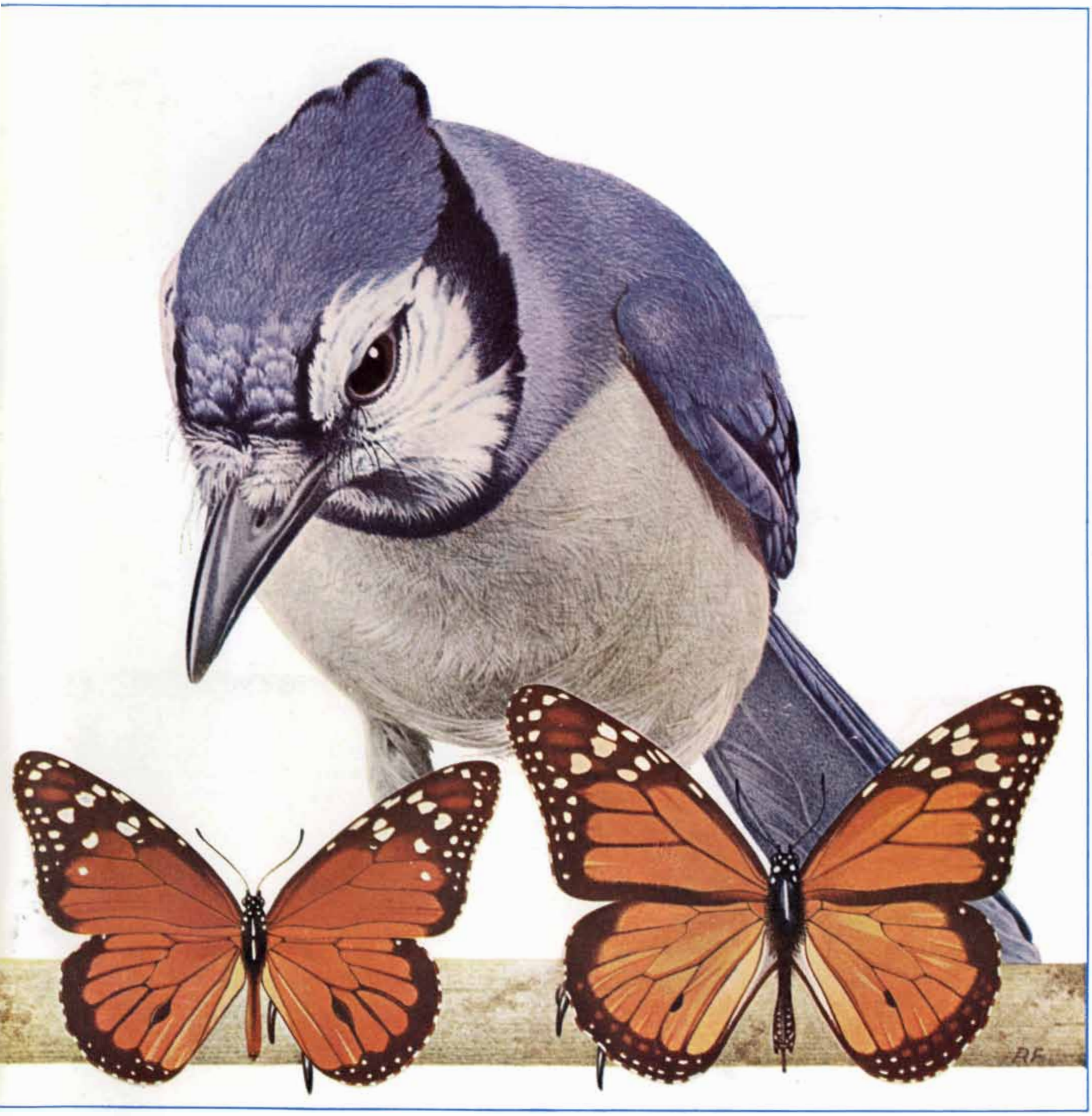
SCIENTIFIC AMERICAN



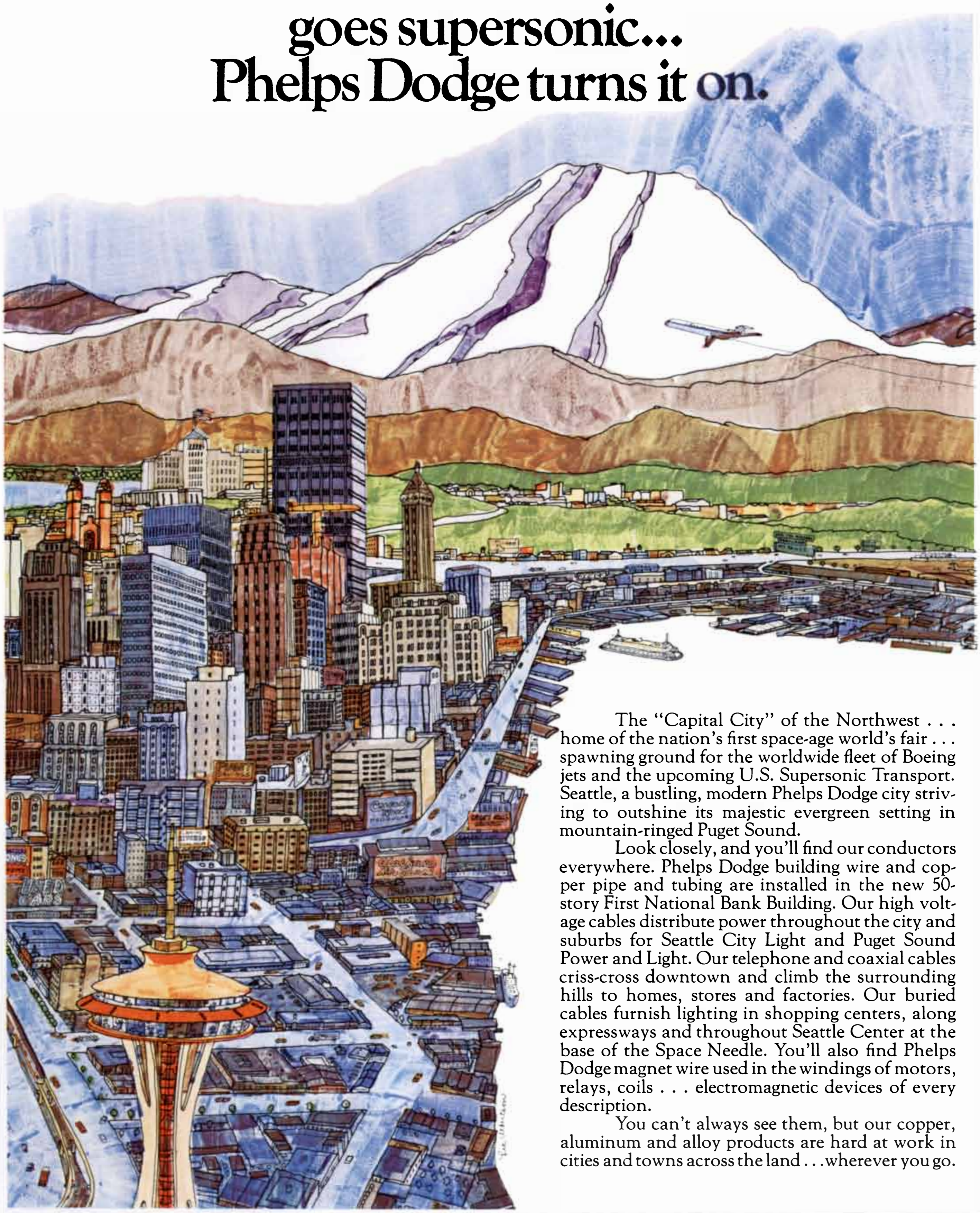
ECOLOGICAL CHEMISTRY

SEVENTY-FIVE CENTS

February 1969

PHELPS DODGE COPPER, ALUMINUM AND ALLOY PRODUCTS

When Seattle goes supersonic... Phelps Dodge turns it on.



The "Capital City" of the Northwest . . . home of the nation's first space-age world's fair . . . spawning ground for the worldwide fleet of Boeing jets and the upcoming U.S. Supersonic Transport. Seattle, a bustling, modern Phelps Dodge city striving to outshine its majestic evergreen setting in mountain-ringed Puget Sound.

Look closely, and you'll find our conductors everywhere. Phelps Dodge building wire and copper pipe and tubing are installed in the new 50-story First National Bank Building. Our high voltage cables distribute power throughout the city and suburbs for Seattle City Light and Puget Sound Power and Light. Our telephone and coaxial cables criss-cross downtown and climb the surrounding hills to homes, stores and factories. Our buried cables furnish lighting in shopping centers, along expressways and throughout Seattle Center at the base of the Space Needle. You'll also find Phelps Dodge magnet wire used in the windings of motors, relays, coils . . . electromagnetic devices of every description.

You can't always see them, but our copper, aluminum and alloy products are hard at work in cities and towns across the land . . . wherever you go.

Build a wall 1 foot thin and 17 tons tough. Then add refrigeration.

SIDE VIEW

While you're at it, make sure these walls can be attached to cargo containers in minutes.

And also make sure that they can be used on just about any container that moves—by ship, train and trailer. In any climate.

This was the assignment given to Carrier's Special Products Group at the birth of an industry-within-an-industry—containerization.

Moving products from place to place with the fewest possible human hands was the objective.

Our job was to get the products from place to place in the same condition as they started.

The Bridge of Freshness. What was needed, of course, was a refrigeration system for each container. One that would keep frozen foods frozen. Fresh foods fresh. And other perishables—from pharmaceuticals to beer—in good condition over long hauls.

In one of these containers, for example, pineapples could go from Hawaii to San Diego by ship; be loaded on a rail car for the cross-country trip; be swung aboard another ship in New York; then transferred to a truck in Le Havre to roll on to Paris.

The pineapples would never have to leave the container as it becomes first part of a ship, then of a train and finally a truck.

But shippers didn't want to give up profitable container space for the traditional "Reefer" unit necessary to keep perishables refrigerated.

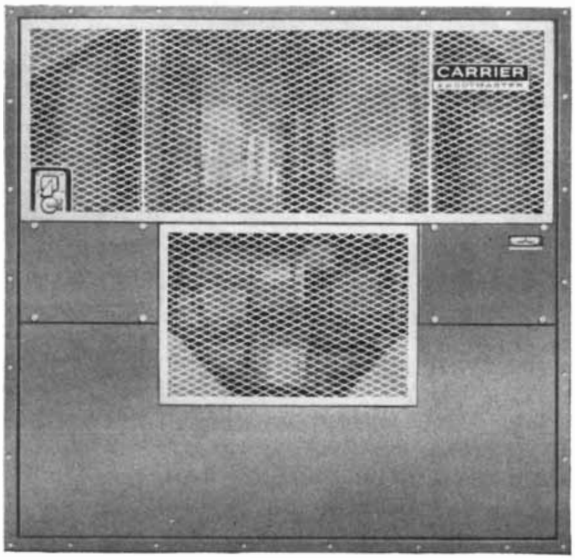
Think Thin. While we had the width and height of a trailer truck in which to work, we set our own depth restriction of 12 inches. We wanted to build the skinniest refrigeration system going.

This meant designing small components (where we could) and stacking them within the wall.

Compressor, evaporator, fans, motors, coils and heater form the middle of a thin poorhouse sandwich. Then the sandwich is liberally spread with two inches of polyurethane insulation.

The 17-Ton Wallop. The shell was designed as the insulated front wall of the container—a one-piece, self-contained unit that actually added as much strength, if not more, as an ordinary fourth wall.

Still operating within our self-imposed 12 inches, we built this wall to be strong enough to withstand a 17-ton jolt against the front.



FRONT VIEW

The Carrier Frostmaster® unit, in fact, passed both the rack and front end load tests as prescribed by the International Standards Organization.

As far as we know, no other unit has even taken the tests.

Put On . . . Plug In. The Frostmaster unit works beautifully.

It takes the least amount of space of any refrigeration system; actually saves over 45 cubic feet of space compared to conventional products.

Since the refrigeration equipment is built into the thin wall, nothing protrudes. The containers can be stacked close together.

To the makers of the containers themselves, production costs are reduced by a substantial amount since the Frostmaster unit becomes the fourth wall.

Cargo temperatures—down to 20 degrees below zero—are precisely controlled with automatic refrigeration, electric heating and evaporator defrost.

Cooling capacity ranges from 20,000 Btu's to 35,000 Btu's at 35 degrees F.

Simple interface mounting flanges allow the unit to be installed in a jiffy.

The record, we think, is 3 minutes, 31 seconds.

Then it's simply plugged into the electric power source.

Special access panels provide for easy maintenance—and fast emergency service—from the outside of the unit.

That Last 5/16 Inch. And the depth? 12 inches, just as we'd planned. Plus a slightly embarrassing 5/16 of an inch which we just couldn't seem to lose.

As a matter of fact, some special subsequent units with larger capacities ballooned to 16½ inches. Even so, they remain the skinniest of the cargo coolers.

Refrigeration and air conditioning challenges may be self-imposed or customer imposed. Either way, we do our best to meet them.

And we're meeting them all the time. In aerospace. Oceanography. Military. Transportation. Food storage. Industry. And many other fields.

We're at your service.

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Carrier Air Conditioning Company Carrier®

Established 1845 **SCIENTIFIC AMERICAN** February 1969 Volume 220 Number 2

ARTICLES

DEPARTMENTS

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THE COVER

The painting on the cover shows an experimental situation in which a captive blue jay (*Cyanocitta cristata*) is offered two butterflies that may or may not be palatable (see "Ecological Chemistry," page 22). The butterfly at left is a queen (*Danaus gilippus xanthippus*) and the one at right is a monarch (*Danaus plexippus*). In Trinidad most of the monarchs are unpalatable because at the larval stage they feed on milkweeds containing substances that affect the vertebrate heart. The larvae assimilate these substances, which persist in the adult butterflies. A bird that eats such a butterfly is made violently but briefly ill and thereafter will ordinarily reject similar butterflies on sight. Most of the queens in Trinidad are palatable, having fed as larvae on different and nonpoisonous milkweeds, but by a form of mimicry the queens have come to resemble the monarchs and thereby to share in the protection from predators that the monarchs gain by their unpalatability.

THE ILLUSTRATIONS

Cover painting by Rudolf Freund

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18	The Granger Collection (*left*), *Columbus Dispatch* (*right*)
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Kodak
Kodak

LETTERS

Sirs:

It was a pleasure to see the importance of faunal analysis in archaeological site interpretation brought to the attention of your readers ["A Hunters' Village in Neolithic Turkey," by Dexter Perkins, Jr., and Patricia Daly; SCIENTIFIC AMERICAN, November, 1968]. Analysis of this kind is important in reaching an understanding of the past activities and environment of prehistoric groups. I should like to point out the possibility of some additional cultural information about the site described in the Perkins and Daly article.

Since the authors relied to some extent on the information derived from archaeological sites on the plains of the western U.S., they seem to have overlooked an important cultural feature noted in the faunal analysis of village sites there. This is the manufacture of "bone grease."

According to ethnographic accounts, bones after butchering were dried for a day or two, then splintered by pounding. The fragments were then boiled to render the oil. By this method an adult bison skeleton could produce approximately six pounds of grease. The result of this practice, judging from the archaeological sites, is debris consisting of a large number of unidentifiable bone fragments and a smaller number of identifiable ones. Those that can be identified generally consist of the more massive and dense bones of the larger animals, frequently foot elements, and the denser articular ends of the long bones of the smaller animals. Considering the 275,000 unidentifiable bone fragments and the 25,000 identifiable ones recovered from the Neolithic site in Turkey described by Perkins and Daly, it would seem that a comparable cultural practice was involved there.

LATHEL F. DUFFIELD

Department of Anthropology
University of Wisconsin
Madison, Wis.

Sirs:

In my review of the Ciba Symposium *Decision Making in National Science Policy* [SCIENTIFIC AMERICAN, November, 1968] I failed to mention the important role played by the Science of Science Foundation Ltd. in organizing this symposium and ensuring its success. I wish to apologize for the omission and stress the crucial role played by the Science of Science Foundation in stimulating these important discussions.

A. DE-SHALIT

Weizmann Institute of Science
Rehovoth, Israel

ERRATUM

In the article "Transplanted Nuclei and Cell Differentiation," by J. B. Gurdon (SCIENTIFIC AMERICAN, December, 1968), the caption for the illustration on page 28 indicates that the transplants outlined in the illustration were conducted with abnormal frog embryos. In actuality these transplants were done with normal embryos.

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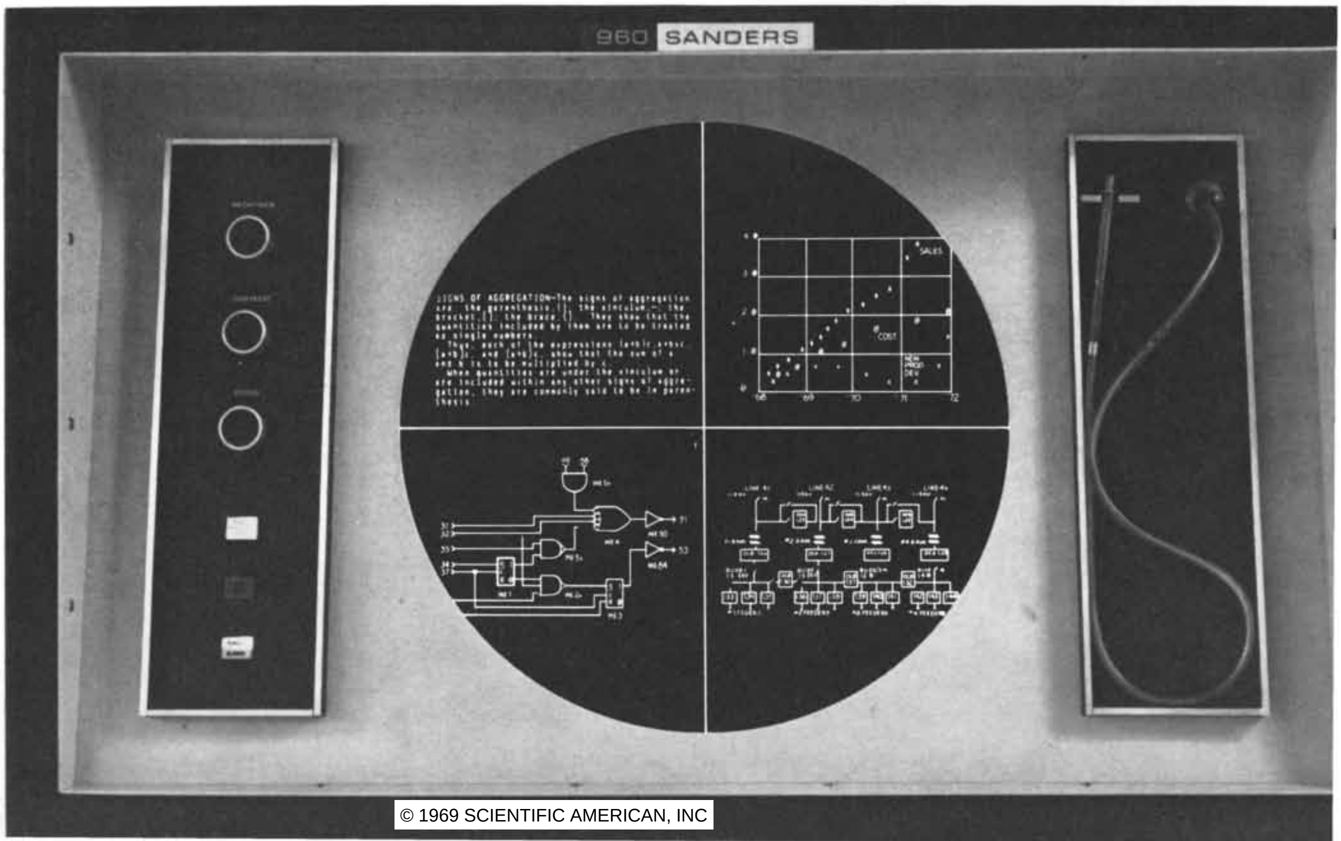

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

FEBRUARY, 1919: "The American people have been getting news of a sort from the peace conference at Paris, but just how far it agrees with the facts the censor alone can tell. So far as the course of events has been disclosed, we maintain that absolutely nothing has transpired to change the naval situation as we defined it several weeks ago. Germany, the one naval power that was a threat to the security of the world, has been eliminated, leaving on the high seas only the fleets of nations that are either our friends or actually our allies. In the midst of this amicable situation we, the United States, professedly the most peaceful nation on earth, suddenly announce that we are going to set out on a scheme of naval expansion exceeding anything of the kind in the history of the world. We are told that this navy will be built, if it ever is, as a rebuke to the nations of Europe, should they not obediently abolish or greatly reduce the fleets which they already possess. Incidentally it will cost us one billion dollars a year thus to play schoolmaster to Europe, and is not this billion-dollar rebuke, delivered ahead of the transgression, somewhat premature?"

