave so!"

It should be said that the discussion of eugenics in *Biology and the Future of Man* is not marred by Galton's gross underestimate of the importance of environmental factors in the shaping of man's traits or by Galton's deplorable racial antipathies. It is also clearly stated that the eugenic proposals put forward in this book can be implemented only at some indefinite time in the future. Some of the difficulties that would be encountered in the establishing of a eugenics program are discussed.

In the preface to the book it is stated that the changes that can come about in the foreseeable future should be mentioned. Are there possible changes in this time span that concern the genetic systems responsible for the mental and behavioral traits of man? In the chapter on the future of man only transmission genetics is considered, and that leads to eugenics. In my opinion the newer genetics, particularly cellular and developmental genetics, provides a more hopeful outlook. The negative attitude toward this kind of genetics is shown by the following sentence in the final chapter: "Man's capacities are, thus, inextricably linked to his genes whose molecular nature is now understood to a very high degree, but which presently lie *outside his control.*" (Italics are mine.) In actuality numerous papers on the control of gene activity are published every month. For example, it was recently shown that when vitamin D is ingested, it is modified in the liver and then reaches the intestinal epithelium, where it activates certain genes and so induces the synthesis of an enzyme that enables the cell to absorb calcium. I have already referred to the role of steroid hormones as controllers of gene activity. The significance of the newer genetics for the development of behavior has recently been well stated by Benson E. Ginsburg of the University of Connecticut: "The developing individual, on this view, has a far wider genetic repertoire than will be activated during his developmental history.... Where environmental events, including external stimulation, alterations in hormone level, vitamins... impinge to alter behavior, they do so, in the sense that we have been discussing, only if they are capable of activating or suppressing existing genetic systems, and only at those times when these become labile.... The genetic potentials for the development of particular neural and behavioral capacities are far broader than those that will be exhibited by a given individual. The activation and/or suppression of these potentials in favor of others occurs as a physiological-genetic process in which particular genes are 'turned on' or off at given stages in development."

As more is learned about factors controlling the genetic systems of higher organisms man's genes will no longer "lie outside his control." That may reasonably be expected to happen in the foreseeable future. It remains to be seen what the attitude toward eugenics will be at that time.

None of these comments alters the fact that *Biology and the Future of Man* represents a great step forward in communication between workers in science and citizens concerned with science—and ultimately all citizens should be concerned with science. In my view the book should be renewed regularly. Five years from now would not be too soon.

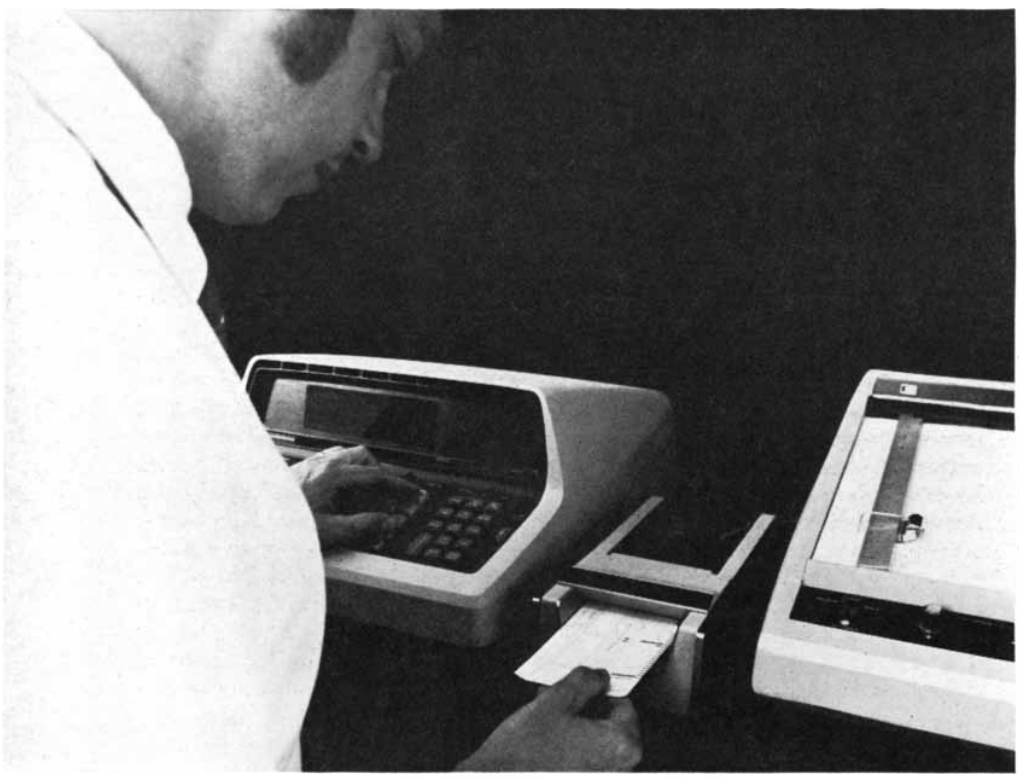
## Shorter Reviews

by Philip Morrison

JOURNEY TO TRANQUILITY, by Hugo Young, Bryan Silcock and Peter Dunn. Doubleday & Company, Inc. ($7.95). THE TIMES ATLAS OF THE MOON, edited by H. A. G. Lewis. Distributed in the U.S. by *The New York Times* ($25). The thunderer of Fleet Street never roars on Sundays. That morning there appears a namesake with a racier air and a taste for bubble-bursting. Three very able writers of *The Sunday Times* of London set forth in *Journey to Tranquility* their full-length appraisal of Apollo—skeptical, probing and documented (if a little inexplicitly). Their conclusion is clear: glitter but not gold. "The quest for prestige" ended with entire formal success. Its end saw a new decade, with a world no longer bipolar, no longer to be won over to the stronger side in a contest from which most world leaders wish "to escape altogether." Apollo was a rallying banner only in America, stilling "the demon of Americans' own belief in their inferiority." It was not for science; "the rocks, of course, did not need man to bring them back." It was not for posterity. The ruined Parthenon still stands, a magnificent gift to all men. Can Tranquillity Base be such a monument? If it is ever to be seen as more than "a transient, empty, virtuoso performance," it will be decades, even centuries, before men use the moon well. For sending men past the moon to Mars the justification can be only "the act itself... the great instinctual leap." These are sharp judgments; many will agree. They comprise the editorial that closes the book.

The heart of *Journey to Tranquility* is the history of the scheme, with an analysis of key decisions at a series of junctures. That history begins here with the young German rocketeers, now the formidable Wernher von Braun team at Huntsville. Theirs was a shared dream, made to come true by the shrewdness with which they tied their rockets to the ambitions of leaders for more than 30

# Some things are changing for the better.



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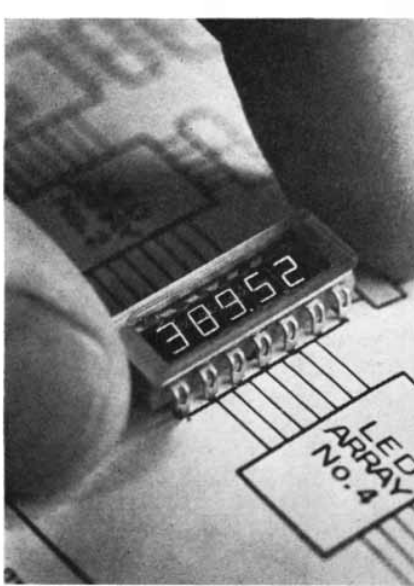
## Keep an eye on solid-state displays: they're moving fast