"Recent researches—largely by A. S. Eddington and Henry Norris Russell—make it probable that a star starts its life as a huge body of highly rarefied and relatively cool gas. As it contracts it becomes hotter and hotter, until at last it gets so dense at the center that it can no longer contract freely. Then its temperature has attained a maximum, and it begins to cool off and finally, after the lapse of ages, goes out. The sun appears to be in early middle age—well past the maximum of temperature but with still a long life of moderate activity before it."

"On January 19th last, Jules Vedrines, the famous French airman, set out from the aviation field at Issy-les-Moulineaux, notwithstanding a thick fog, and flew toward Paris. He flew rather low over the boulevards in order to get his bearings. On approaching the Galeries Lafayette, a large department store near the St. Lazare station, Vedrines shut off his engine and volplaned toward the roof. Skimming the parapet by a few inches, he made a spectacular landing, although the machine was slightly damaged. Vedrines won a prize of 25,000 francs ($5,000) for being the first airman to land on the roof of a house."

SCIENTIFIC AMERICAN

FEBRUARY, 1869: "Among the great projects of the age are those for building canals, railways, bridges and tunnels. In canals we have the project of one around the Falls of Niagara; a re-enlargement of the Erie for vessels of 1,000 tuns; the Suez, nearly completed; one across the Alleghanies in Virginia; one through the Nicaragua Lake or Panama, and one from Lake Huron to Lake Ontario. In railways we have the Union Pacific on the eve of completion; the Mont Cenis in rapid progress; one across the continent from Rio de Janeiro begun, and many others of magnitude. In bridges we have those in progress across our great Western rivers; one proposed across the East River at New York of 1,600 feet clear span; two over the Hudson, above and below West Point; another across the Strait of Messina, covering the 'Scylla and Charybdis' with clear spans of 1,000 meters (two-thirds of a mile) each and with piers of 700 feet high, half in and half out of the sea, and finally the modern 'Pons Asinorum,' a bridge project across the Straits of Dover 16 miles long, in clear spans of two miles each, with piers of 1,000 feet depth in the water. In tunnels we have that of Mont Cenis, eight miles in length, and of the Hoosac, five miles, both in rapid progress; one of wrought-iron tubes at London and another at Chicago, almost completed; tunnels are also proposed under the East and North rivers at New York, under the Ganges at Calcutta and under the Straits of Dover."

"An article under the title 'Birth of the Solar System' appears in the *Atlantic* for February. It purports to enunciate a new theory of the origin of the earth, sun and other heavenly bodies. We should not, perhaps, strictly say origin, as the theory of cosmical vortices held in common by Laplace and other philosophers is retained, but with the difference that in the new theory the cosmical matter is considered to be intensely cold, and its precipitation toward and concentration around the vortices to be the cause of heat, which increases with the size of the orb thus formed until the body becomes self-luminous, in short becomes a sun. Thus the earth is, according to this doctrine, an embryo sun in a meteoric vortex, constantly growing by the attraction of cosmical matter to itself and its temperature constantly rising. We have not space to note at length all the strong or weak points of this theory. Evidently written, however, by a daring and speculative mind and throwing down the gage of battle to all the systems hitherto accepted, and appearing in a periodical read by most thinkers in this country and many abroad, this new theory cannot fail to attract great attention and will probably give rise to much discussion."

"The practice of the transfusion of blood seems to be coming more prominently into notice at the present time than it has been for some years past. The *Medical Record* gives an account of a successful operation for the transfusion of blood recently performed by Dr. Enrico Albanese at the hospital of Palermo, Sicily. A youth aged 17, named Giuseppe Ginazzo, of Cinisi, was received at that establishment on the 29th of September last with an extensive ulceration of the leg, which in the end rendered amputation necessary, the patient being very much emaciated and laboring under fever. The operation reduced him to a worse state than ever, and it became apparent that he was fast sinking, the pulse being imperceptible, the eyes dull and the body cold. In this emergency Dr. Albanese had recourse to the transfusion of blood as the only remedy that had not yet been tried. Two assistants of the hospital offered to have their veins opened for the purpose, and thus at two different intervals 220 grammes of blood were introduced into the patient's system. After the first time he recovered the faculty of speech and stated that before he could neither see nor hear but felt as if he were flying in the air. He is now in a fair state of recovery."

"It is stated that there are now before the Senate, lying on the table or referred to committees, no fewer than 110 bills asking aid for the Pacific railroad routes or connecting lines in the territories and Pacific states. In the House there are 112 pending. An approximate statement puts the amount of the bond subsidy asked for at about $250,000,000 and the land grants at 120,000,000 of acres."

THE AUTHORS

L. SPRAGUE DE CAMP ("The End of the Monkey War") is a free-lance writer whose home is in Villanova, Pa. He received a bachelor's degree in aeronautical engineering from the California Institute of Technology in 1930 and a master's degree in engineering and economics from Stevens Institute of Technology in 1933. Although he has worked as an educator, editor, lecturer, engineer and patent expert, he has spent most of the past 30 years as a writer. He is the author or coauthor of more than 60 books, including popularizations of science and technology, textbooks, historical novels, science fiction, fantasy and juvenile nonfiction. Several of his books were written in collaboration with his wife, Catherine Crook de Camp.

LINCOLN PIERSON BROWER ("Ecological Chemistry") is professor of biology at Amherst College. A graduate of Princeton University in 1953, he obtained his Ph.D. from Yale University in 1957. After a year as a Fulbright scholar at the University of Oxford he joined the Amherst faculty. Brower writes: "Professionally my goal is to increase our understanding of how ecology and behavior operate in their natural setting by utilizing the powerful tool of controlled manipulation in integrated laboratory and field experiments. I have chosen insects and birds as the experimental animals because of their life in a three-dimensional environment that I feel is aesthetically pleasing (particularly because of the role that color and pattern play in the setting; one day I shall add coral-reef fish for the same reason). My interests in photography and education have prompted me to produce two color sound films about my work so as to reach a wider audience. Other interests include gardening, skiing and a quest for ever more palatable food—so eminently well prepared by my gourmet wife and colleague, Jane Van Zandt Brower."

PETER SOROKIN ("Organic Lasers") is a physicist with the Research Division of the International Business Machines Corporation. He was graduated from Harvard College in 1952 and received his Ph.D. from Harvard University in 1958, a year after he joined IBM. He writes that he and his colleague Mirek J. Stevenson discovered in 1960 "the second and third lasers on record, ones that for the first time utilized the rare earths as active elements." Since then, Sorokin says, "I have been credited with a number of primary discoveries in the following areas of laser physics: stimulated electronic Raman emission, *Q*-switching by organic dyes and organic lasers." Of his outside interests Sorokin writes: "In the winter I manage to enjoy some weekend skiing in Vermont, and during the summer I play tennis fairly regularly, although not with exceptional skill. I also enjoy working around the grounds of our summer place on Lake Memphremagog in southern Quebec. My reading interests, I must confess, are now largely confined to other branches of science."

V. L. GINZBURG ("The Astrophysics of Cosmic Rays") is head of the Sub-Department of Theoretical Physics in the P. N. Lebedev Physical Institute of the Academy of Sciences of the U.S.S.R. He was graduated from the physics faculty of Moscow State University in 1938 and obtained his D.Sc. in 1942. He has worked in the Lebedev Institute since 1940. Since 1945 he has also been visiting professor of physics at Gorky University, and since 1968 professor at the Institute of Physics and Technics in Moscow. Ginzburg became a corresponding member of the Academy of Sciences of the U.S.S.R. in 1953 and a full member in 1966.

FERRIS N. PITTS, Jr. ("The Biochemistry of Anxiety"), is associate professor of psychiatry and assistant professor of pediatrics at the Washington University School of Medicine. He did both his undergraduate and his graduate work at Washington University, receiving his bachelor's degree in 1952 and his M.D. in 1955. After serving as an intern and an assistant resident at the St. Louis Children's Hospital he became first an assistant resident in psychiatry and then chief resident in psychiatry at Barnes and Renard Hospitals of the Washington University School of Medicine. He has been a member of the faculty at the school since 1955.

RADA and NEVILLE DYSON-HUDSON ("Subsistence Herding in Uganda") are at Johns Hopkins University. Mrs. Dyson-Hudson is a biologist; at Johns Hopkins she is a research associate in ecology and animal behavior. Her husband, an anthropologist, is an associate professor in the department of social relations. Both of them obtained the Ph.D. degree at the University of Oxford. For the past 15 years they have studied nomadic herders; during eight of those years they were working in Africa with the support of several American foundations. Their long-range interest is in the development of rigorous methods for the ecological analysis of human communities.

WALLACE CHINITZ ("Rotary Engines") is associate professor of mechanical engineering at Cooper Union for the Advancement of Science and Art. He was graduated from the City College of the City of New York in 1957 and received a master's degree from the Polytechnic Institute of Brooklyn in 1959. While completing requirements for the degree he worked as a research engineer at the Fairchild Engine and Airplane Corporation and at the Republic Aviation Corporation. In 1960 he joined the staff of the Polytechnic Institute of Brooklyn as research fellow and instructor; in 1962 he obtained his Ph.D. from the institute. He spent a year there as assistant professor and four years at the General Applied Science Laboratories, Inc., where he worked on chemically reacting supersonic flows and advanced propulsion devices.

MARIAN NEUTRA and C. P. LEBLOND ("The Golgi Apparatus") are respectively a biologist and a professor of anatomy at McGill University. Mrs. Neutra, who is the wife of a physician in Boston and the mother of two small children, was graduated from the University of Michigan in 1960 and obtained her Ph.D. from McGill in 1966. During two years that she spent with her husband in the Southwest she made a cytogenetic study of peyote users among Navaho Indians. Aside from her professional activity she enjoys cross-country skiing. Leblond, who is chairman of the department of anatomy at McGill, holds both M.D. and D.Sc. degrees, the former from the University of Paris in 1934 and the latter from the Sorbonne in 1945. He went to McGill in 1941 as a lecturer in histology and embryology. In 1965 he was elected a Fellow of the Royal Society. His interests include dynamic histology, where he demonstrated that the lining of the stomach and intestine is renewed every few days, and the mode and rate of production of thyroid hormone by the cells of the thyroid gland.

ALEXANDER RICH, who in this issue reviews *Comprehensive Biochemistry*, edited by Marcel Florkin and Elmer H. Stotz, is professor of biophysics at the Massachusetts Institute of Technology.

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The End of the Monkey War

The Fundamentalist crusade against the theory of evolution subsided soon after the Scopes trial of 1925, but it was only three months ago that the last antievolution law of any consequence was killed

by L. Sprague de Camp

At the end of his *Descent of Man and Selection in Relation to Sex* (1871) Charles Darwin wrote: "The main conclusion arrived at in this work, namely that man is descended from some lowly organized form, will, I regret to think, be highly distasteful to many." Half a century later his prediction was fully realized in the U.S., where many Americans waged what is sometimes called the "monkey war." Fundamentalists—Christians of various denominations who believed that evolution contradicted the Bible—sought to check the spread of evolutionary thought by making it a crime to teach it. Not until November 12 of last year, when the U.S. Supreme Court ruled that a law barring the teaching of evolution in public schools and colleges was unconstitutional, could it be said that the monkey war had come to an end.

The best-known battle in this ideological conflict was fought in 1925, when John Thomas Scopes was tried in Dayton, Tenn., for teaching evolution. The jury found Scopes guilty. The antievolution statute of Tennessee remained on the books, and following the Scopes trial similar bills became law in Mississippi and Arkansas. Evolution was thus not taught, except at the risk of committing a crime, in the public schools and colleges of three states. For 40 years these statutes helped to hold back the spread of disturbing new ideas about man's place in the universe.

The antievolution law of Arkansas, the Rotenberry Act, reached the U.S. Supreme Court in 1968. (The Scopes case did not go beyond the Supreme Court of Tennessee.) The Rotenberry Act, which forbade the teaching of evolution in public schools and colleges on pain of dismissal and fine, went unchallenged from 1927 to 1965. Then Susan Epperson, a 24-year-old biology teacher at the Central High School of Little Rock (backed by the Arkansas Educational Association), filed a suit to test the law's constitutionality in the chancery court of her county.

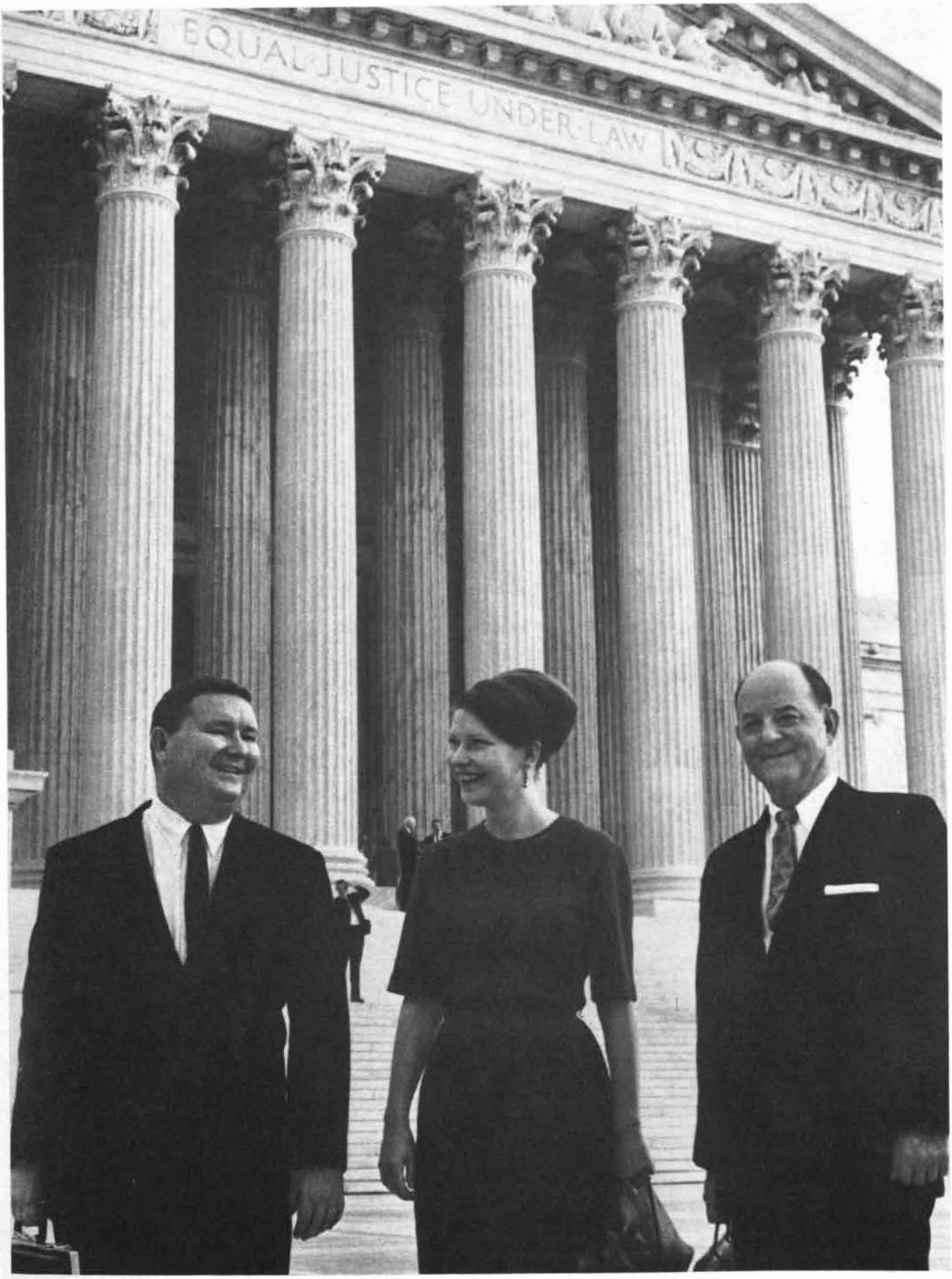
The chancellor, Murray O. Reed, ruled that the law was unconstitutional, on the ground that it limited a teacher's freedom of speech. The state appealed. The Supreme Court of Arkansas reversed Judge Reed's decision, holding that the Rotenberry Act was a legitimate exercise of the legislature's power to control the curriculum of public schools.

Mrs. Epperson then appealed to the U.S. Supreme Court. There her attorney, Eugene R. Warren, argued that the Rotenberry Act was unconstitutionally vague. If the word "teach" were construed as meaning merely to describe or mention (rather than to teach as being true, that is, to proselyte or indoctrinate), the act made it a crime to acquaint students with the very existence of Darwin's ideas. It would be illegal even to direct students to any standard dictionary or encyclopedia, which contain definitions of evolution and articles about it.

The testimony exposed the paradoxical position of a biology teacher in Arkansas. In spite of the law's prohibition against teaching "that mankind ascended or descended from a lower order of animals," the biology text used in most Arkansas schools discussed the evolution of living forms, including man. Faced with the problem of teaching from this text, some teachers skipped the chapters touching on evolution. (Some schools omitted biology altogether.) Other teachers got around the law by telling students that it was illegal to read the evolutionary chapters, knowing that students hearing this would be all the more likely to read them.

Speaking in the law's defense, Don Langston, the assistant attorney general of Arkansas, showed little enthusiasm. He even saw fit to inform the justices that he had inherited the Epperson case from a former administration. This remark prompted Chief Justice Warren to suggest that perhaps Langston's administration did not like the Rotenberry Act and, if so, "it might not be too late" to say as much.

A month after this hearing Justice Fortas delivered the opinion of the Supreme Court in the case of *Epperson* v. *Arkansas*. The majority of the justices held that, since the purpose of the Rotenberry Act was plainly to forbid any teaching that gainsaid the account of man's creation in Genesis (interpreted literally), the act did in effect establish a religious doctrine, and this was forbidden under the First and Fourteenth



SUSAN EPPERSON AND ATTORNEYS stand outside the U.S. Supreme Court after the hearing of her case challenging the constitutionality of Arkansas's antievolution law. The court upheld Mrs. Epperson on November 12, 1968, thus ending the monkey war. On Mrs. Epperson's right is Don Langston, assistant attorney general of Arkansas; on her left is her attorney, Eugene R. Warren.

Amendments to the Constitution. The Court declared: "It is clear that fundamentalist sectarian conviction was and is the law's reason for existence."

Concurring opinions were filed by three other justices. Justice Harlan objected to part of the peripheral discussion but agreed with the majority. Justice Black thought that the law should have been declared unconstitutional solely on the ground of vagueness. Justice Stewart held that the essential point was that the state had levied criminal penalties against a teacher who had merely talked about a subject in class, and that this violated the guarantees of freedom of speech.

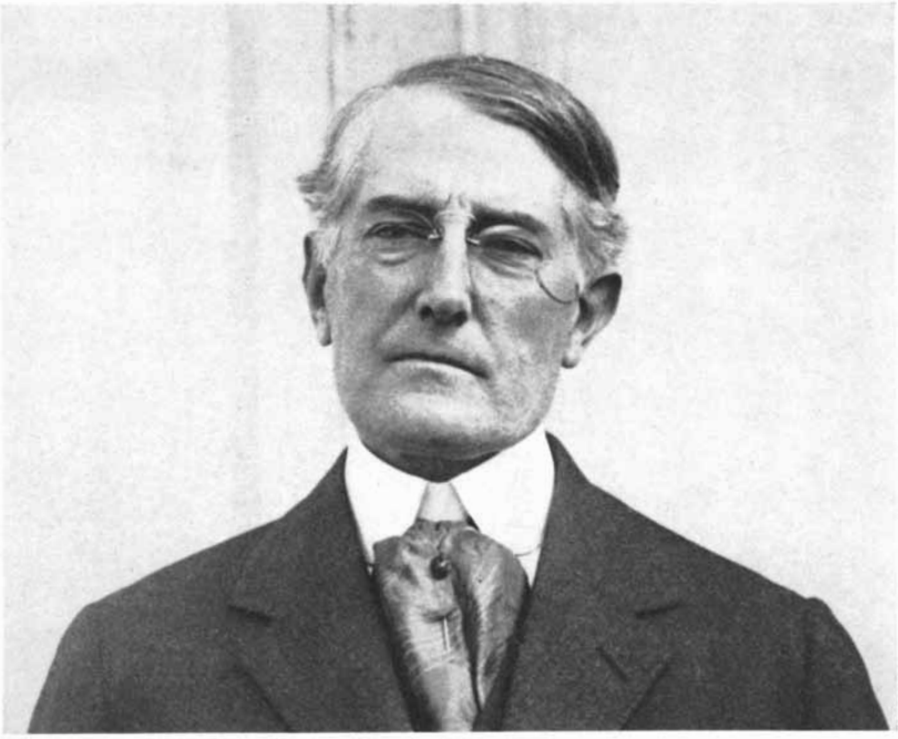
With the Supreme Court's decision in the Epperson case the only remaining monkey law is Mississippi's. (The Butler Act of Tennessee, at issue in the Scopes trial, was repealed in 1967.) Mississippi's statute is unlikely to be either adjudicated or enforced.