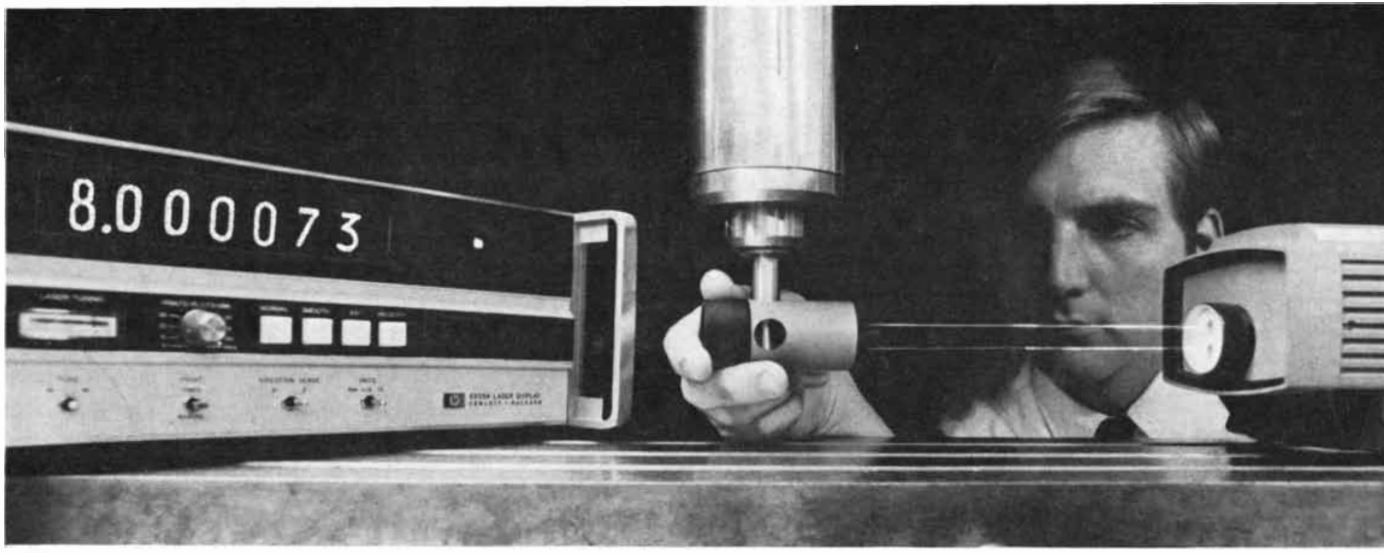
If you haven't been paying very close attention in the last several months, some fast-moving developments in solid-state displays based on GaAsP light-emitting diodes (LED's) have undoubtedly escaped your attention.

Earlier this year, HP introduced an alphanumeric display that incorporates 35 LED's per character, arranged in a 5 x 7 dot pattern. There are two outstanding advantages to this design: it can display highly readable letters and symbols as well as numbers, and it is suitable for dynamic as well as static operation. In static operation, all of the diodes that are needed to form a character are *on* continuously; in a dynamic display, the LED's are scanned one row or column at a time, at high speed. If the scanning rate approaches 100 times per second, the eye sees only the complete character and there is no flicker. The scanning technique not only permits sharing the same character generator and scanning circuits by several displays but also greatly reduces the number of interconnections.

HP scientists have just announced the development of a monolithic display which is fabricated from a single GaAsP chip into which seven LED's are diffused. Its seven-segment character (contrasted to the previous 35 dot matrix) is suitable only for number generation. Counter-balancing this, its fabrication from a single chip is fully automated, a fact that has already reduced its price to $7 per character (compared to $30 for the alphanumeric) and promises a further reduction to $2 in large quantities.

All HP solid-state displays are hermetically sealed, IC-compatible and have a life expectancy of at least 100,000 hours. We'll be glad to send you technical data on any of them.






## For interferometers, two frequencies are better than one

All interferometers built since Michelson's original experiments in the 1890's use two light beams of the same frequency. They measure distance by counting the cycles of beam intensity in the reflected light caused by alternate constructive and destructive interference of the two beams, as the reflector is moved. Direction is measured by detecting the phase difference between two portions of the measuring beam. These two signals are used to drive a counter one way or the other, after dc amplification.