The controversy over evolution that ended with the Epperson case began after the Civil War. The *Origin of Species*, in which Darwin presented a mass of evidence to back his convincing explanation of evolution, appeared in 1859. In Britain the book's publication at once aroused violent opposition from such figures as Samuel Wilberforce, the Anglican Bishop of Oxford.

In the U.S., however, the impact of the book on the public was delayed by the Civil War. Then in the 1870's American religious leaders became uneasily aware of Darwin's explanation of man's origin. At the same time scholars in Europe were raising new questions about the Bible. They suggested that the Bible, far from being a book dictated by God, to be accepted as literally true in all details, was an anthology of ancient philosophy, law, sermons, myths, legends, parables, poems, history (some of it fictional) and not a few outright forgeries.

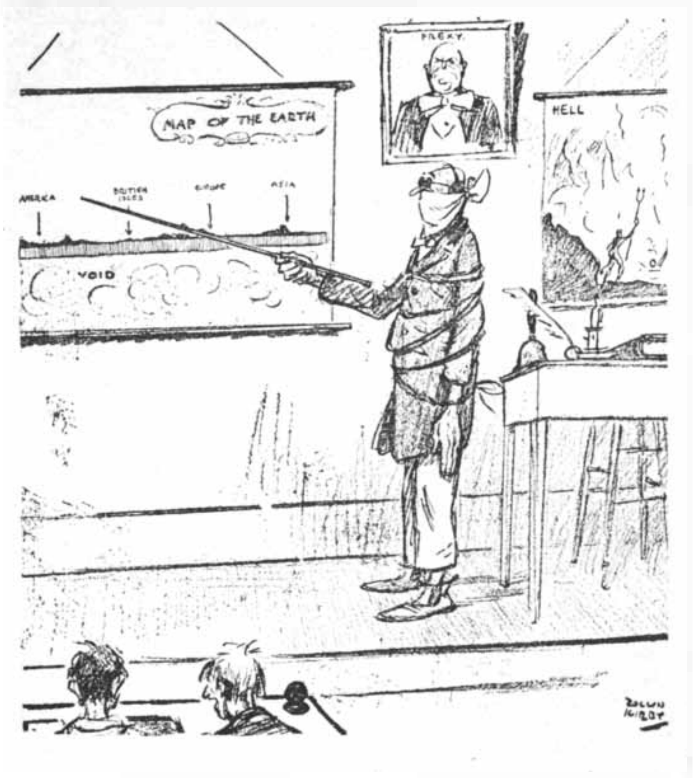
At annual gatherings of orthodox American Protestants, known as Bible conferences, conservative leaders began to inveigh against the menace of destructive Biblical criticism abroad and liberalism at home. A number of ministers and professors, accused of corrupting the minds of others with the new teachings, lost their posts. The geologist Alexander Winchell was dismissed from Vanderbilt University for telling his students that they were descended from organisms that lived before Adam.

In 1895 the Niagara Bible Conference put forth a statement purporting to reduce Christian doctrine to five essential points: (1) the inerrancy, or infallibility,



JOHN ROACH STRATON led a vigorous campaign against liquor, dancing and the theory of evolution during the 1920's. He was pastor of the Calvary Baptist Church of New York.

AIMEE SEMPLE McPHERSON preached against evolution in the Angelus Temple of Los Angeles. At the time of the Scopes trial she presided at ritual hangings of "monkey teachers."



MUZZLED PROFESSOR appeared in New York *World* during Scopes trial, testing Tennessee's monkey law. Caption, "Classroom in Proposed Bryan University of Tennessee," refers to William Jennings Bryan.

SPREADING INFECTION of monkey laws was seen possible in the *Columbus Dispatch* after Scopes was found guilty of teaching evolution. The cartoon was labeled "The Big Worry."

of the Bible, (2) the divinity of Jesus Christ, (3) the virgin birth of Christ, (4) the substitutionary atonement of Christ (the freeing of man from sin by Christ's self-sacrifice) and (5) the physical resurrection of Christ and his eventual Second Coming.

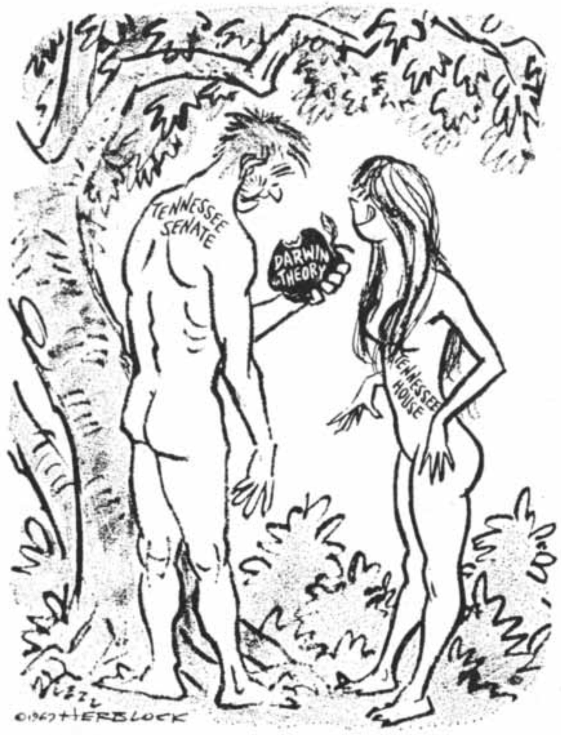
The first of these points, declaring the Bible to be literally true, brought the creation story of Genesis into conflict with the theory of evolution. Over the years the five points were cited, with numerous variations, on many occasions. They formed the basis for a series of pamphlets, issued in 1910 as *The Fundamentals* by the Los Angeles Bible Institute, founded by the brothers Lyman and Milton Stewart. *The Fundamentals,* widely circulated with funds provided by the Stewarts, furnished the basis for a growing Fundamentalist movement.

After World War I and the successful campaign to outlaw liquor, the Fundamentalists turned their fire on the theory of evolution. Leaders of the movement included William Bell Riley of the First Baptist Church of Minneapolis, John Roach Straton of the Calvary Baptist Church of New York, John Franklin Norris of the First Baptist Church of Fort Worth, Aimee Semple McPherson of the Angelus Temple of Los Angeles and, most prominent of all, William Jennings Bryan. In addition to his accomplishments as lawyer, lecturer, journalist, editor, Secretary of State and thrice-defeated candidate for President, Bryan was a prominent lay member of the Presbyterian church and a Sunday-school teacher. In 1921, at the age of 61, he moved from his home state of Nebraska to Florida. There he sold real estate, served as a lobbyist for several Latin-American countries and lent his rich baritone to the Fundamentalist cause.

The great orator was more moderate in his views than many of his followers, who said that evolutionists ought to be burned or crucified. Bryan advocated antievolution statutes without penalties. In private he revealed that he was less than dogmatically certain of his Fundamentalism; once he remarked to some younger associates, "Now, you boys will probably live to see whether or not evolution is true. I won't."

During the early 1920's several "monkey bills" were narrowly defeated in state legislatures. In Oklahoma a bill outlawing evolutionary textbooks became law, and in Tennessee a bill introduced by John Washington Butler, making it a crime to teach evolution, passed the House of Representatives without debate by a vote of 75 to five. Many who voted for the Butler bill were not Fundamentalists; they voted for political reasons, expecting the bill to die in the Senate. The Senate, however, pursued the same logic and passed it, anticipating a veto by the governor. In March, 1925, Governor Austin Peay, under pressure from fellow Baptists, signed the Butler Act. He tried to disarm criticism by saying: "Nobody believes that it is going to be an active statute."

The Scopes case, contrived to test the Butler Act, took shape in the following way. On April 4, 1925, the *Chattanooga Times* reported that the American Civil Liberties Union was prepared to finance the defense of a case to test the constitutionality of the Butler Act. On the following day in the small town of Dayton, in Rhea County in southeastern Tennessee, an argument arose in Robinson's Drug Store. The disputants were Walter White, superintendent of public schools in Rhea County, Sue K. Hicks, a young lawyer (he had been named after his mother), and George W. Rappleyea. Rappleyea, superintendent of the local coal mines, had grown up in New York City and worked his way through college. One of the few evolutionists in Dayton, he was regarded as something of an outsider.



SUPREME COURT RULING on the Epperson case reversed the Arkansas Supreme Court, inspiring this cartoon in the *Arkansas Gazette.* The line: "Gee, I Wish You Had Said That!"

FORBIDDEN FRUIT became legal in 1967 with repeal of Tennessee's monkey law. Caption of the cartoon (from *The Herblock Gallery*, Simon & Schuster, 1968) was "Okay, If You're Sure It's All Right to Eat."

Rappleyea proposed to stage the A.C.L.U.'s suggested test case in Dayton. He argued that the trial would "put the town on the map." White and Hicks, although not convinced Fundamentalists, favored the Butler Act. They were won over to Rappleyea's idea when he presented it as "a sporting proposition." As it stood, the Butler Act was not enforced. If the courts were to find it unconstitutional, it would be repealed. On the other hand, if the law were upheld, White and Hicks would win, because the law would be enforced.

An obvious candidate for token arrest was John Thomas Scopes. He was a science teacher in the Dayton High School and had been teaching evolution both because he believed in it and because it was discussed in the school biology textbook. He was 24, unmarried and could afford to risk his job. Summoned to the drugstore, Scopes agreed to accept his sacrificial role, and Rappleyea sent a telegram to the A.C.L.U. outlining his plan. On receiving a favorable reply he swore out a warrant against Scopes.

After Bryan had accepted an invitation from Hicks to serve on the prosecution and Scopes had retained two Tennessee lawyers to defend him, Clarence Darrow, the master jury-pleader and noted agnostic, offered the defense his services and those of his friend Dudley Field Malone, a well-known divorce lawyer. They were joined by Arthur Garfield Hays, counsel to the A.C.L.U. Among the other members of the prosecution were Bryan's son, William Jennings Bryan, Jr., and A. T. Stewart, the attorney general of the Eighteenth Circuit (which includes Rhea County). Volunteers on both sides served without pay.

A swarm of spectators, concessionaires, evangelists, eccentrics and fanatics descended on quiet, conventional Dayton, among them a bewhiskered prophet who called himself John the Baptist the Third and showmen with chimpanzees to rent to the litigants to lend color to the trial. More than 100 journalists also came to Dayton, including H. L. Mencken. He did not endear himself to the local populace by calling them, in dispatches to the Baltimore *Sun*, "anthropoid rabble" and "gaping primates."

The defense had persuaded a number of scientists and Biblical scholars to come to Dayton and serve as expert witnesses. (Most of the group were young; a number of older and more eminent people had declined.) When the trial began on July 10 and the defense proposed to call its expert witnesses, to show that evolution was a well-established fact and that it did not necessarily conflict with a liberal, allegorical reading of the Bible, the prosecution objected. The judge, John T. Raulston, ruled out the testimony of the witnesses as irrelevant. Then Darrow lost his temper, insulted the judge and was cited for contempt. The next day he apologized to the court and was forgiven. To lay the foundation for an appeal, Hays read (in the absence of the jury) a summary of what the expert witnesses would have said if they had been allowed to speak.

The masterstroke of the defense came on July 20. The trial had been moved to the courthouse lawn because Raulston feared that the floor of the old building would give way under the weight of the spectators. It was reported that Bryan's fluttering palm-leaf fan froze in his hand when Hays suddenly announced that the defense wished to call Bryan himself to the stand to testify as an expert witness on the Bible. The state's other lawyers leaped to their feet, shouting objections. Raulston put it up to Bryan, who said he was willing to be questioned.

For an hour and a half in the blistering heat Darrow relentlessly grilled Bryan. Did he believe: That Joshua had lengthened the day by making the sun stand still? That, before the Tower of Babel was built, all men spoke but one language? That the earth was created in seven days? In reply to the last question, Bryan conceded that a day might be taken to mean a span of time much longer than 24 hours. He admitted ignorance of subjects on which he had earlier pontificated.

When Darrow asked his witness how the Serpent had walked before it was told by God to crawl on its belly—had it perhaps hopped along on its tail?—there was a guffaw from the audience of 2,000. Bryan lost his temper, Darrow responded in kind, and in a near-riot of the spectators the judge adjourned the court.

The next morning Raulston ruled that Bryan's testimony be stricken from the record. In his closing address Darrow broadly hinted that he wanted a verdict of guilty in order to make an appeal possible. This verdict was duly brought in, and Scopes was fined $100.

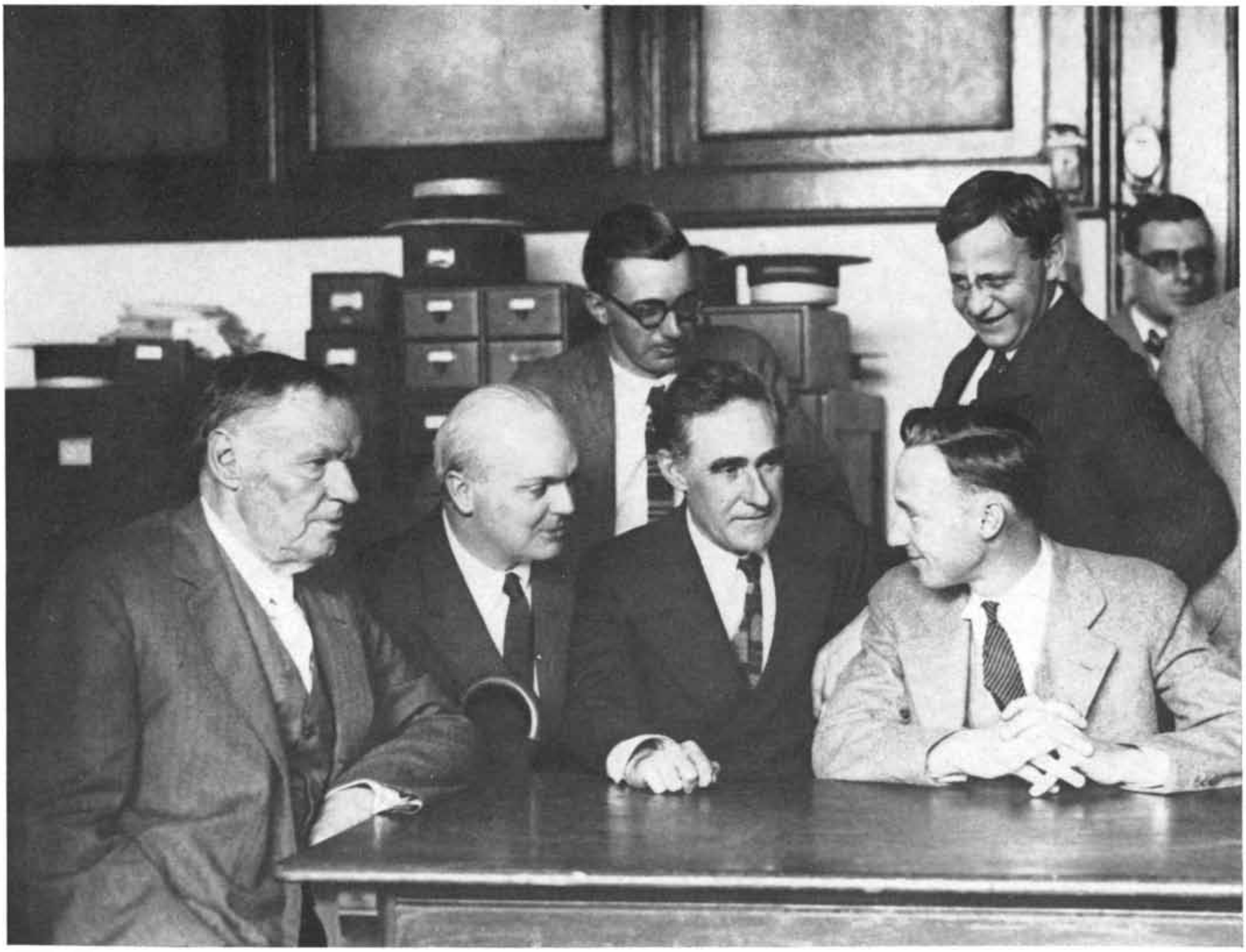
Five days after the trial was over, Bryan died in his sleep. The exact cause of his death was never established. He was a diabetic, did not keep to his diet and ate voraciously. Darrow's inquisition, together with the heat, had doubtless weakened him.

The "monkey trial" was followed at once by a surge of antievolutionary activity. A dozen monkey bills were introduced into state legislatures. A host of societies dedicated to stifling the heresy blossomed: the Bible Crusaders, the Bryan Bible League, the World Christian Fundamentals Association, the Supreme Kingdom, the Defenders of the Christian Faith and two curiously named groups, the Research Science Bureau and the American Science Foundation. There were plans to amend the Constitution to outlaw the teaching of evolution on a national scale. In Meridian, Miss., the superintendent of high schools presided at a public bonfire of pages on evolution torn from textbooks. "Within 12 months every state in the Union will be thoroughly organized," announced the Fundamentalist William Bell Riley.

Meanwhile Darrow and his associates had appealed the Scopes case to the Tennessee Supreme Court. The verdict was announced in January, 1927. Of the five justices, one disqualified himself, one held the Butler Act unconstitutional because of its vagueness and one held it valid but not violated. The remaining two justices found the law constitutional and violated.

Ordinarily the opinion of the last two justices would have prevailed, but here Rappleyea's plan came to grief. The court seized on a technicality (the manner in which the fine had been levied) and remanded the case to the lower court. The justices advised District Attorney Stewart to desist from further prosecution of "this bizarre case," and Stewart complied, leaving the law intact and Scopes unpunished. (He left teaching to become a graduate student at the University of Chicago and then a geologist with the Gulf Oil Company.)

The antievolutionary boom that fol-



JOHN THOMAS SCOPES AND ATTORNEYS met at the American Civil Liberties Union shortly before his trial in 1925. Seated are *(from left)* Clarence Darrow, Dudley Field Malone, John Randolph Neal and Scopes. Scopes was 24 years old, Darrow was 68.