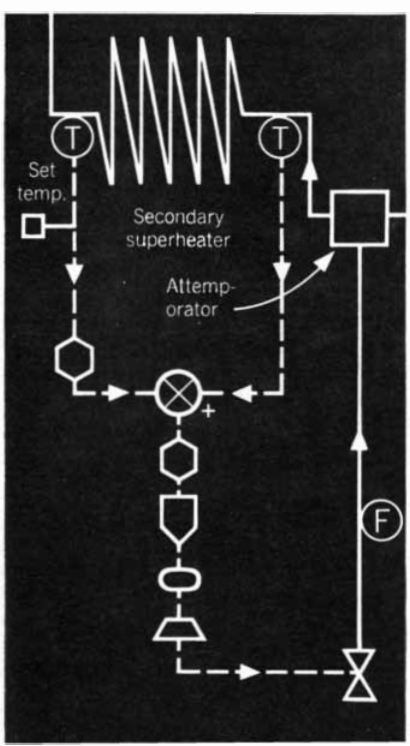
And there's the rub. Any variation in the intensity of the light source due to atmospheric disturbances or normal dc amplifier drift, can cause erroneous readings or put the system out of commission.

A new interferometer completely avoids this problem by the simple expedient of operating entirely on ac. This was made possible by the development, in the HP Laboratories, of an entirely new laser which oscillates *on two frequencies simultaneously.* An axial magnetic field Zeeman splits its main spectral line into two frequencies, 1.8 MHz apart and of opposite circular polarization (thuseasily distinguishable).

One of these frequencies ($f_1$) is isolated in a reference path. The other ($f_2$), isolated in a measuring path, is bounced off an external reflector and recombined with $f_2$ at the interferometer. If the external reflector remains stationary, the difference between the two is exactly 1.8 MHz. But when the reflector is moved, the measuring beam's frequency is Doppler-shifted at a rate of about 1 MHz for a 1 foot-per-second reflector velocity, and the difference between these two frequencies becomes $(f_1 \pm \Delta f - f_2)$.

Movement is determined by sensing differences between the Doppler signal and the constant reference signal $(f_1 - f_2)$ and counting the cycles on separate registers. A subtractor keeps a running count of the differences in quarter-wavelengths of light, while a built-in IC calculator converts wavelengths to units of length.

Besides a radical decrease in susceptibility to air turbulence, the HP Model 5525A Interferometer ($11,500) measures distance to 1 microinch resolution, requires no warmup and tunes itself automatically. These characteristics suggest great utility in metrology laboratories, for measurements from microinches to 200 feet, as well as machine tool use. The August 1970 issue of the HP Journal tells the whole story: write for your copy.




## New tool for on-line system analysis

Very recently at a large power station in England, a system analysis of an attemperator or temperature control loop was completed on-line, without disturbing plant output in any way. As the control characteristic of the loop was displayed on a screen during the experiment, adjustments were made to optimize the control system and the results were displayed immediately.

The job of the control system engineer —to predict how the system will react to a given input pulse — has not always been so easy. If he tests the system with an impulse that is large enough to produce a measurable response, plant output is changed in a way that cannot be tolerated.

Some progress was made when control system analysts discovered the power of cross-correlation. With this mathematical technique, a test noise signal is applied to system input at such low levels that system output is not changed beyond normal background disturbances. Yet by cross-correlating the test noise with the system output over a relatively short period, the engineer is able to extract the impulse response of the system; background disturbances do not interfere because they are uncorrelated with the test noise.

At first, cross-correlation did not help because it could only be accomplished after the fact, through off-line digital computation. What made the difference in the English experiment was the availability of two new HP instruments: a Model 3721A on-line correlator that's about as easy to use as an oscilloscope, and a Model 3722A precision noise generator that synthesizes repeatable pseudo-random noise, ideally suited to system analysis. The correlator costs $8325 and the noise generator $2650. On request, we'll be glad to send you a packet of information on these two instruments, correlation and the on-line experiment.

If you're involved in the techniques of digital analysis or correlation, we can offer a new product-oriented handbook, "Discrete Signal Analysis," which will help. For this 96-page booklet or any of the other material mentioned, write to: Hewlett-Packard, 1508 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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**Measurement, Analysis, Computation**

00016

years and in two nations, in hot war and in cold. "For us," von Braun's associate Ernst Stuhlinger says, "rockets were always destined for other things besides war." Where they came down was someone else's department.

Three years after the first ICBM funds passed Congress, Secretary of Defense Charles E. Wilson thought that it did not matter if the Russians orbited first. From the end of the war there had been both service and civilian proponents of the indispensability of U.S. leadership in space. It was 1955 before President Eisenhower, pressed by an IGY resolution for study of a satellite launching, agreed that a U.S. satellite should be built, but he insisted that it be kept away from warfare, hot or cold. Sputnik preempted this calmness. "One small ball in the air," said Ike, "does not raise my apprehensions." Then our first Vanguard became Flopnik. The Huntsville pinch hitters happily belted out Explorer, and with it Dr. James van Allen found his famous belts of trapped electrons. In January, 1958, we were in orbit at last.

The services battled offstage for the wild black yonder, but the ailing President resisted all of them, and by the spring of 1958 he had converted that "modest body," the civilian National Advisory Committee for Aeronautics, to NASA. The Air Force held the monopoly of big military boosters, but Huntsville went to NASA. The von Braun team was accustomed to a direct link between development and production, whereas "the air force, the incarnation of free enterprise in government," had never worked that way. The Air Force was the intimate of the aerospace corporations and had no Government shops. Huntsville, however, meant Saturn, and Saturn later came to mean the moon. (It was a decade before the Air Force was to be entirely separated from man in space.) Eisenhower, with full support from his scientific advisers, was "not about to hock his jewels" for any lunar Columbus.

John Kennedy took office in January of 1961, a man "unskeptical in his belief in prestige." In April of that year Major Yuri Gagarin became the first man in space. Within a week the landing forces at the Bay of Pigs had been defeated. There is a note of April 20 from J. F. K. to L. B. J., who was already zealous for space: "Do we have a chance of beating the Soviets. . . , Is there any other space program which promises dramatic results in which we could win?"

The Hundred Days was a time for drama, but there was more behind it. The quiet man who specialized in space in the Bureau of the Budget speaks to the point: "Space was the answer. It was a way of keeping up the aerospace economy . . . without escalating the arms race." Apollo was under way, all $24 billion of it.

*The Sunday Times* authors revel in the account of the wheeling and dealing that led to the contract with North American Aviation for the spacecraft and the second stage of Apollo (but not the lunar lander), coming to the tidy total of $6 billion. "If you get it, what can North American do for Oklahoma?" So said the late Senator Kerr to the chief North American lobbyist, according to that agile man, who was fired by the company in the eddies of the Bobby Baker scandal. Three decisions of a more technical nature followed: the three-man crew (eight-hour shifts, perhaps?); rendezvous in lunar orbit, which saved the most booster weight, but at some risk; the nylon-net cable lashings that fueled the fatal launching-pad fire, which was traceable to management errors and stubbornness, the authors say.

The book is an effective astringent for the more perfumed myths of the handout press, but it does not transcend the journalist's view. It contains no real study, not even a listing, of how much work went where in the country. Not very many of all those billions were in fact sent to the moon. Most of them stayed here, and towns from Lexington to Biloxi and Palo Alto show it. *Journey to Tranquility* is a kind of political history in the old style, concentrated on which of the getters got. Just what they got and what the aggregate meant in wider social and economic terms calls for a different book. We need that book; any overall change in the aerospace industry—the largest in the U.S.—means a great deal for the nation, and particularly for changing times for science and technology in America.

There were necessary for Apollo a high note of idealism, devotion and affection, and the loyalty of a great many people both humble and high in the ranks of that army. An enterprise begotten by rivalry from the bitter womb of the arms race, Apollo has nonetheless achieved a kind of beauty. Most of man's epics from the *Ramayana* onward tell of bloody war itself; the bard of Apollo need feel no shame in candor about the selfish passages of his tale. We taxpayers spent well on Apollo, compared with our purchases at Long Binh, Camranh Bay and Yankee Station.

*The Times Atlas of the Moon* is the work of the daily paper, an ornamental auxiliary to its very useful atlas of this world. It presents handsome shaded relief maps, drawn in a single moonshine tone, of the entire visible face of the moon. The book is printed by the capable firm of Bartholomew; the maps are essentially those prepared since 1960 by the Aeronautical Chart and Information Center of the U.S. Air Force. One hundred and ten maps cover the near side, an area close to that of South America, at a scale of about 20 miles to the inch. The lunar tropics are mapped with altitude contours shown, using the marvelous photographs from the Lunar Orbiters in the style of earthbound aerial photography. There is a precise triangulation base, resting on the series of careful photographic measurements made before World War I by the astronomers S. A. Saunder and Julius Franz.