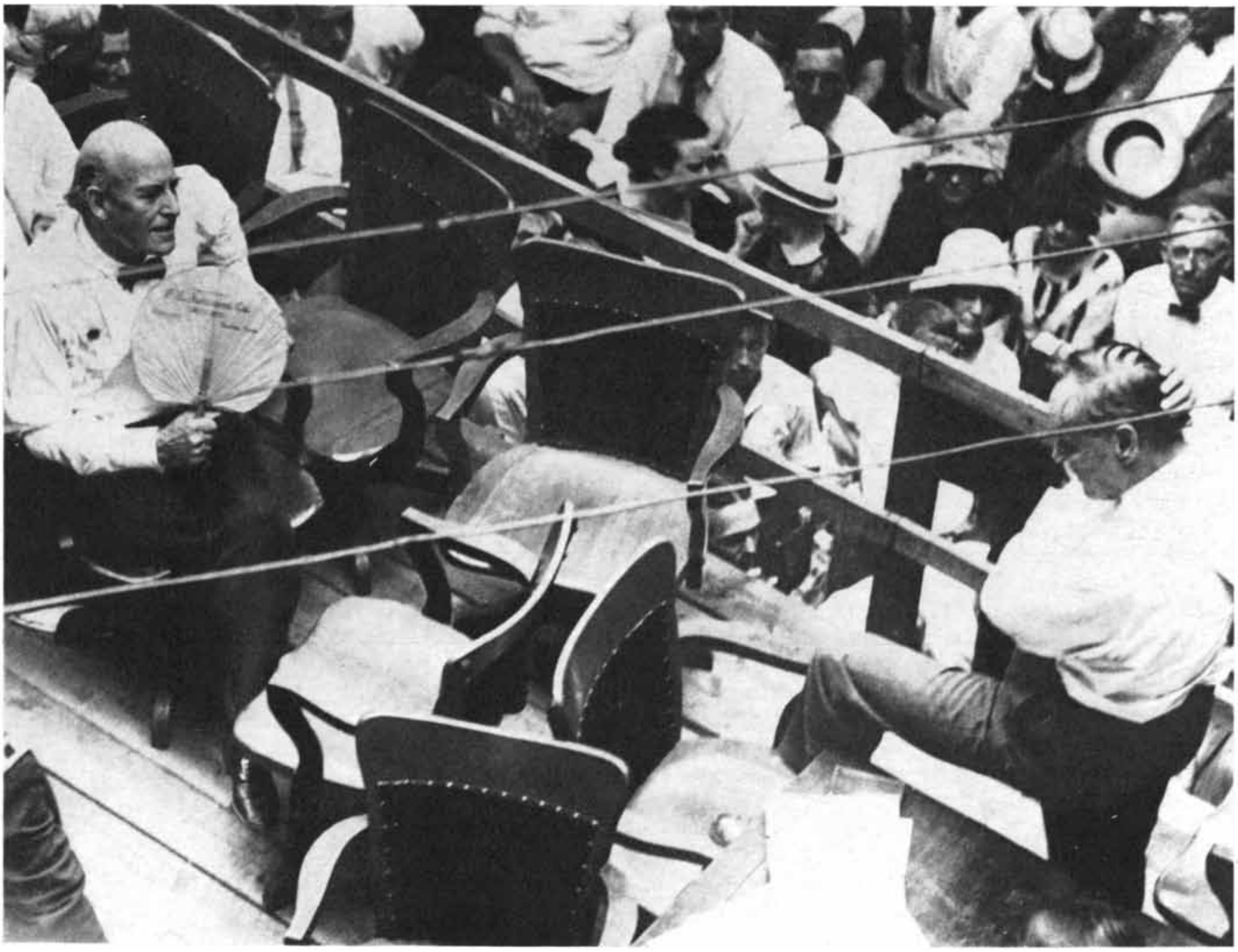
lowed the Scopes trial did not last long. Of the 12 monkey bills voted on during 1926 and 1927, only the one in Mississippi passed, and in 1926 Oklahoma repealed its law restricting textbooks. Legislators found ways to avoid an open vote on the question of evolution. For example, Delaware's monkey bill was referred to the Committee on Fish, Game and Oysters, where it died a quiet death.

The last Fundamentalist victory was the passage of the Rotenberry Act in 1927. The bill was pushed by Reverend Ben M. Bogard's American Anti-Evolution Association, an organization that declared itself open to all save "Negroes and persons of African descent, Atheists, Infidels, Agnostics, such persons as hold to the theory of Evolution, habitual drunkards, profane swearers, despoilers of the domestic life of others, desecrators of the Lord's Day and those who would depreciate feminine virtue by vulgarly discussing sex relationship." When the Rotenberry bill failed to pass the legislature, Bogard obtained enough signatures to put the question on the ballot at the next general election. In the form of a referendum the bill passed by 108,991 votes to 63,406.

The decline of the Fundamentalist movement was doubtless assisted by the shortcomings of its leaders. In 1926 a Fundamentalist congressman, John W. Langley, was jailed for stealing liquor from Government warehouses. In the same year Aimee Semple McPherson vanished from a beach in California, to reappear in Mexico with a tale of having been kidnapped by the hirelings of her deadliest foes: the gamblers, the dope peddlers and the evolutionists. It came to light that she had been enjoying a holiday from Christian austerity with Kenneth G. Ormiston, her former radio technician. The Fundamentalist John Franklin Norris launched a violent campaign against the Roman Catholic Church; when an unarmed member of that church called to complain, Norris shot him dead. (He was acquitted on a plea of self-defense.)

The Scopes trial, although legally inconclusive, helped to end the monkey war. It created an enormous revival of popular interest in evolution. Furthermore, Darrow's verbal manhandling of Bryan had not made the antievolution crusade any more attractive. Politicians drew back from the "Adamist" movement, if not for love of science, then for fear of ridicule. Thus in a sense the defense in the Scopes case won after all.

In comparison with many other doctrinal struggles that have agitated men, the American monkey war appears relatively mild. It is true that some teachers were harassed or lost their jobs, but these episodes seem to have been few and far between. Resistance to new ideas is a universal human trait, and the country can be thankful that in this case it took no more sinister form.



CLIMAX OF SCOPES TRIAL came when William Jennings Bryan (*left*) of the prosecution was questioned about the Bible by Darrow, who stands before him. The verbal duel took place outside the courthouse on a sweltering day before 2,000 spectators.

ECOLOGICAL CHEMISTRY

Certain insects feed on plants that make substances that are poisonous to vertebrates. Hence the insects are unpalatable to bird predators. These relations have surprising results

by Lincoln Pierson Brower

Many plants synthesize chemical compounds that apparently serve no purpose in the plant's metabolism. Some of these compounds are quite complex, and even if they were simple it would be puzzling that the plant should make them; the synthesis calls for a considerable expenditure of energy. Why, then, does the plant manufacture these substances? One reasonable explanation is that they promote the survival of the plant either by repressing the growth of competing plants and parasitic microorganisms or by repelling insects or other animals that would otherwise feed on it.

There is reason to believe this is only part of the story of the secondary substances made by plants. My colleagues and I (at Amherst College, the University of Oxford and the University of Basel) find evidence that such substances can play a much subtler role in a community of interacting plants and animals. For example, certain plants manufacture compounds that are poisonous to vertebrates, but certain insects are able to feed on the plants. An insect that feeds on such a plant ingests the poison and is therefore unpalatable to vertebrate predators. Moreover, an insect that does not feed on the plant can mimic the appearance of the insect that does, and is thus avoided by predators even though it is palatable. In the light of such relationships one begins to perceive that the study of secondary substances can be characterized as ecological chemistry.

A striking instance of the effectiveness of the secondary substances in repelling animals is provided in Costa Rica by the milkweed *Asclepias curassavica*. In the province of Guanacaste large herds of cattle completely avoid the plant even though it grows abundantly in the grass. The cattle do so with good reason: this plant and others belonging to the large family Asclepiadaceae often cause sickness in livestock and occasionally death.

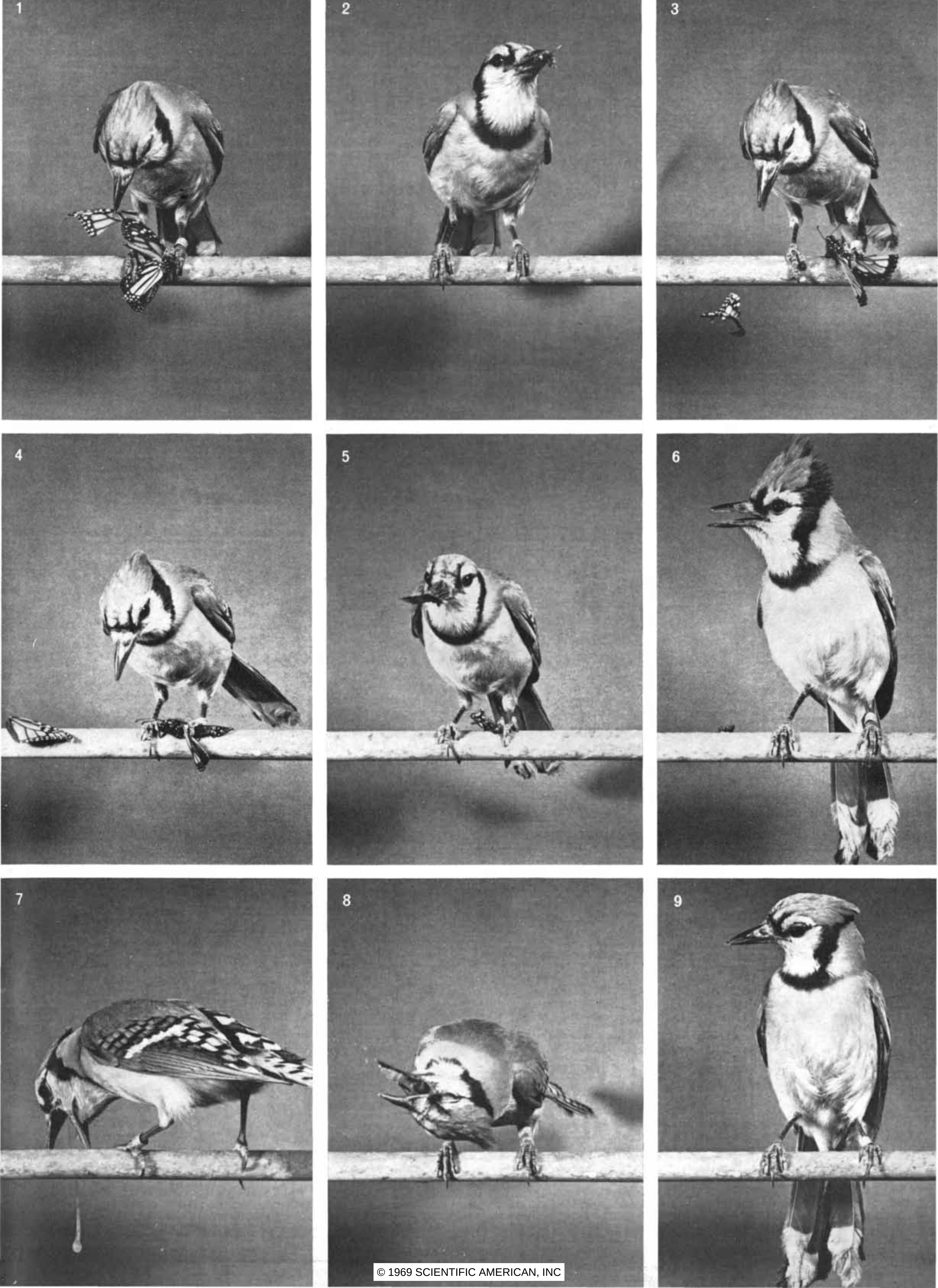
The poisons in the asclepiads have attracted much attention among pharmacologists and organic chemists because the substances are chemically similar to the drug digitalis; they share with it the remarkable property of having a highly specific effect on the vertebrate heart. These drugs, called cardiac glycosides or cardenolides, cause a weak and rapidly fluttering heart to beat more strongly and more slowly. Like most other drugs, cardiac glycosides produce side effects. One of profound importance is the activation of the nerve center in the brain that controls vomiting. Pharmacologists working with cats and pigeons have found that the dosage necessary to cause emesis is just about half the amount required to cause death. Hence an animal that eats a food containing cardiac glycosides will, provided that it is capable of vomiting, rid itself of the poisons before a lethal amount can be absorbed. In other words, although the animal suffers a very unpleasant gastronomic experience, vomiting protects it from being killed by the poisonous food.

In contrast to the animals that are made ill by eating milkweeds containing cardiac glycosides are the animals that eat the plants with no apparent adverse effects. For example, milkweeds are the exclusive food of the larvae of an entire group of tropical insects: the Danainae, which includes the familiar monarch and queen butterflies. Naturalists have observed for more than a century that insect-eating vertebrates, particularly birds, avoid these butterflies. A widely accepted hypothesis has been that the predators avoid the butterflies because the larvae have assimilated the poisonous substances from the milkweeds. The implications of this hypothesis are most interesting: the Danaine butterflies not only must have developed the ability to feed on the poisonous milkweeds but also apparently are able to use the poisonous substances against their predators.

We undertook to test this hypothesis with a threefold approach. First, our group at Amherst reared a large number of monarchs on *Asclepias curassavica*, and John Parsons of Oxford subjected them to a series of pharmacological tests. Assaying extracts of the butterflies, he found that they contained cardiac glycosides similar to digitalis in their effects. Second, with new facilities at Amherst we were able to rear some two pounds of monarchs (1,540 butterflies) on *A. curassavica*, and Tadeus Reichstein of the University of Basel chemically analyzed both the butterflies and the plants. His results showed that the plant and the butterfly contain at least three cardiac glycosides that are identical. They are calactin, calotropin and calotoxin [*see bottom illustration on page 25*].

In the course of rearing the butterflies and plants for chemical analysis we had begun our third line of attack. By selec-

REACTION OF BLUE JAY to palatable and unpalatable monarch butterflies appears in the photographs on the opposite page. At top the jay attacks a palatable butterfly (*1*), eats it (*2*) and later eats another monarch (*3*). When the same jay is presented (*4*) with a monarch that is unpalatable because it fed on poisonous milkweed at the larval stage, the bird eats only part of it (*5*) and then reacts (*6*). Soon it vomits (*7*), and after drinking water it vomits again (*8*). It soon recovers (*9*) but rejects subsequent monarchs on sight.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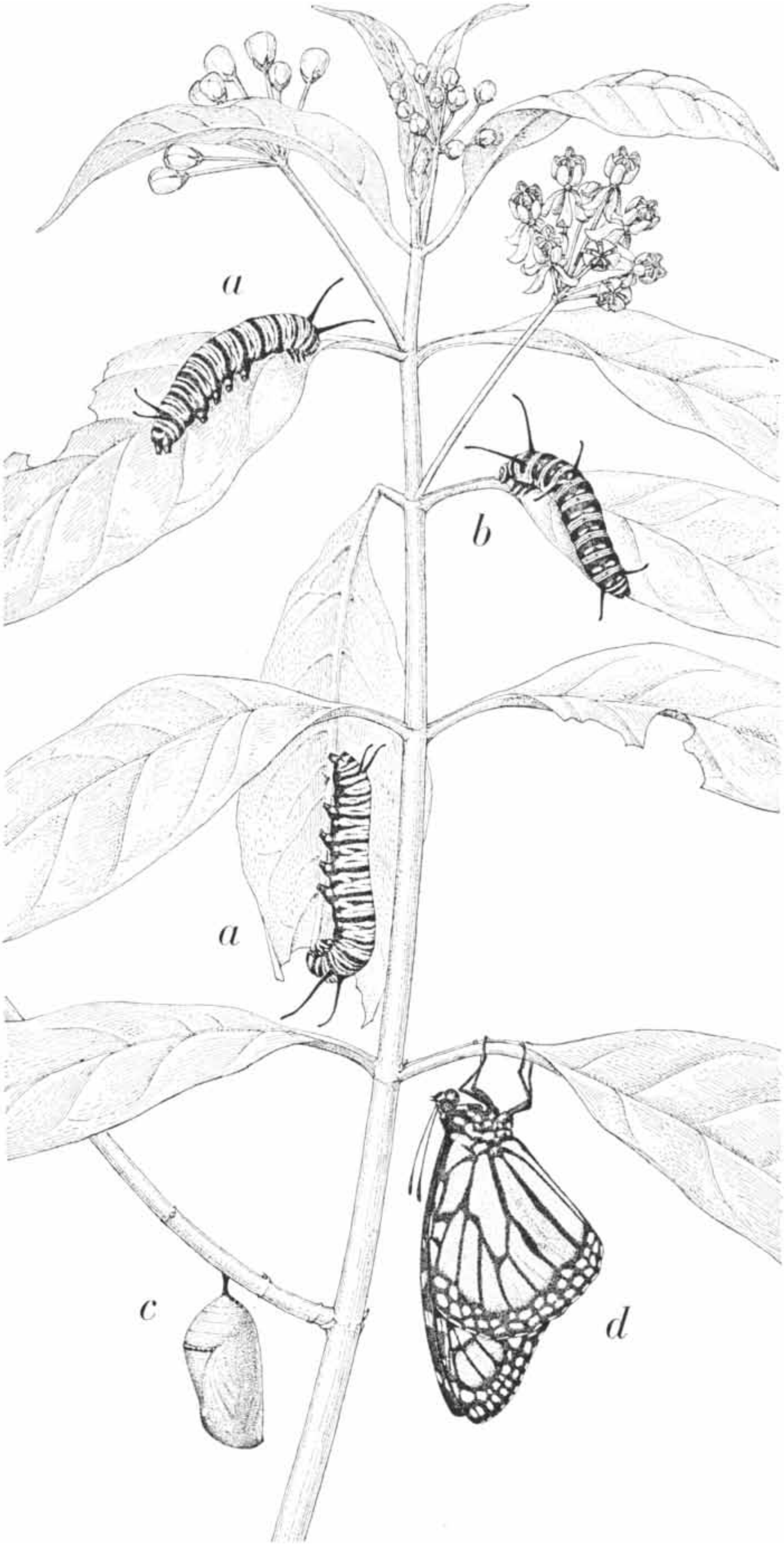


ECOLOGICAL SETTING of the plant-butterfly-bird relationship includes the milkweed *Asclepias curassavica* and the larval stage of such butterflies as the monarch (*a*) and the queen (*b*). The plant produces substances called cardiac glycosides, which have a strong effect on the vertebrate heart. Larvae assimilate the substances, which are retained by adults, so that an adult monarch (*d*) is unpalatable to birds. At *c* is a monarch butterfly chrysalis.

tive breeding we obtained a strain of monarch butterflies that could develop on cabbage, a plant known to lack cardiac glycosides. Our assumption was that cabbage-reared monarchs would prove acceptable to our test birds, which were blue jays captured locally. At first all our blue jays were extremely reluctant to attack the monarchs. We found, however, that if we deprived the jays of food for several hours, they would become hungry enough to attack and eat the butterflies. Once the jays had been induced to try the monarchs they would accept them readily whenever we offered them and would devour them with no signs of sickness.

Having broken down the initial reluctance of the blue jays, we then offered them monarchs reared on *A. curassavica*. Most of the birds promptly ate at least one butterfly. Within 12 minutes, on the average, every bird became violently ill, vomiting the ingested material and continuing to vomit as many as nine times over a half-hour period. All the birds recovered fully within about half an hour.

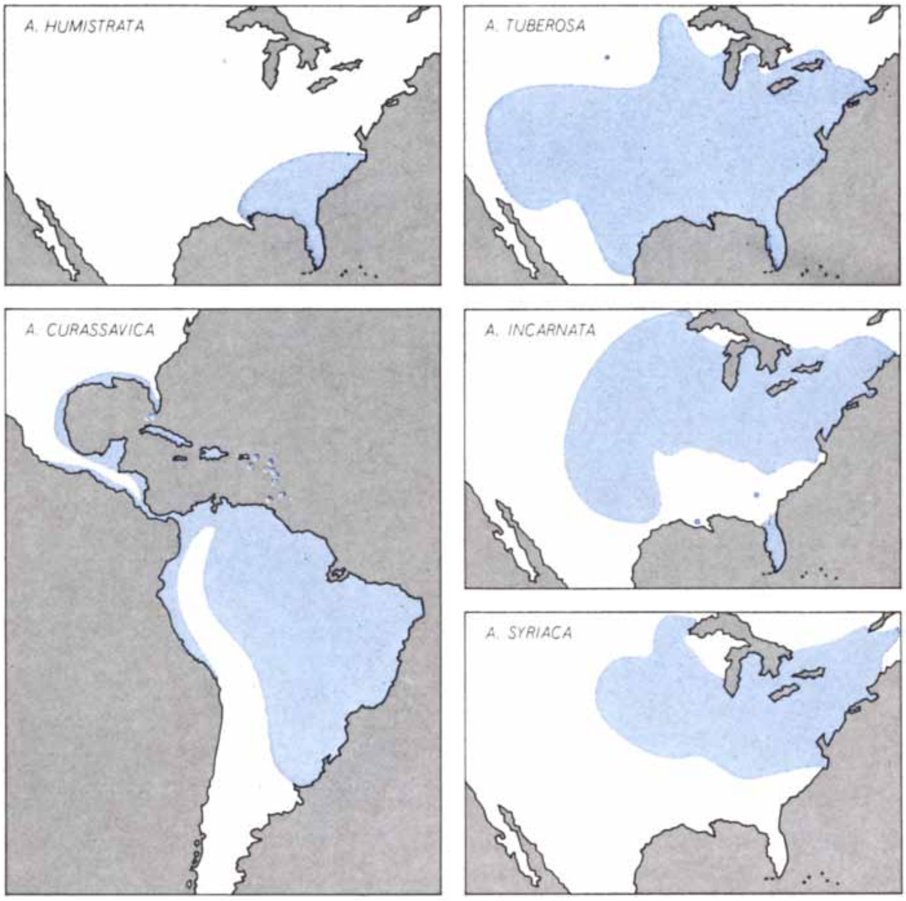
In preparation for our feeding experiments we had also cultivated several other milkweed plants in our greenhouse. Much to our surprise, one species from the tropical Western Hemisphere, *Gonolobus rostratus*, produced monarch adults that were as acceptable to birds as the cabbage-reared butterflies were. As the reader can readily imagine, we were delighted when Reichstein analyzed our *Gonolobus* plants and found that they completely lack cardiac glycosides. These findings showed clearly that the palatability of the monarch butterfly is directly related to the kind of plant eaten by the larvae: if the plant contains cardiac glycosides, the adult butterflies also contain them, and if the plant lacks the poisons, the butterflies also lack them.