The far side of the moon appears in much less detail, covering only three pages. The reference role of mean sea level on this waterless world is perforce played by an imaginary spheroid constructed for the purpose. The 17th- and 18th-century names of lunar geography, as now internationally agreed on, a contour map of the invisible mass concentrations and other interesting and helpful pages are included.

EAST IS A BIG BIRD: NAVIGATION AND LOGIC ON PULUWAT ATOLL, by Thomas Gladwin. Harvard University Press ($9.95). "We sat at a table, a chart of the Central Caroline Islands between us and a typewriter in front of me. I recorded everything . . . as we went along. Hipour cannot read or write. . . . He soon learned to 'read' this one, easily distinguishing the conventional signs. . . ." Hipour is a master navigator, one of the half-dozen acute men who are the leaders of their profession and therefore of their low green atoll 1,000 miles west by south of Bikini. Four hundred people live on Puluwat, their staples the breadfruit and the taro, their game the sea fish, their rulers now the American Trust Territory officials on Truk, 150 miles east.

Dr. Gladwin is an anthropologist with the language and experience of years on Truk, come to study the methods and the minds of the voyagers. More "than anywhere else in the Pacific" the people of Puluwat depend on a marvelous navigational system to guide their constant voyages to the atolls that lie strewn about them in the ocean. A week's lonely stretch in a sailing canoe takes the brave crew several hundred miles to its first landfall. The big interisland canoes are still busy: each of the atoll's fleet of 15 averages three or four voyages a year.

The canoes—"flying proas" 26 feet long—are powerful, graceful craft, carved subtly by the master builders of Puluwat out of the timber of that atoll, fastened together solely with coconut-husk fibers spun into coir lines of every size. They are single-outrigger canoes, stable but keelless for the shallow reef entries, knife-thin but blunt-ended for speed. The sails are now made of imported cotton cloth (once they were pandanus mats). The people of Puluwat are more at home in these sea canoes than those of Los Angeles in their cars on the freeways. Adding up all the full-size places available in the working canoes, the island total is 490, even though there are fewer than 400 people.

Once the canoes made sea war, and for a long time the people of the Carolines have holidayed, fished, traded, married and resettled after some devastating typhoon—all by the sailing canoe. Puluwat builds canoes for many islands; their designs are judged the best in the Carolines. Nowadays the little powered trading ships, although bound by schedule and routine, are competing with the canoes, and the export trade is falling off. Truk, the big capital atoll, has almost no sailing canoes left. On Puluwat, however, the people still rejoice in the skill and power of their sailing. A detailed account is given, with a good photographic sequence, of the main points of canoe-carving, although much of the art remains inexplicit. The continuity of hull forms and the complex demands made on any practical design represent engineering too difficult to understand fully with the modest means and resources employed.

Besides the cloth sails, and a sheave block on the main sheet, the innovations in canoes include a much smoother hull. This was introduced long ago, when the Spanish first brought iron blades for adze and plane. A related advance, made only since World War II, is the result of the deliberate and pragmatic dropping of all old maritime ritual and taboo after direct experiment, following missionary religious conversion. This step made more men eligible to handle the tools, and so brought many hands to work on the painstaking removal of every imperfection in the hull contours. Ikuliman, "the greatest living navigator and canoe-builder" (and he looks it, wise and assured), consistently builds proas of outstanding performance, tested in long racing, with unusual double-contoured convex bottom surfaces.

The heart of Gladwin's account is the Puluwat navigation system, which is good enough to make a dead-reckoning

landfall on a small atoll at a distance of 800 miles. The atoll target is enlarged by the reef outline, a sea-surface feature much studied by the navigators, and by the 10-mile flight radius of specific shore birds, which are also part of the system. The distance made good is judged by experience with the canoes under sail, by sun time and star time, and interpreted by an elegant abstract method in which the canoe is regarded as being fixed in the sea and islands along the way are considered as sliding one after another through a set of known bearings.

There are two professional schools of instruction in navigation, each using both ground-school and sea experience. Hipour teaches how to find bearings by the stars. (The sun is assimilated into the star compass by noting daily where it rises or sets among the stars.) In Puluwat they make a scale map of the islands with pebbles in the white beach sand, and the student learns all the bearings, going and coming, for every likely voyage, with alternates and fail-safe courses to allow for wind and drift. There are 32 named star bearings, unequally spaced.

The scheme is superbly adaptive. It relies heavily on the kind of accurate bearings one can use only in the Tropics, near and yet not too near the horizon, since in low latitudes the star trails are almost vertical. The system includes entire constellations such as the big and little dippers for north-south bearings; these are plainly less well defined than single stars. The Carolines, however, are a narrow ribbon of islands along one parallel of latitude; no long north-south voyage need ever be made. The precision built into the system seems to be about five degrees of arc, an error of only 20 miles in 200 or 300.

The use of recognizable sea-swell patterns to judge the directions of long fetch, and hence under cloud to find bearings that are at least probable because of the regularity of the distant winds, seems real. The magnetic compass has been used in latter decades as a transfer medium for bearings at sea, and also to tide the navigator over clouded times. There are discrepancies and confusions too, but they apply mainly to voyages almost never made. "No style of thinking will survive which cannot produce a usable product when survival is at stake."

Altair is their Big Bird, as it is our Eagle. In spite of what Dr. Gladwin says, however, that star rises due east of no island in the world, not even of Puluwat. It did bear true east of Puluwat (and all other islands) a couple of centuries ago. The eight-degree error does not make much difference now on the voyage to big Truk. Nonetheless, there clearly is more we ought to ask Hipour and his colleagues.

Dr. Gladwin had a complex rationale for his study: he holds that these obviously able thinkers, the navigators, are good at abstraction and secure with concrete observation but remain unskilled at innovation, problem-solving and all heuristic thought. He set them a little puzzle of stacking poker chips to test this notion; a man as deep as Hipour made scant progress. The author quite rightly says that we need to judge poor Americans, as we judge the wonderful Puluwat navigators, by scales quite other than those of our schoolroom tasks. This is a compelling truism, although his argument is faulted. It is not heuristic thought they lack on Puluwat; it would seem that the magnetic compass and the chart present contrary evidence. It is only useless little academic problems with chips that they are not moved to solve. (The ghetto kids may act the same way.)

That ethnoastronomers ought to study spherical triangles at least as much as they study Jean Piaget is one other conclusion the reader may draw from this engrossing book. Back to Puluwat!

AKENFIELD: PORTRAIT OF AN ENGLISH VILLAGE, by Ronald Blythe. Pantheon Books ($6.95). THE SHELL BOOK OF COUNTRY CRAFTS, by James Arnold. Hastings House, Publishers ($6.95). "Village folk have been buried over and over again in the same little bits of churchyard ... three or four sometimes. I always put all the bones back so that they lie tidy-like just under the new person." So says the gravedigger, come to witness. The 100 houses and 300 people of Akenfield in East Anglia can trace their village back to the Domesday Book. The two square miles of flat fields on the margin of the cold North Sea bear well, their yield of grain, livestock and fruit larger than ever before.

Fifty villagers, change ringer and smith, doctor and farmer, wheelwright and vicar, poet and pig farmer, tell their life story. These tales span the years of man and woman from 17 to 88, and they seek not only to narrate but also to explain and to justify. The stories were drawn out and surrounded by a commentary both beautiful and sharp by a novelist, himself a Suffolk man, whose art it has been to forge an intense and glowing form from these artless, intricate recollections.

The wind is doctrinal over this wide clay plain, "a quite unmysterious wind, dispelling the fuzziness of things. On a clear day ... you can see as far as you can bear to see, and sometimes farther. It is a suitable climate for a little arable kingdom where flints are the jewels and where existence is sharp-edged." About 85 people work for a living in Akenfield (the name is fiction but the village is real); some 55 work directly on the land, and a number of others in farm-related trades such as flour milling.