The next question we asked was: Is there a spectrum of palatability in monarch butterflies that is dependent on the particular plants the larvae eat? To investigate the matter we first determined which species of milkweed produce emetic butterflies. Our technique was to induce the birds to eat the nonemetic butterflies reared on *Gonolobus* and then to offer them butterflies reared on a variety of other milkweeds. So far we have found that three species of *Asclepias* common in eastern North America produce palatable butterflies, whereas two milkweeds from the southeastern U.S. produce emetic ones. In addition we have discovered that monarchs reared on two African milkweeds belonging to the genera *Calotropis* and *Gomphocarpus* are emetic.

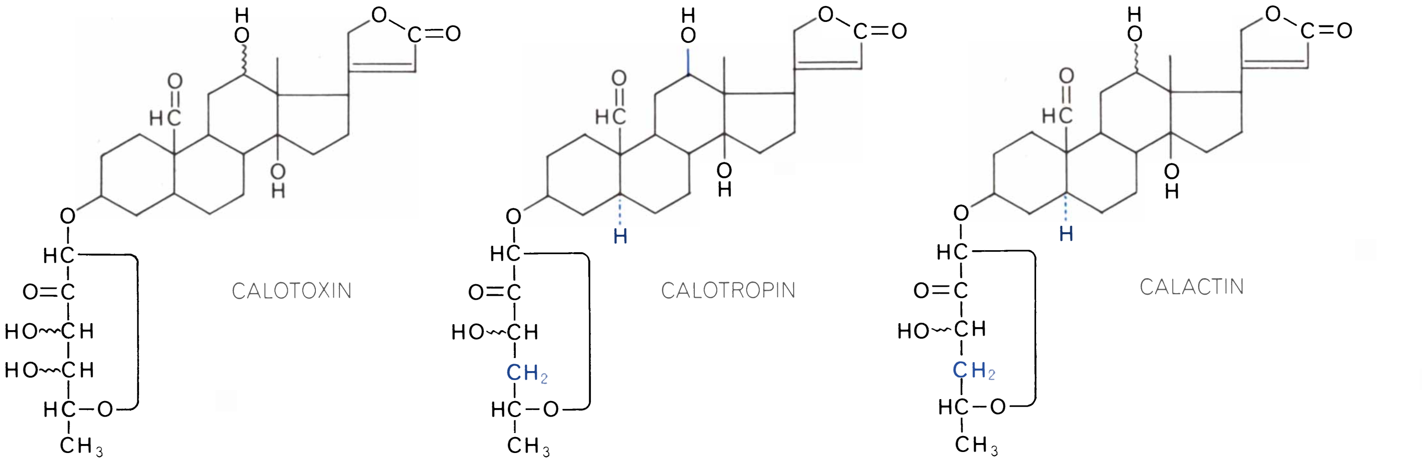
Having established this emetic series, William N. Ryerson (who is now at Yale University) and I developed a new method for comparing the degree of toxicity of the monarchs reared on the various plants. The technique consists in drying adult butterflies and grinding them to a fine powder, which we load into gelatin capsules that are force-fed to the birds. In this way we could determine the precise dosage of butterfly needed to cause emesis. Then, on the basis of the average weight of both monarch butterflies and blue jays, we calculated the number of blue jay emetic units per monarch butterfly [*see top illustration on next page*]. The experiments showed that a monarch that has eaten *Asclepias humistrata* contains enough poison to make approximately eight blue jays vomit; a butterfly reared on *Calotropis procera* contains 4.8 blue jay emetic units; one that has eaten *A. curassavica,* 3.8 units, and one that has eaten *Gomphocarpus,* .8 unit. In other words, there is a palatability spectrum, and the most unpalatable butterfly is at least 10 times as emetic as the most palatable one. Since the genus *Asclepias* consists of 108 known species in North America alone, and there are several other genera of milkweed on the continent, it seems likely that the spectrum of palatability is very wide indeed.

Moreover, we have here an ecologically important criterion for measuring the palatability of food to wild animals. Clearly a butterfly is unsuitable food if it causes emesis, but if it carries less than an emetic dosage, it could serve as an emergency ration during periods of food shortage, provided that the birds ate successive individuals at a sufficiently slow rate. Measuring palatability by the criterion of emesis not only is more objective than many of the vague concepts of palatability that are so often discussed in the technical literature of biology but also provides insight into the kinds of problems that confront wild animals in their quest for food.

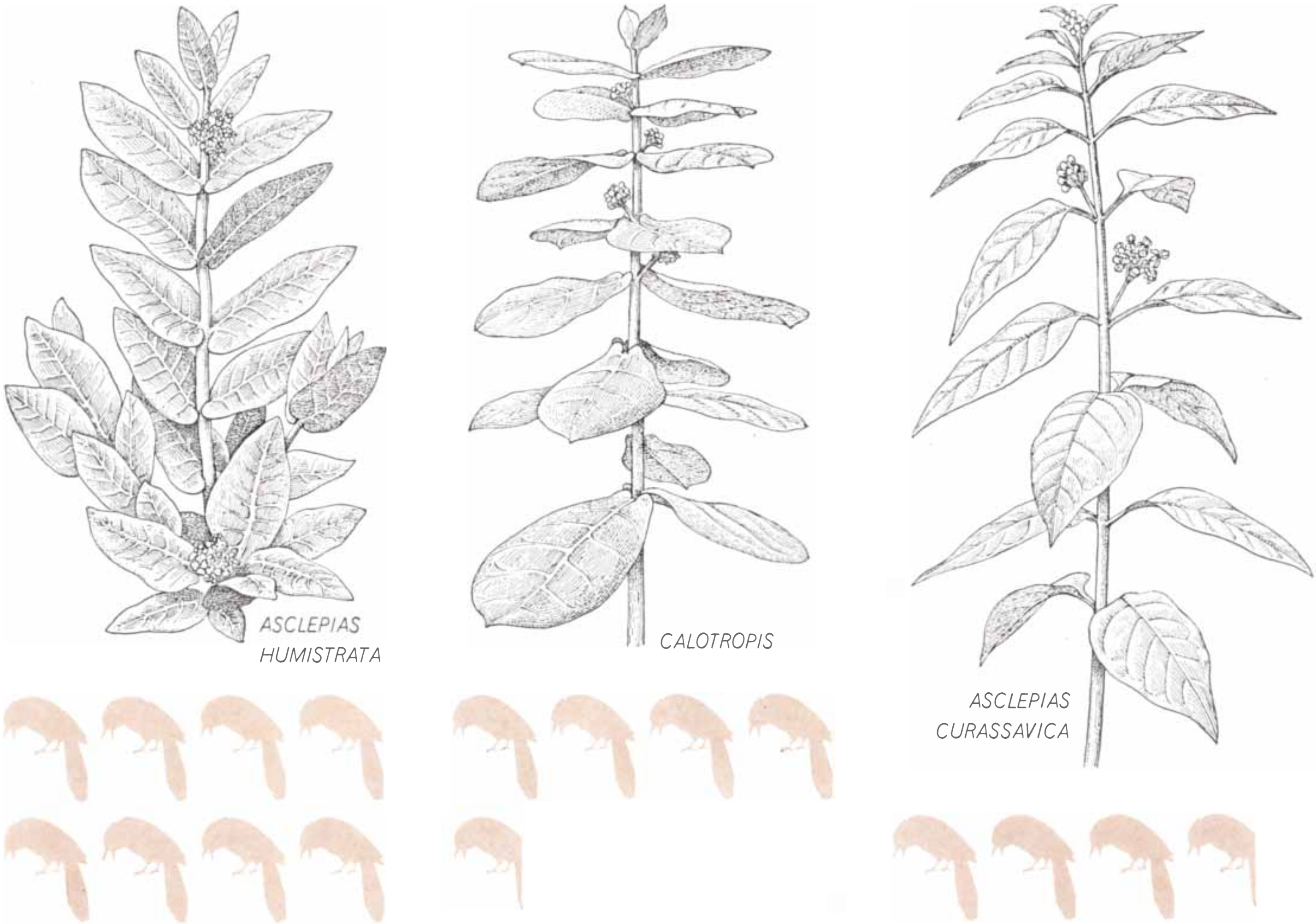
I have mentioned that most of the blue jays we trained to eat the nonemetic butterflies subsequently ate without hesitation the first highly emetic one we gave them. After recovering from their bout of vomiting the birds usually rejected all subsequent monarchs on sight alone. By again depriving the jays of food, however, we were able to induce



APPROXIMATE DISTRIBUTION of five species of milkweed of the genus *Asclepias* is indicated. The two species at left produce cardiac glycosides, so that butterflies feeding on the plants are unpalatable to birds. The three species at right lack the cardiac glycosides.



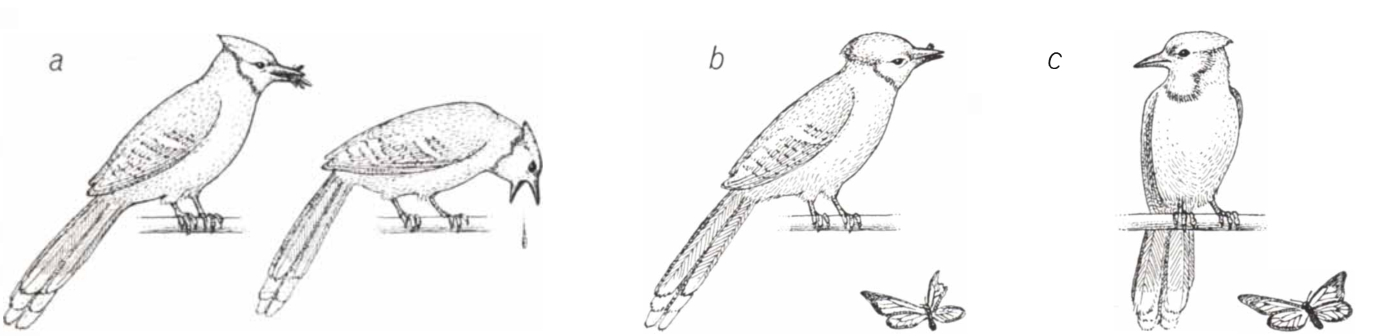
CHEMICAL STRUCTURE of three cardiac glycosides found in both the milkweed *A. curassavica* and the monarch butterflies that feed on the plant is indicated. Assays of the plants and butterflies were made by Tadeus Reichstein of the University of Basel. It was he also who hypothesized the structures of calotropin and calactin on the basis of the known structure of calotoxin (*left*).



RELATIVE TOXICITY of several milkweeds and of monarch butterflies raised on them is expressed in terms of blue jay emetic units. The units represent the number of blue jays that will be made ill by the poisons in one monarch butterfly raised on a given

them to attack another nonemetic monarch. Now instead of swallowing the butterfly rapidly a bird would peck it apart, manipulate the mangled pieces in its bill and often regurgitate pieces several times before finally swallowing them.

This behavior has led us to propose a new way of looking at the biological significance of taste; we call it "the gourmand-gourmet hypothesis." According to this hypothesis items of food in the natural environment have a variety of flavors that in themselves convey no relevant information to a vertebrate animal eating the food for the first time. Hence the naïve animal will initially accept a wide range of food. If the animal eats the food and then vomits, however, it will associate the taste signals present in the food as it is expelled through the mouth with the noxious experience of the entire emesis syndrome. In other words, just as an animal can learn to associate an unpleasant experience with the color pattern of a food item and subsequently to reject the food on sight, so can it probably associate the taste of the food with the noxious effects. Initially a gourmand, the animal becomes by conditioning a gourmet, and for the rest of its life the taste signals in its food convey relevant information. Once conditioned in this way the animal will exer-



GOURMAND-GOURMET HYPOTHESIS put forward by the author holds that a bird can reject a poisonous insect at three physiological levels. To a naïve bird (*a*) flavor conveys no particular information, so that the bird will eat any food it finds and is a gourmand. When a bird is made ill by an insect, it associates the flavor of the insect with the illness and thereafter can reject a similar insect by tasting it (*b*), so that the bird becomes something of a gourmet. At that level, however, the bird must still take the time to catch the insect. Hence birds usually learn to reject such insects on sight (*c*), which is the most efficient level of rejection.

plant. For example, a single butterfly raised on milkweed *Asclepias humistrata* contains enough cardiac glycosides to cause emesis in eight blue jays (*left*). *Gonolobus* is nonemetic.

cise judgment in assessing the taste of potential food items.

A plant-eating animal or a prey-catching one will always be confronted with a wide potential of food items in its natural environment. In terms of our blue jay–monarch butterfly system it is important to realize that the bird has three levels at which it can reject a poisonous butterfly. The most basic level is the automatic gastronomic rejection brought on by the emetic effect of the cardiac glycoside. Clearly this is the least efficient form of rejection, since the bird not only is made sick but also loses any food that was in its crop before it ate the poisonous insect. Once the bird has suffered this noxious primary experience and has learned to avoid food with the particular flavor, it can reject the same type of butterfly merely by tasting it. This is the second level of rejection. It too is rather inefficient, because if it is to operate, the bird must first catch the butterfly. The most efficient level of rejection is provided by the capacity to associate the visual characteristics of the food with its unpalatability, since the bird then need neither get sick nor even waste time catching the insect in order to determine its flavor.

The fact that many naturally occurring plant poisons, including alkaloids and cardiac glycosides, are bitter is highly relevant. The poison itself could very well be tasteless, provided that it was always associated with a flavor that could serve as a cue for conditioning predators. These considerations raise the possibility that certain plants and prey animals have flavors usually associated with particular poisons but actually lack the poisons. They would thus be exhibiting a form of mimicry.

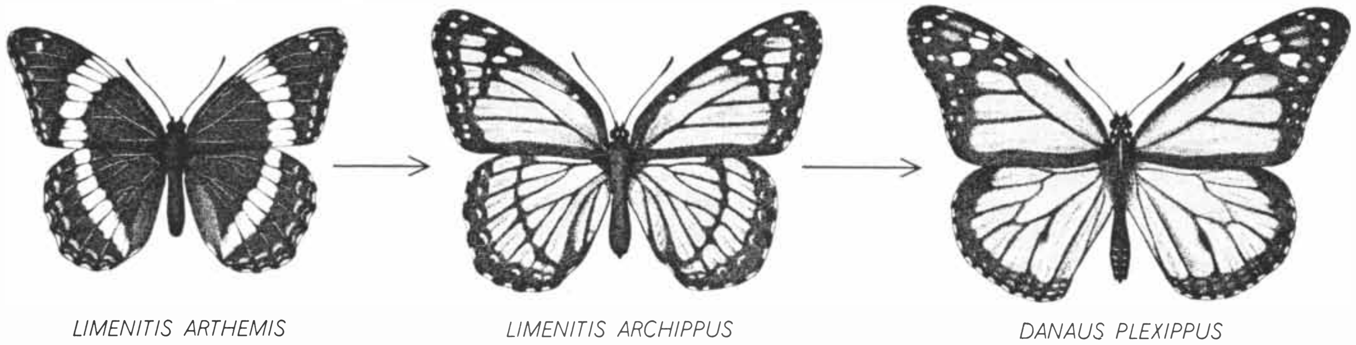
Mimicry in insects usually refers, of course, to the imitation by one species of the distinctive coloration of another species. One can see how natural selection favored the evolution of distinctive coloring in unpalatable species, because the coloration operates as a cue that reminds the predator of its earlier unpleasant experience. The warning coloration is of advantage to both prey and predator: the prey is less frequently attacked, and the predator can hunt more efficiently because it does not need to waste time catching unpalatable insects.

Once unpalatable insects with a warning coloration evolved, the opportunity arose for natural selection to favor modifications in palatable species so that they came to look like unpalatable ones. This phenomenon, which is called Batesian mimicry after the 19th-century English naturalist Henry W. Bates, is widespread and involves many different groups of insects and other prey organisms. The mimic takes advantage of the fact that the predator has learned to avoid the model: the unpalatable prey with a warning coloration. Clearly the mimic must not become too common with respect to the model or the system would tend to break down because the predators would so frequently encounter palatable mimics.

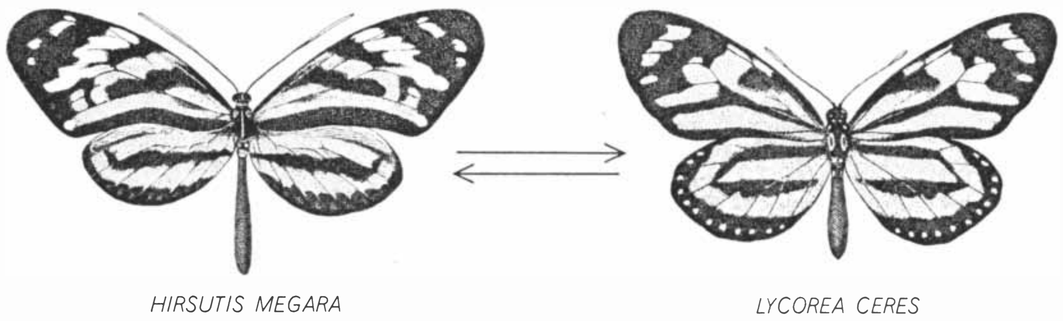
Another form of mimicry is called Müllerian after Fritz Müller, a German zoologist of the late 19th century. It entails resemblances among unpalatable insects. Tropical regions abound with groups of unpalatable insects that have come to look alike because natural selection has favored the evolution of a few common warning colorations. This type of mimicry benefits predators by reducing the number of color patterns that need to be remembered. The prey benefit because the numbers of individuals that are killed in each group of Müllerian mimics are reduced: once predators learn to avoid one species on sight they will tend to reject them all.

If, as our experiments suggest, certain plants and prey insects have the flavors usually associated with particular poisons but do not contain the poisons, they would be flavor mimics and would gain the usual advantages of Batesian mimicry. Other foods could contain different poisons but have similar flavors. They would gain the mutualistic advantage of Müllerian mimicry.

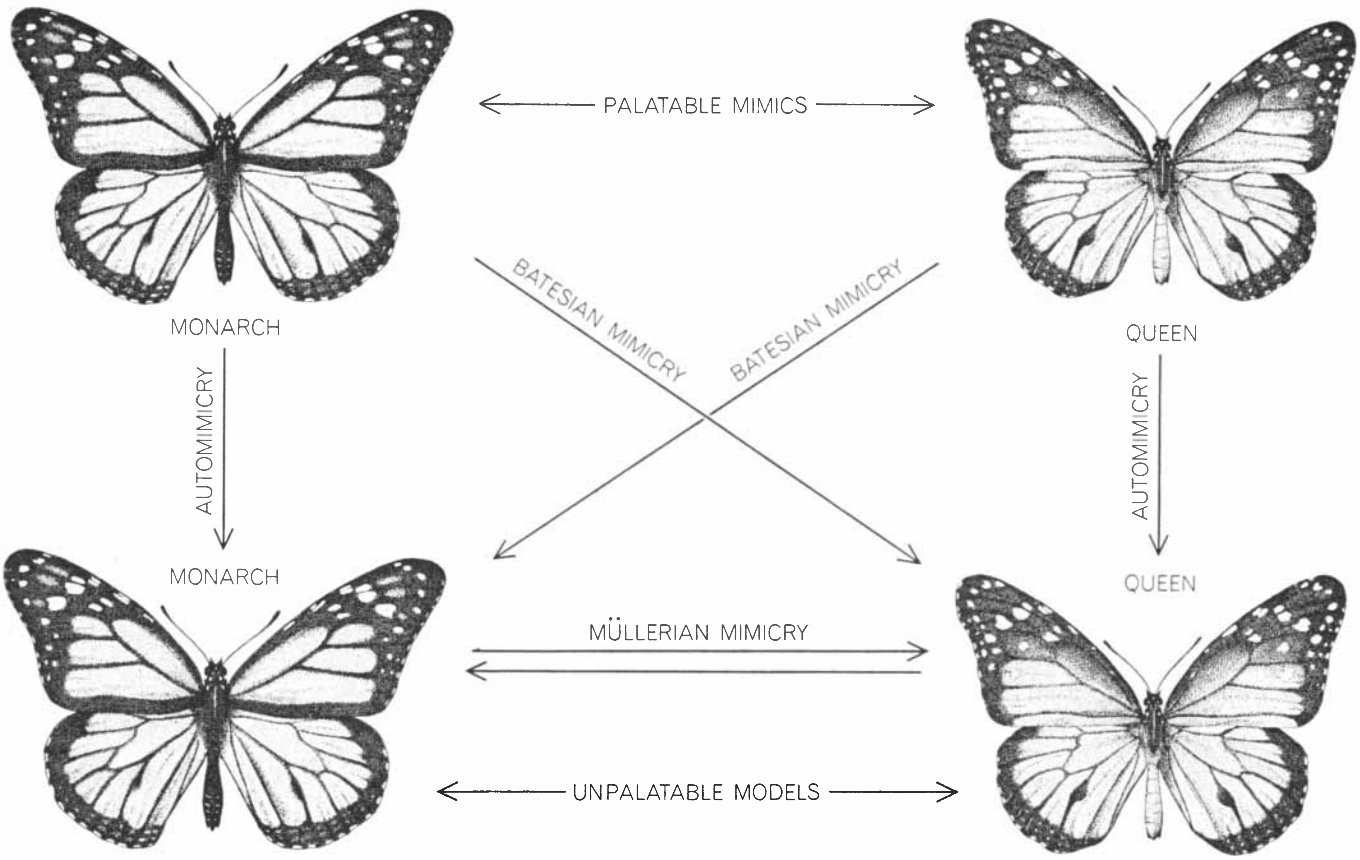
The fact that monarch butterflies exhibit a spectrum of palatability from completely acceptable to totally unacceptable has led us to propose an extension of mimicry theory to include what we call automimicry. In our view butterflies that feed on poisonous plants can serve as unpalatable models and protect the individuals of their own species that have not fed on such plants. Since both butterflies are of the same species, the palatable individuals can be called automimics of the unpalatable ones. The advantage gained by an automimic is somewhat greater than the protection secured by a Batesian mimic; whereas the Batesian mimic has evolved a close re-



BATESIAN MIMICRY, named for the 19th-century English naturalist Henry W. Bates, arises when a palatable insect comes to look like an unpalatable one, thereby sharing the unpalatable one's capacity to repel predators. An example is the North American butterfly *Limenitis*. From its original form (*left*) it has evolved a form (*center*) that mimics the monarch butterfly *Danaus* (*right*).



MÜLLERIAN MIMICRY, named for the 19th-century German zoologist Fritz Müller, appears when two species of unpalatable insects come to look alike. An example from Trinidad is the resemblance between butterflies *Hirsutis megara* from the family Ithomiidae (*left*) and *Lycorea ceres* from the family Danaidae (*right*). Similarity enables each species to gain protection from the other.



MULTIPLE MIMICRY found in Trinidad between monarch and queen butterflies is charted. Palatable monarchs resemble unpalatable queens in Batesian mimicry, as is the case with palatable queens resembling unpalatable monarchs. Unpalatable monarchs and queens resemble each other in Müllerian mimicry. Automimicry describes recent discovery that not all monarchs and queens are unpalatable. The term refers to the fact that palatable butterflies gain protection from unpalatable ones of the same species.

semblance to its model, the automimic is a perfect mimic because it is a member of the same species.

We have calculated that if birds continued eating monarchs until they encountered an emetic one, and they then stopped eating monarchs, the protection afforded a butterfly population in which only half of the individuals are unpalatable would be nearly as great as if the entire population were unpalatable. Let us assume, for example, that a bird can eat up to 16 butterflies but stops eating them as soon as it eats an unpalatable one. Under these circumstances a butterfly population with 50 percent unpalatable members would suffer only 7 percent more predation than a population with 100 percent unpalatable members. Indeed, at the same level of predation a population that was only 25 percent unpalatable would still gain an immunity of 75 percent. As the level of potential predation increases, the advantage of automimicry tends to stabilize [*see illustration on this page*].

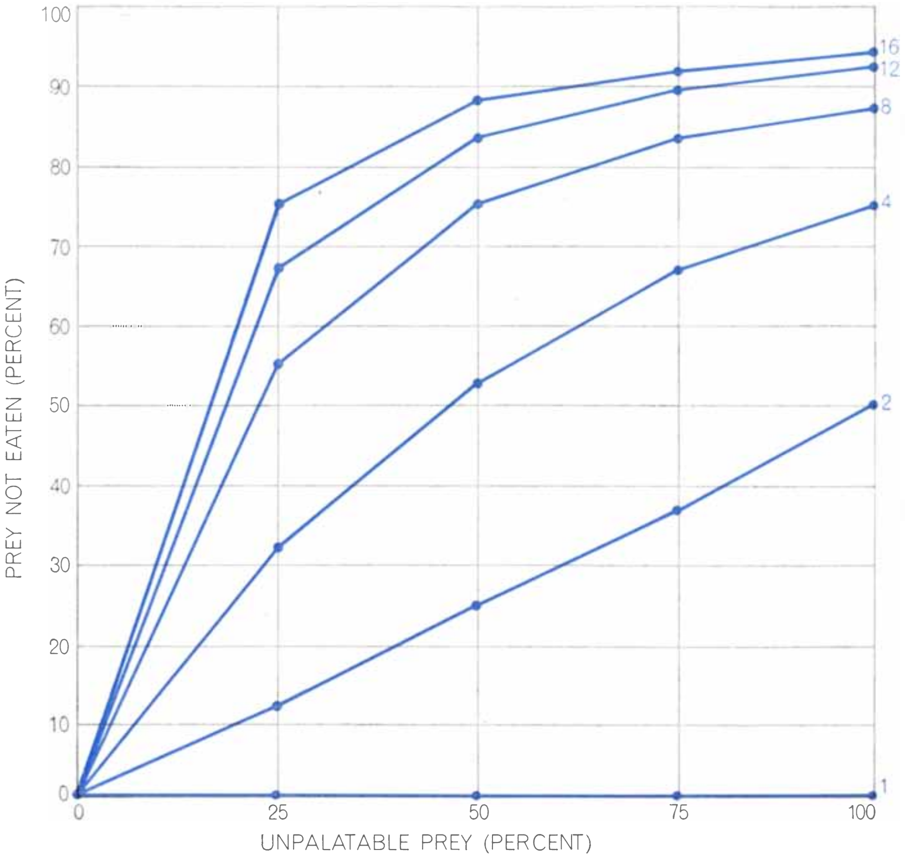
It might seem ecologically strange for prey that can become unpalatable simply by eating poisonous plants to feed on nonpoisonous ones. Yet we have found thus far that only two out of eight species of North American milkweeds produce emetic butterflies. The two are *Asclepias curassavica* and *A. humistrata*. We were surprised to find that three very common eastern species—*A. syriaca, A. tuberosa* and *A. incarnata*—produce palatable butterflies. These species are widely fed on by monarch larvae. Evidently this is the key to understanding the selective advantage of automimicry: If the majority of milkweeds in a given area are nonpoisonous, the monarchs will be forced to lay eggs on those plants and will deposit eggs on poisonous milkweeds only when they can find them. Automimicry enables the species to more than double its numbers without losing much of its protection from predation.

Our studies have established that wild populations of monarchs do include both palatable and unpalatable individuals. Last fall we collected a number of wild monarchs in western Massachusetts during their southward migration and subsequently dried and force-fed one butterfly each to 50 blue jays. Twelve of the butterflies (24 percent) caused emesis; the other ones proved to be palatable automimics. This finding agrees well with the minimum proportion of unpalatable individuals needed to confer a substantial automimetic advantage as shown in the illustration at the right. It will be interesting to press further with the investigation to discover what milkweeds in the Northeast do produce emetic butterflies.

On the Caribbean island of Trinidad monarch butterflies live together with another species of the Danainae, the queen butterfly. In this part of their range both butterflies look very much alike in size and color pattern, and it has been assumed that they both are unpalatable species enjoying the mutualistic protection of Müllerian mimicry. In this area, as in North America, several species of asclepiad plants are available as food. The monarch lays its eggs almost exclusively on the common and poisonous *A. curassavica* but occasionally feeds on other asclepiads lacking cardiac glycosides. As one would expect, the majority (65 percent) of the monarchs from this area are emetic.

On the other hand, the queens are rarely found on *A. curassavica,* and only 15 percent of the adults captured are emetic. In the laboratory, however, the queens lay their eggs on the plant and freely feed on it. It seems likely that in this area of Trinidad the monarch somehow partly displaces the queen to the nonpoisonous milkweeds, which is why relatively few queens become emetic. Yet the queens in Trinidad have evolved a great similarity to the monarchs in color pattern, which is not the case over most of the range where the two species live together. Hence the queens that are palatable gain the advantage of Batesian mimicry of the predominantly unpalatable monarch population, and the unpalatable queens share a Müllerian advantage with the unpalatable monarchs. At the same time the palatable monarchs are protected by the unpalatable monarchs and the palatable queens are protected by the unpalatable queens, so that automimicry is also involved. Thus in Trinidad the mimetic relations of the two species are complex and simultaneously involve Batesian mimicry, Müllerian mimicry and automimicry [*see bottom illustration on opposite page*].

The discovery that certain insects can assimilate plant poisons they in turn employ as a defense against their predators provides a remarkable example of what George Gaylord Simpson has called the opportunistic aspect of evolution. Clearly ecological chemistry and its implications provide a fertile field for extending our understanding of the interrelations of ecology, sensory physiology and animal behavior.



ADVANTAGES OF AUTOMIMICRY are charted for six levels of predation. Colored numbers refer to the maximum number of prey eaten by a single predator in a given time. A butterfly population in which only 25 to 50 percent of the individuals are unpalatable from having fed on poisonous plants is almost as well protected as if all individuals were emetic.

ORGANIC LASERS

Complex organic-dye molecules have been induced to emit coherent laser light. The most remarkable feature of this new type of laser is that each can be tuned continuously over a range of wavelengths

by Peter Sorokin

Until recently one feature most lasers had in common—whether they were of the solid, liquid or gaseous type—was that the actual radiators of light were comparatively simple. In the original ruby laser, for example, the active radiators were the sprinkling of chromium ions that make an aluminum oxide crystal a ruby. Other solid lasers and certain liquid lasers incorporate various rare-earth ions for the same purpose. In gas-discharge lasers the active role may be played by atoms, ions or even simple inorganic molecules such as carbon dioxide. Only in semiconducting junction lasers is the crystal lattice of the host material primarily involved in the light-generation process. Here, however, a certain amount of simplicity is introduced by the fact that the radiating atoms are disposed in a periodic array.

Within the past three years it has been discovered that complex organic-dye molecules—each consisting of dozens of atoms—can also be induced to emit coherent laser light. The active molecules in these new lasers are usually dissolved in common liquid solvents such as water or alcohol, but a solid matrix such as polymethyl methacrylate (Plexiglas) can also serve.

One of the main advantages of the organic dyes as potential laser materials is that a large number of such dyes, each fluorescing at a specific wavelength, are available over the entire range of the visible spectrum. Therefore it should be possible to design a "tailor-made" organic-dye laser that emits at any given visible wavelength. More remarkable is the fact that each of these lasers is individually tunable, that is, its output can be changed continuously over a smaller range of wavelengths.

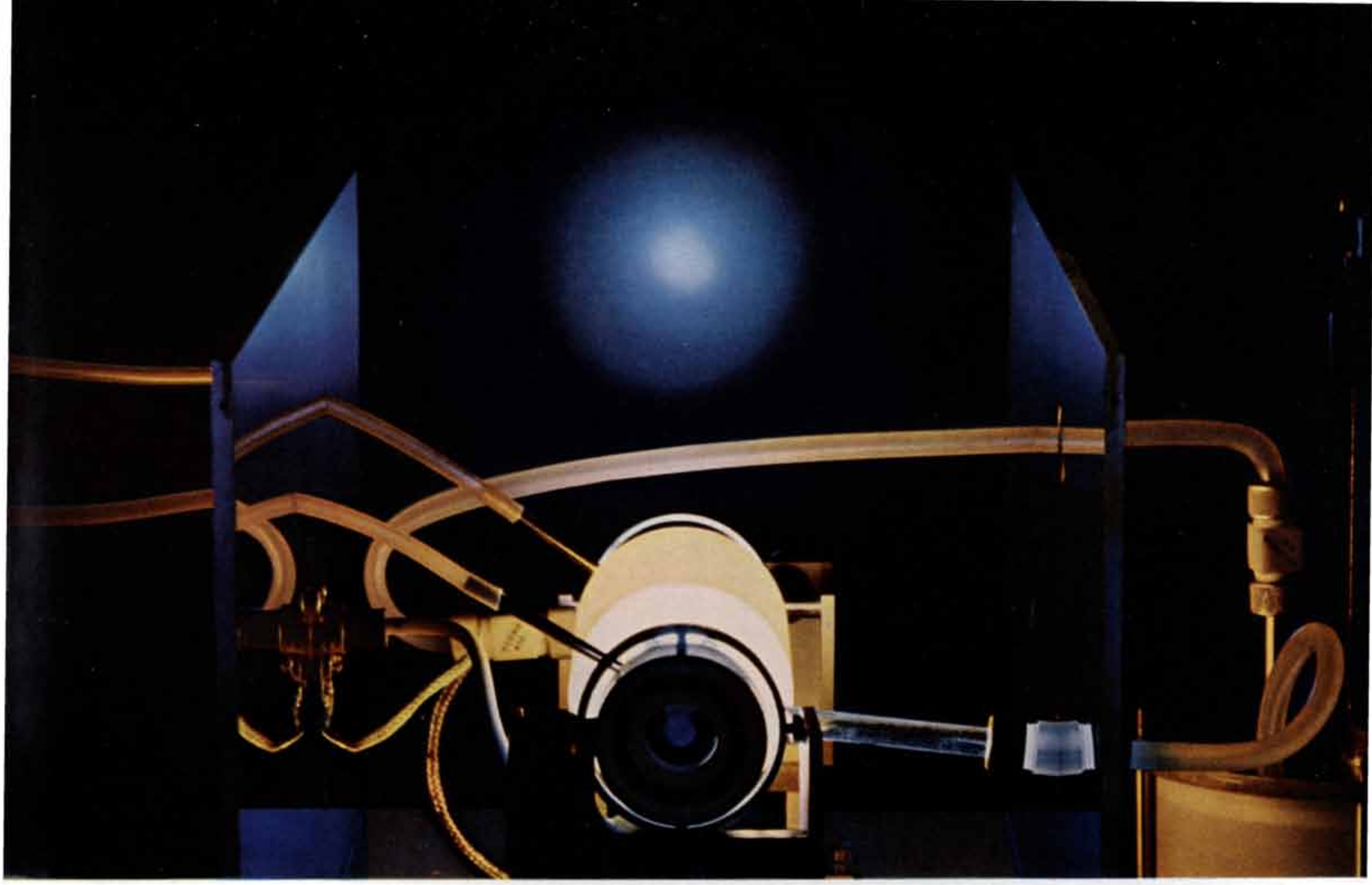
The novelty of this last feature is worth stressing. In the past few years various methods have been devised to convert the energy of a primary laser beam into the energy of a frequency-shifted secondary beam. These schemes all exploit special optical effects that take place in materials exposed to the primary beam [see "The Interaction of Light with Light," by J. A. Giordmaine; Scientific American, April, 1964]. The organic-dye lasers represent the first instance where the primary beam itself can be continuously tuned.

The discovery of laser emission from organic molecules was made in 1966 by my colleague John R. Lankard and me at the Thomas J. Watson Research Center of the International Business Machines Corporation. It was actually an accidental discovery. We had been trying to observe the optical effect known as stimulated Raman emission from solutions of organic-dye molecules in ethyl alcohol. The molecules we were working with, called metal phthalocyanines, are distinguished by the fact that they absorb light in a fairly narrow spectral band, which lies in a region of the visible spectrum that is near the wavelength of the light emitted by a ruby laser [*see illustration on page 33*]. The actual position of this absorption band depends in part on the type of metal ion that occupies the center of the phthalocyanine molecule.

It was known at the time, on the basis of some quite general theoretical calculations, that the amount of Raman light emitted by a molecule is enhanced whenever the wavelength of the stimulating light happens to be close to the wavelength of the molecule's principal absorption band. Therefore we had some reason to believe frequency-shifted Raman light would emerge from the cell containing the phthalocyanine solution when the beam of a pulsed ruby laser was fired at the cell. The difference in frequency between the ruby-laser beam and any secondary light produced would then tell us the Raman frequencies of the phthalocyanine molecule; these were quantities of interest that had not been measured up to that time.

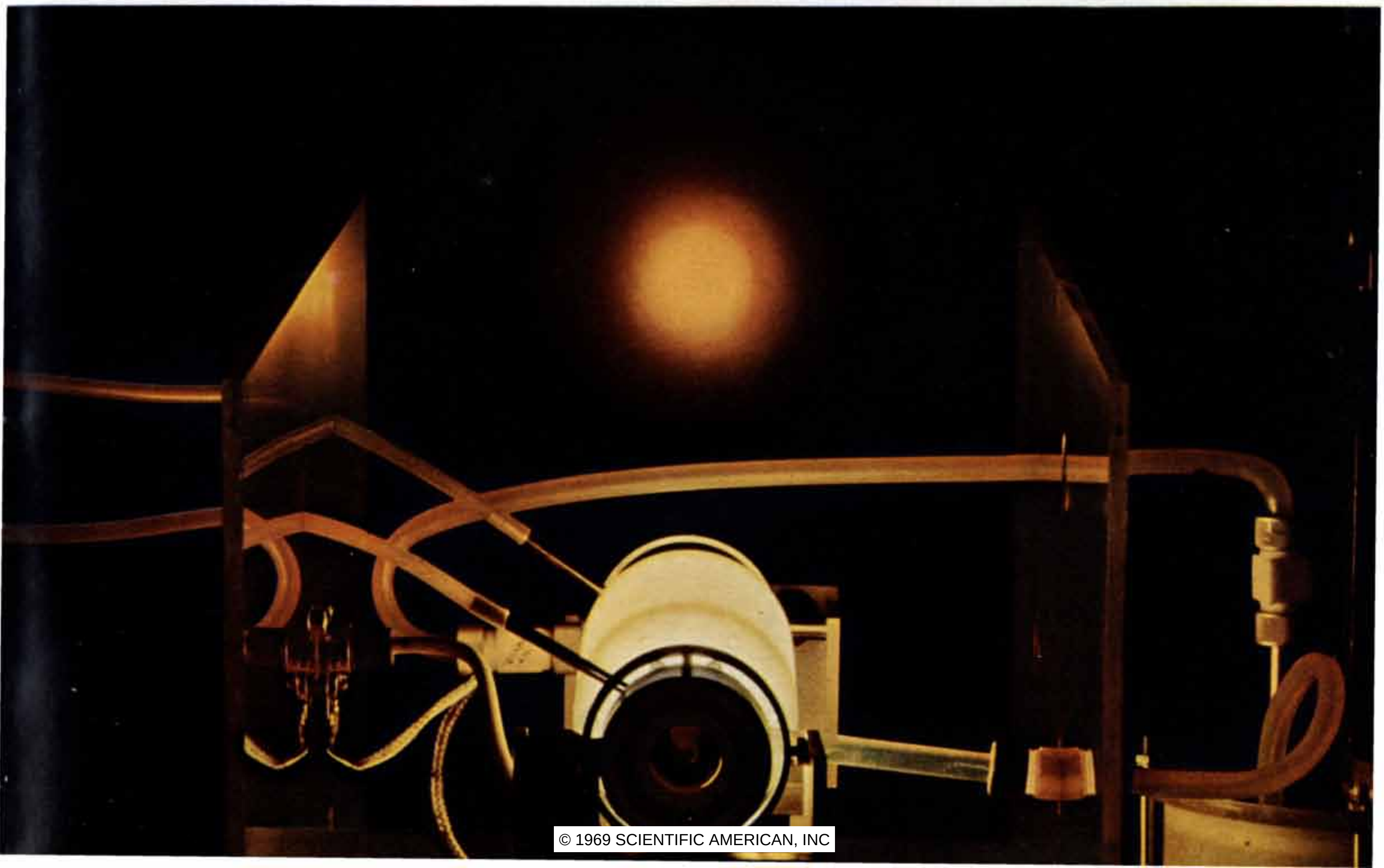
To ensure that the Raman light, however weak, would have a good chance of being detected, a lens system was assembled that was capable of gathering a large fraction of all the light scattered from the dye cell in the forward direction. This light was then focused on the entrance slit of a grating spectrograph, which was adjusted to record on a photographic plate any spectral features present in the range of wavelengths roughly between 7,000 and 12,000 angstroms. As it happened, the first plate we examined revealed a diffuse band near 7,555 angstroms. The diffuseness of the band ruled out Raman emission, however, and we were immediately led to consider the possibility that incipient laser action might be occurring, particularly since the wavelength of the detected band seemed to coincide with the peak of one of the fluorescence bands of phthalocyanine. Confirmation of this last hypothesis followed quickly. When the dye cell was incorporated into a proper resonant cavity, a powerful laser beam at a wavelength of 7,555 angstroms emerged along the axis of the secondary resonator.