The volume is a work of literature; it engages and it fascinates. It is history told by actors playing bit parts, like ourselves. It gains review here as science, as good social anthropology seized with questions wider than the Suffolk plain.

Class interest has ruled this land over the past century. After World War I the slow, silent men of the fields organized an Agricultural Labourers' Union. It was crushed by the farmers, themselves hard, proud, quiet and self-assured men, and "it took a brave man to show his politics in Suffolk all through the 1930s." Wages in the fields are still low but no longer are the young men able to see no future except a half-feudal life in a tied cottage with a claim on gleaning rights. The more imaginative people depart for the less satisfying but better-paying impersonal factory job in the ugly city. "These young men, they changed the farmers. ... It was a good thing. Their power had got too great." "My father used to say that farm-working was bad pay but a good life."

Now there is factory farming, and the head plowman no longer walks behind the big, slow horses but drives his tractor. "[There is] about 400 acres of cornland and I plough it all." When the plowman's tractor stops, "the village experiences a similar kind of dragging silence to that caused by a clock stopping in a room." The penned hens and pigs are prisoners, and the veterinarian can "hardly bear thinking about" the chickens. The very hogs have changed, now reaching less than half the usual old weight ("With our pigs it is a short life—and a happy one." "It was a world of great pigs. The villagers needed all this fat ... to keep them warm.... The Suffolk women won't buy fat now—perhaps it reminds them of [the] shivering men in the lea of the wind ... chopping at pure white hunks of the stuff.... The miners still like it very much.") Work calories now come from petrol, and body heat is saved by plenty of good warm clothing. "You can hear the paper packs being torn open and in five minutes it's dinner. I don't call that dinner," says the old retired plowman.

The Suffolk mind is opener now, but it remains passive. Most of the people have traveled only in wartime, or to leave the land for good. ("While the others thundered their way through the multiplication tables... Michael made rag rugs with incredible speed and ingenuity.... He cannot read or write a single letter.... It is this which cuts him off.... Nobody seemed to realize that a child who could work so hard and who could make such good designs might have been able to learn if learning had been a less rigid thing.")

There is still the book fear that the young learn. They need to read now about pigs and engines, but they reach no further. The magistrate thinks that television doesn't touch the young people, "not yet, anyway." Once there were "scores of Peeping Toms... part of the old frustrated cooped-up feeling." Sex "used to be in the hedgerows and now it is in the back of the car." It was never as restricted as people imagined.

The reader will never quite leave Akenfield. The book will greatly reward those who seek in it a village in our day. Let Gran have the last word, as she waters her pot plants. The author writes: "A swing-wing bomber from Bentwaters knifes up the iridescent Akenfield afternoon, its scream momentarily and intolerably trapped in the cottage. 'Blessed Yanks!' says Gran—'If ever I should swear!' "

Smith, wheelwright and roof thatcher still ply their trades in Akenfield. The master smith there is busy and prosperous, signing his name, as his predecessors never did, to the output of his forge, now almost entirely ornament. *The Shell Book of Country Crafts* is a fulfilling complement to *Akenfield*. In its own right it is a general reader's guide to the cunning crafts of woodland and coppice, anvil and reed roof, and 35 other specific trades of preindustrial Britain. They are each well described, with history, surroundings and a sketch of the craft, its tools and its product. The plaiting of the corn dolly from dampened golden wheat straw to adorn the last load of the harvest grain is Neolithic and continent-wide. The farmers' wives in the Akenfield Women's Institute are reviving the practice ("How dare you think of putting a pagan idol in our church!"), although it was always the men who made them in the old days, and an aging woman near Akenfield had a "kind of goddess wrapped in a plastic bag" that she had watched her grandfather plait. A dolly called "the Suffolk horseshoe" is here in a photograph; it is the old Earth Mother transformed and tame.

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This photo of Taiwan, taken from a NASA Gemini spacecraft, could double that nation's fishing yield.

The deep blue water along the upper west coast, an upwelling that raises nutrients from the ocean floor, is an ancestral fishing ground. The similar upwelling on the east coast, discovered by this photo, may prove to be as rich in fish as the traditional grounds.

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