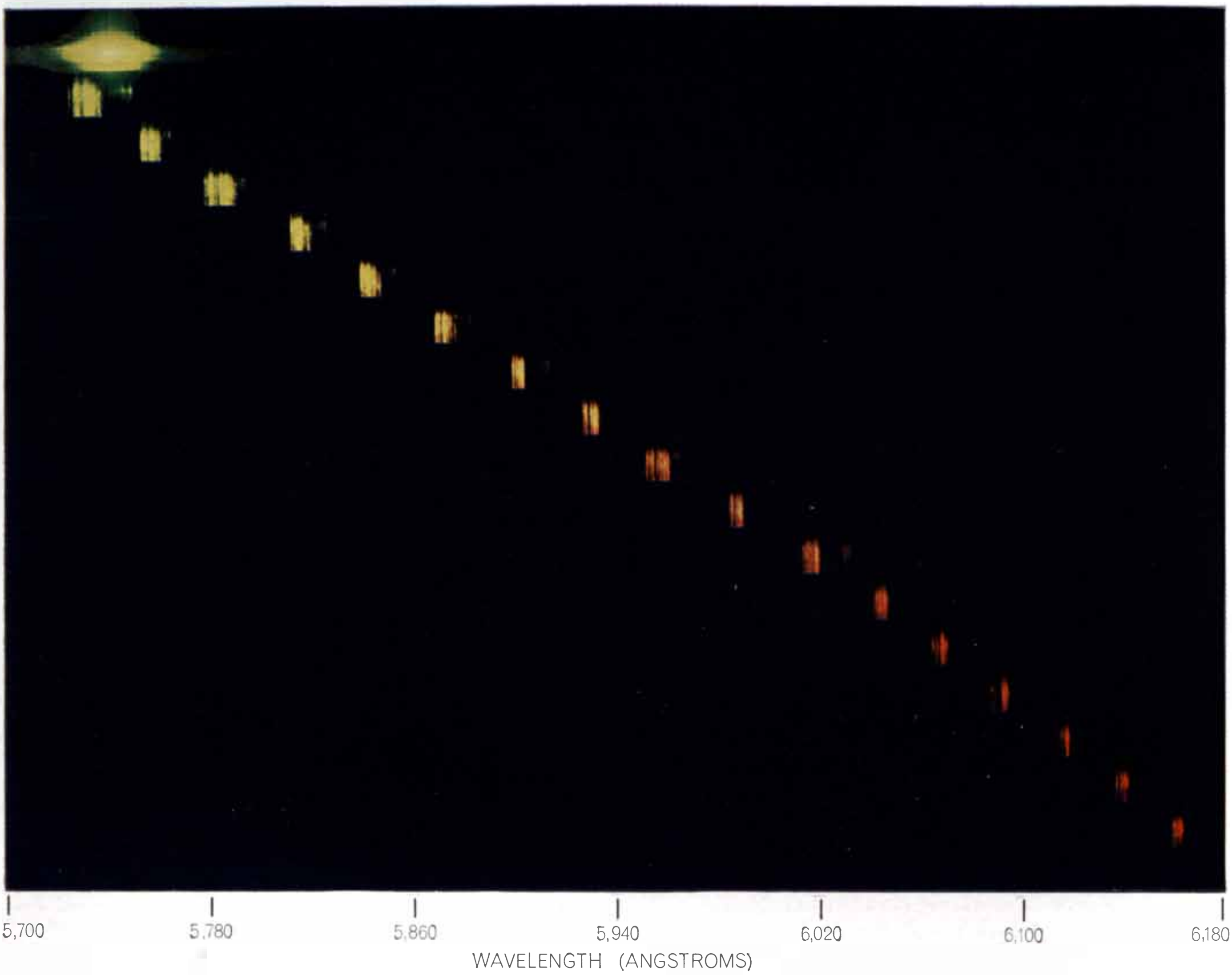
An analysis of the mechanism by which coherent light was generated in this experiment made it seem likely that the same effect would be observable with other fluorescent organic molecules, primarily because such molecules all resemble one another in the general arrangement of their energy levels. It was clear that the light from the ruby laser acted on the long-wavelength "wing" of the phthalocyanine absorption band,



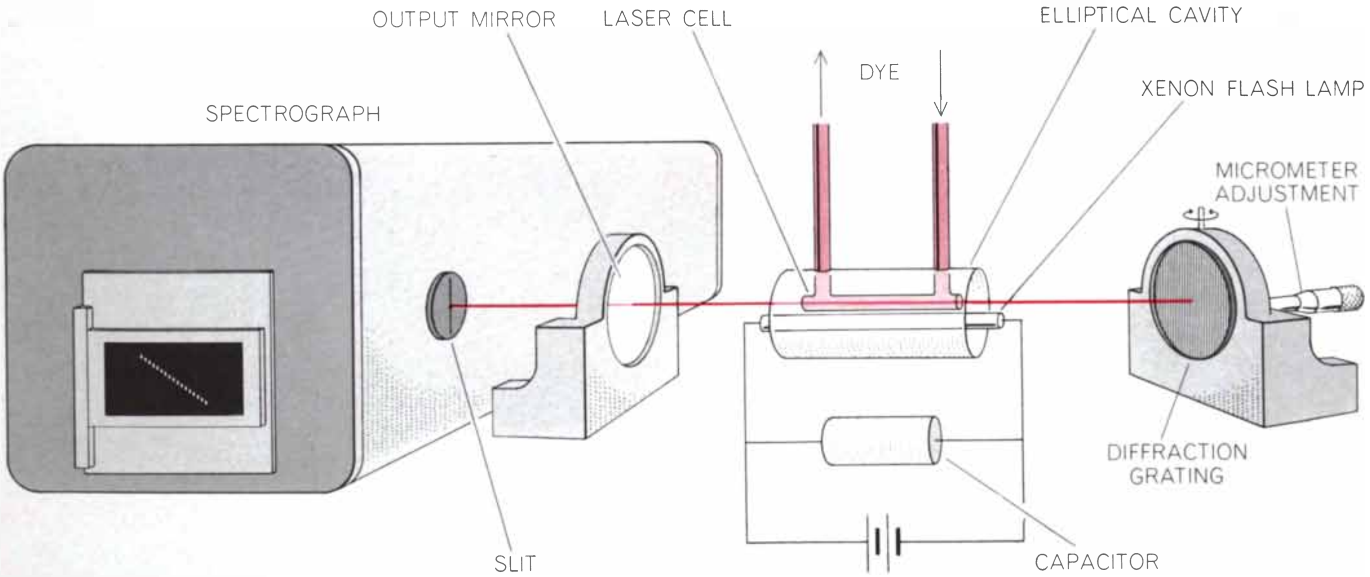
BLUE LASER BEAM (*above*) was produced by molecules of an organic dye called 7-diethylamino-4-methyl coumarin. The dye, which was dissolved in ethyl alcohol, can be seen fluorescing in the glass tube at lower right, which leads from a reservoir into the laser cell. The beam was projected backward at an opaque screen.

ORANGE LASER BEAM (*below*) was produced by another organic dye called Rhodamine 6G. The coumarin dye was simply flushed out of the system and the solution containing the new dye pumped in. In both cases the dye molecules were excited by a flash lamp, which caused the sleeve around the laser to appear yellow.





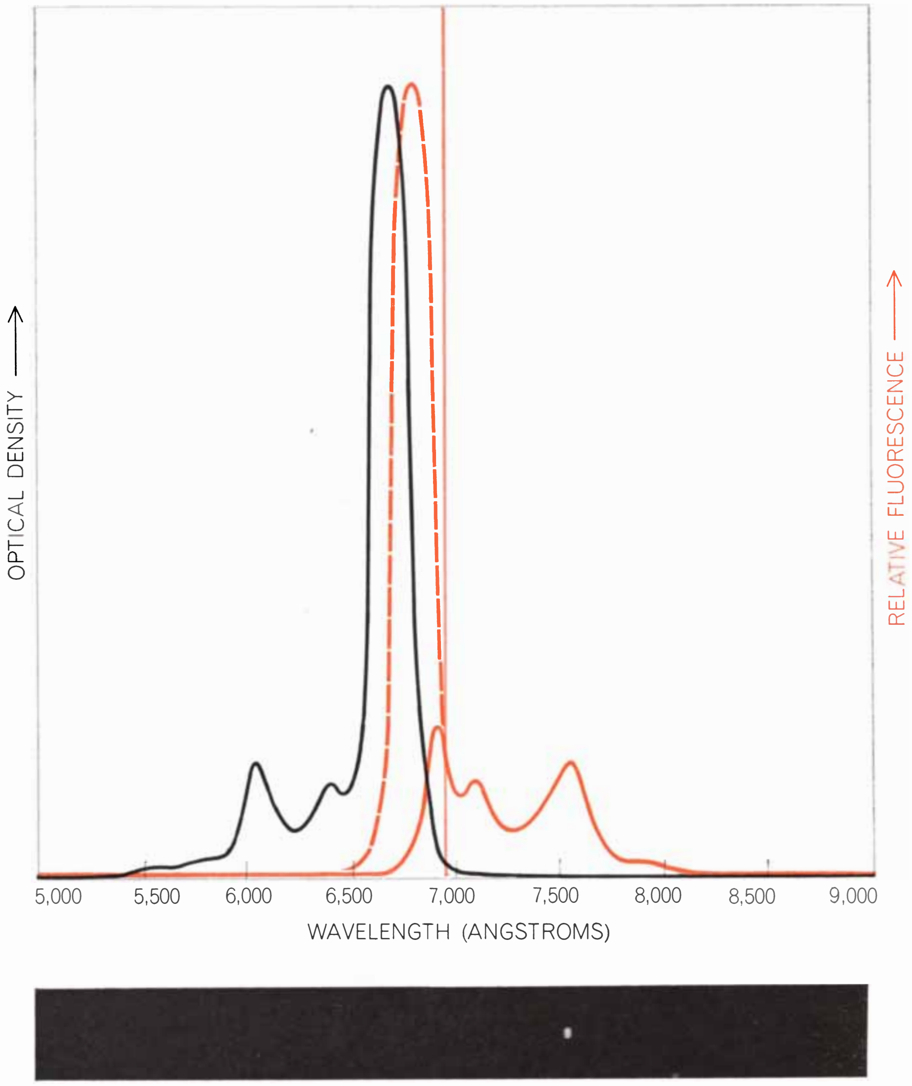
TUNABILITY of an organic-dye laser is demonstrated by this photograph, which shows the images formed on a sheet of color film that was substituted for the normal black-and-white photographic plate of a spectrograph (*see illustration below*). The wavelength of the laser output was changed by adjusting the angle of a plane diffraction grating, which replaced the usual mirror at one end of the laser cavity. The laser was fired once for each angular setting of the diffraction grating and the film was advanced one step vertically to record a new image at a slightly different wavelength. The images span a spectral range of about 440 angstroms from green to red. The bright "broad band" image at the upper left end was made with the usual cavity mirror instead of the grating.



APPARATUS employed to make the photograph at the top of this page is illustrated schematically here. The laser itself was a rather primitive, flash-lamp-pumped device containing a fixed concentration of Rhodamine 6G dye, which was circulated continuously through the laser cell. A laser constructed with better optical components would have made narrower spectral lines over same range.

thereby exciting these molecules from their "ground" state to what is termed the lowest excited singlet state. All organic molecules possess a lowest excited singlet state, and fluorescence, when it occurs, always originates from this state. In making a fluorescent transition the molecule reverts back to its ground state, simultaneously emitting radiation.

The spectrum of the fluorescent radiation from an organic dye often has more than one maximum, and it usually spans a region no less than several hundred angstroms wide. The reason for this large bandwidth is that the radiation is actually made up of hundreds of components, corresponding to transitions originating from various sublevels of the first excited singlet state and terminating at various sublevels of the ground state. These sublevels are associated with specific vibrations of the molecule as a whole. Since some of the vibrational sublevels of the ground state may be high enough in energy so that they are normally unoccupied, the possibility exists that a "population inversion" sufficient for laser action can be established between the states from which fluorescence originates and some of the higher vibrational levels of the ground state. In our experiment the enormous power of the ruby laser absorbed by the phthalocyanine solution was sufficient to pump the required number of dye molecules directly into the fluorescence-emitting states, allowing the threshold for laser action to be attained. Once this threshold is reached all the excess energy used to excite the dye molecules is converted into the energy of a single coherent output beam whose light frequencies are contained within a relatively small interval centered near one of the broad fluorescence peaks. The spectrum recorded for the laser beam thus overlaps only a small portion of the usual fluorescence spectrum.

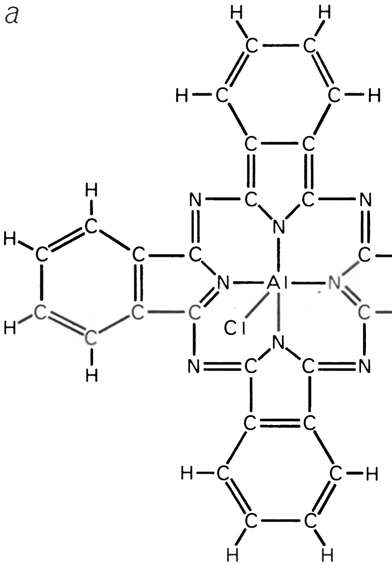


COMPARISON OF SPECTRA obtained for the organic dye chloro-aluminum phthalocyanine indicates the relation of the laser light obtained from this dye (*photograph at bottom*) to the dye's ordinary fluorescence spectrum (*colored curve at top*) and to its absorption spectrum (*black curve at top*). The stimulated emission in this case is centered on a subsidiary fluorescence peak and is much narrower than the total spectral region spanned by the fluorescence. The highest peak of the measured fluorescence curve is severely attenuated by self-absorption. The actual fluorescence curve should be the "mirror image" of the absorption curve, as is indicated by the broken colored line. The wavelength of light emitted by the ruby laser used to excite the dye laser is represented by the light-colored vertical line.

Considering the generality of this mechanism, it was not surprising that laser emission was demonstrated shortly afterward in many other red-absorbing, near-infrared-emitting organic dyes. This work was done both by ourselves and by other investigators who were turning their attention to the phenomenon. (Among the earliest to publish new findings were F. P. Schäfer and his colleagues at the University of Marburg in Germany, M. L. Spaeth and D. P. Bortfeld of the Hughes Research Laboratories and Michael Bass and Thomas Deutsch of the Research Division of the Raytheon Company.) From the results achieved collectively it began to appear that many of the dyes normally used as photographic-film sensitizers would also generate laser beams when they were excited by the intense, short pulses of a "Q-switched" ruby laser. In fact, it is now possible to cover the entire range between 7,100 and 11,700 angstroms with dye lasers of this class. It was also found that a ruby laser can generate enough second-harmonic light (at half the wavelength of the primary beam) to pump organic-dye lasers, thereby further increasing the range of the visible spectrum spanned by the new lasers.

A number of different optical arrangements have been worked out for experiments with organic-dye lasers [*see illustrations on page* 35]. The most symmetrical method of pumping involves a longitudinal geometry. This approach generally produces a laser beam with less divergence than a beam generated by a transverse pumping arrangement. With both types of geometry fairly good conversion efficiencies have been obtained. In one experiment utilizing longitudinal pumping it was possible to convert up to 40 percent of the energy of a ruby-laser beam into the energy of a near-infrared dye-laser beam.

Schäfer's group was the first to recognize the gross tuning effect inherent in the dye-laser emission mechanism. They found that the location of the stimulated-emission band can be made to shift by as much as 600 angstroms by changing the concentration of the dye or by lengthening or shortening the longitudia



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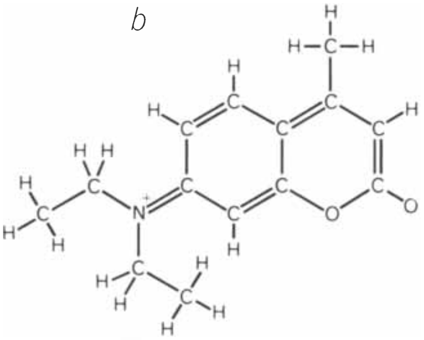

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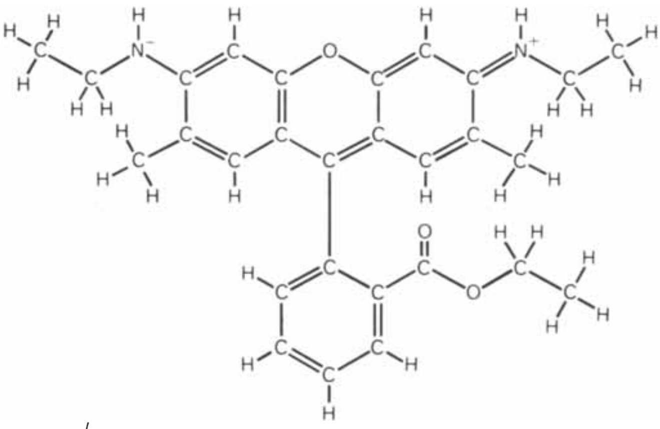

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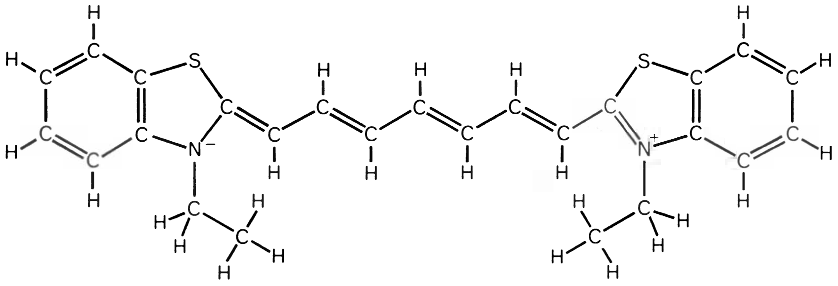


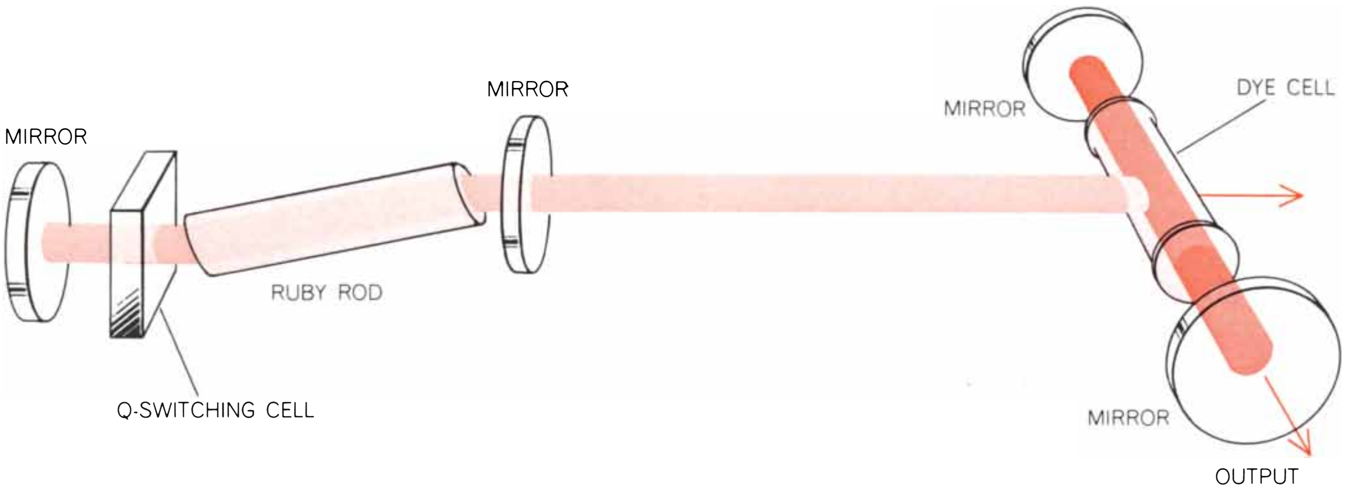
MOLECULAR STRUCTURES of four organic dyes that have been induced to emit laser beams are shown here. At top is a molecule of chloro-aluminum phthalocyanine, the substance in which organic laser action was first discovered. This dye, which is exceptionally stable in an ethyl alcohol solution, is widely used as a pigment in blue paint. It emits light in the near-infrared region of the spectrum at a wavelength of about 7,555 angstroms. Second from the top is 7-diethylamino-4-methyl coumarin, a dye found in commercial detergent whiteners. The coumarin dye shows good stability in ethyl alcohol and emits a strong blue laser beam that is tunable from 4,300 to 4,900 angstroms. Second from bottom is Rhodamine 6G, the substance with which the most powerful dye-laser pulses thus far achieved have been obtained. Of moderately good stability, Rhodamine 6G is tunable over a range of several hundred angstroms in the spectral region in which the eye is most sensitive to color changes (green to red). At bottom is a typical red-absorbing, near-infrared-emitting photosensitive dye called 3,3′-diethylthiatricarbocyanine iodide. This dye generates laser beams with wavelengths slightly longer than 8,000 angstroms. Its stability in solution is quite poor. Of these four dyes, only *b* and *c* have been made to emit laser light with flash-lamp excitation. All four can be pumped with a pulsed ruby-laser beam or with its second-harmonic light.

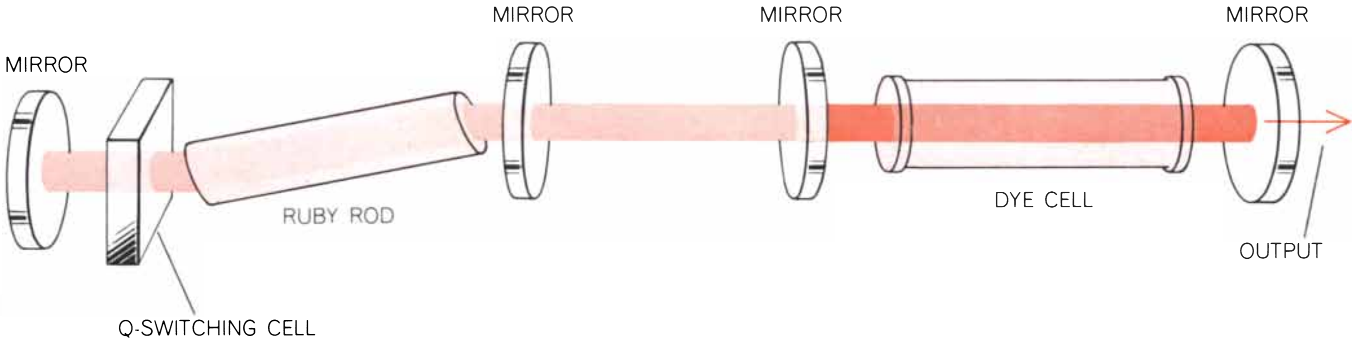
nal dimension of the dye cell [*see illustrations on page 40*]. As the dye concentration is increased, the spectral region of laser emission moves to longer wavelengths in response to the increasing attenuation associated with the low-energy wing of the principal absorption band. The output power of the dye laser remains fairly constant over the range of concentrations involved, which typically encompasses a change of two orders of magnitude.

Although the spectral output of a dye laser appears characteristically diffuse when the mirrors of the resonant cavity are "broad band" reflectors, it is possible to dramatically narrow the beam's spectral width by a rather simple procedure. This narrowing, moreover, occurs in such a way as to conserve most of the beam's energy. This effect was discovered by Bernard H. Soffer and B. B. McFarland of the Korad Corporation in an ingenious experiment performed in 1967. They replaced one of the broadband cavity mirrors by a reflective flat diffraction grating, which was mounted so that it could be rotated, with the grooves vertical, around a vertical axis. The initial angle of the grating was set so that the first-order diffraction wave that would be produced by a beam of light striking the grating along a direction parallel to the optical resonator axis would be sent back along the resonator axis. Since the exact angle at which incident rays and diffraction peaks coincide depends on the wavelength of the radiation, a continuously tunable narrowband optical cavity was thus created.

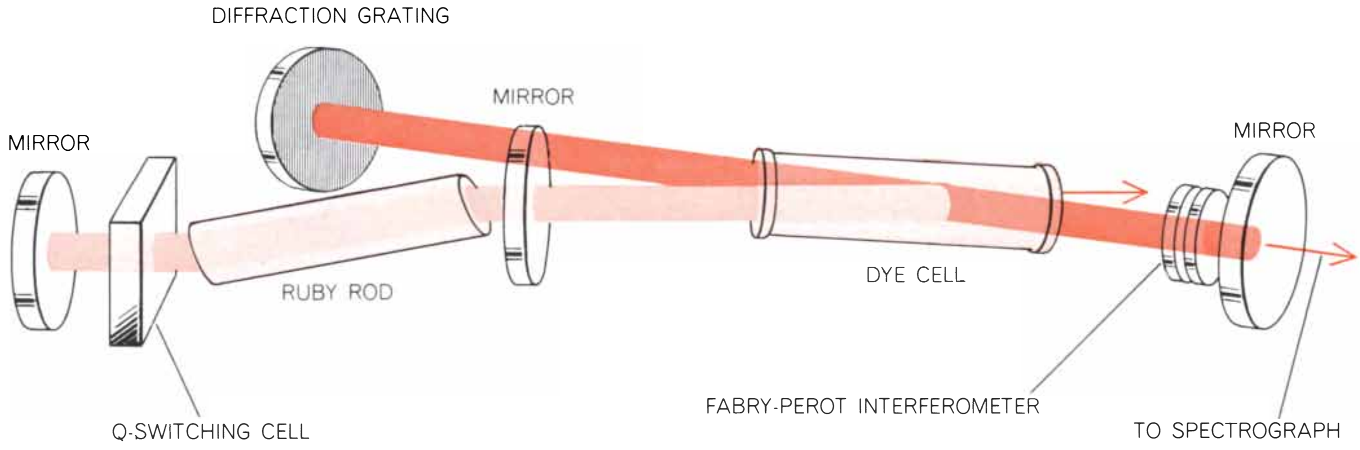
With the grating installed, it was found that the spectral width of the laser beam narrowed down to a sharp line only an angstrom or two wide. Normally, for the particular laser dye studied by Soffer and McFarland (a dye known commercially as Rhodamine 6G), the spectral width of the output beam amounts to 150 angstroms or so. They found in addition that there was no significant loss in total output power compared with the power generated when broad-band mirrors are employed. Finally, they noted that, as the grating was rotated from its original position, the wavelength of the spectrally condensed laser emission changed. Continuous, efficient laser tunability over a range of 300 or 400 angstroms was obtained in this way with a fixed concentration of the Rhodamine 6G dye. From a visual standpoint the color of the beam from this laser can be made to change continuously from a shade of green through yellow and orange to a shade of red as the micrometer screw determining the angle of the grating is rotated [*see illustrations on page 32*].

Tuning of the output beam can be accomplished to some extent with every organic laser. To understand how energy is channeled into a narrow line in this situation one must go a little deeper into the role played by molecular vibrations in the fluorescence of dye molecules. It is convenient first to consider a simple diatomic, or two-atom, molecule [*see illustration on next page*]. Here the structural coordinate on which the potential energy in any given energy state depends is the distance between the two nuclei of the molecule. The distance at which the minimum occurs in the ground state determines the normal linear dimension of the molecule. From quantum mechanics it is known that a system vibrating on the atomic or molecular scale can have only distinct energy levels. These are represented by horizontal lines between the right and the left boundary of the well-shaped potential curve. The vertical separation between adjacent vibrational levels is given by the product of the vibrational frequency times Planck's constant. One can picture the molecule in any given vibrational level as oscillating back and forth be-

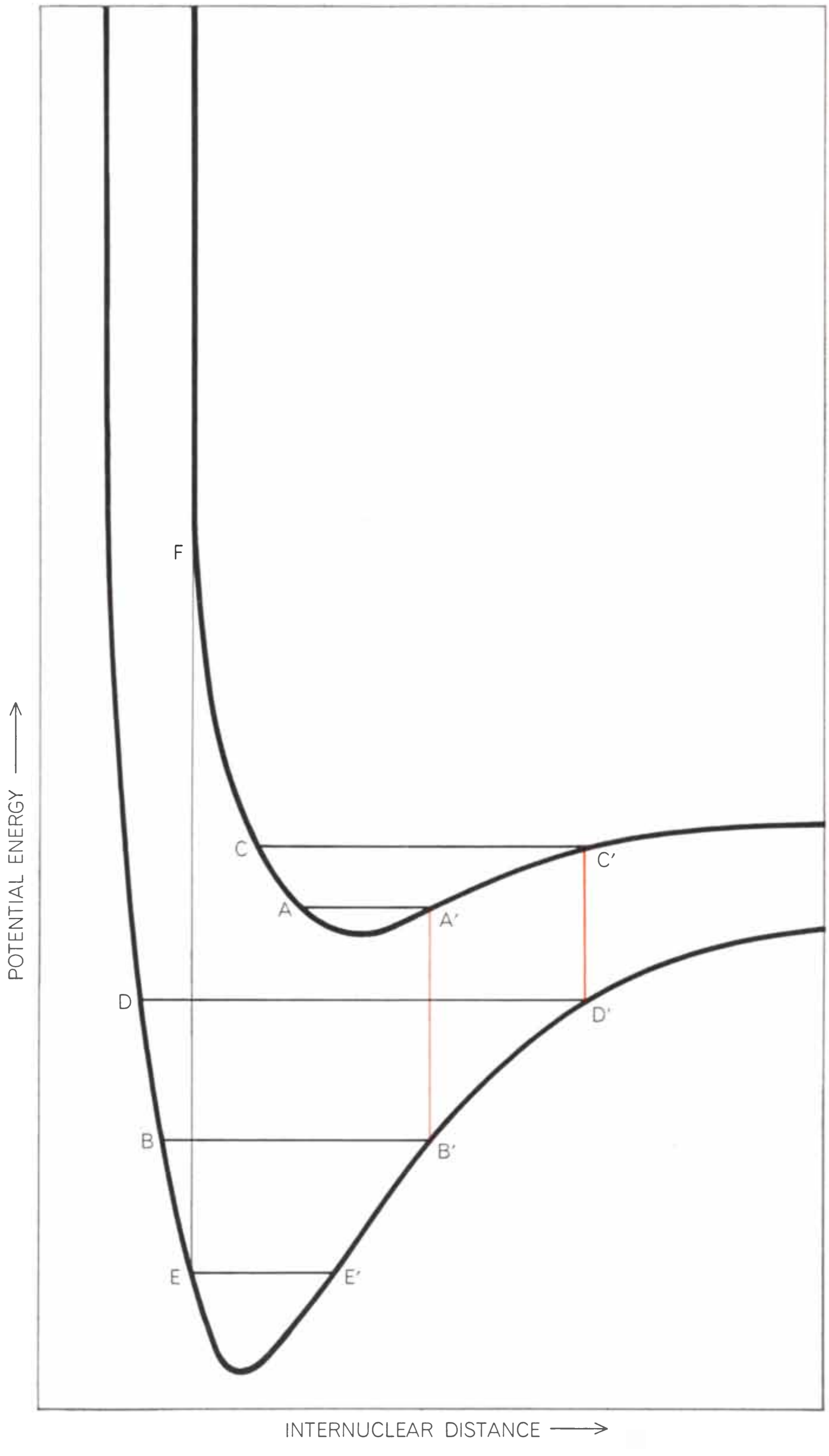




TWO POSSIBLE ARRANGEMENTS in which an organic-dye laser can be excited by a "*Q*-switched," or giant-pulse, ruby laser are the transverse-pumped geometry (*top*) and the end-pumped geometry (*bottom*). More symmetrical pumping is achieved in the case of the end-pumped arrangement. This approach results in narrower beam divergences and somewhat higher conversion efficiencies.



ACTUAL EXPERIMENTAL ARRANGEMENT combines the advantages of end-pumping with the narrow-band emission and tunability that results from the use of a reflective diffraction grating at one end of the secondary laser cavity. To improve the monochromaticity of the output beam additional optical components have been inserted. Near-infrared beams with a spectral width of less than a hundredth of an angstrom have been produced with this type of arrangement by D. J. Bradley of Queens University in Belfast.



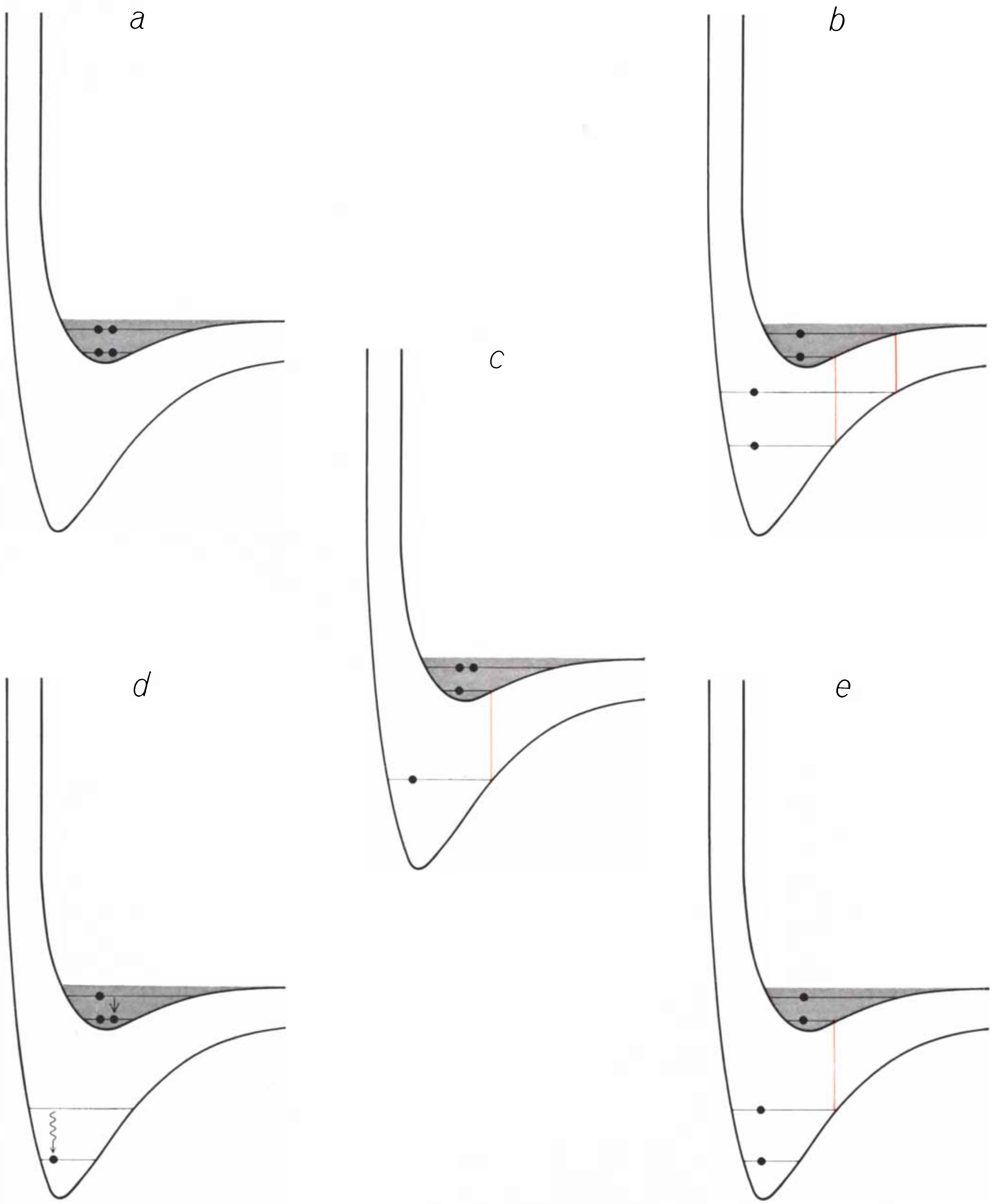
POTENTIAL-WELL CURVES represent the potential energy of the "ground" state (*bottom*) and an excited state (*top*) of a typical diatomic, or two-atom, molecule. The wavelengths at which the molecule emits or absorbs light are determined by the relative positions of such potential curves. For example, a molecule vibrating in the upper state between the limits *C* and *C′* will emit most strongly when it drops from the vicinity of its right-hand turning point *C′* to the point *D′* on the lower potential curve. Here a new vibrational motion begins, bounded by the end points *D* and *D′*. Similarly, molecules vibrating between *A* and *A′* will, after fluorescing, acquire a vibrational motion that reverses itself at points *B* and *B′*. The respective emission frequencies are proportional to the lengths of the segments *C′D′* and *A′B′*. Molecules in relatively unenergetic states, such as *EE′*, will absorb light at much shorter wavelengths, the absorption frequencies being proportional to the lengths of segments such as *EF*. For diatomic molecules the structural coordinate on which the potential energy of the molecule depends is simply the distance between the two atomic nuclei.

tween the end points located on the potential curve.

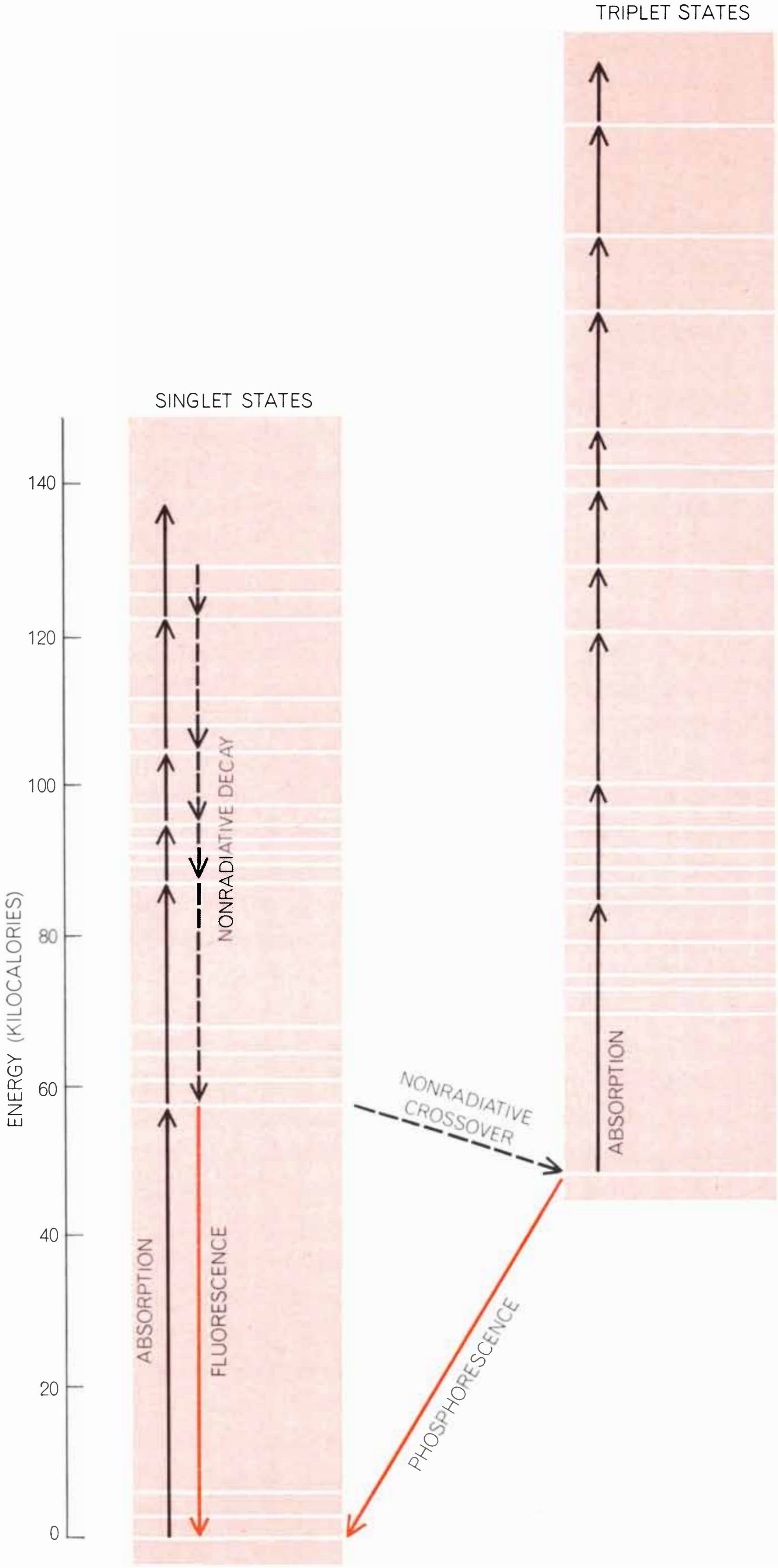
Now, in general the strongest optical transitions, that is, the strongest transitions between different electronic states of the same molecule, take place between pairs of vibrational levels for which the Franck-Condon principle is satisfied. In nonmathematical terms this principle, which was first advanced by James Franck in 1925 and which was later given a rigorous wave-mechanical basis by Edward U. Condon, asserts the following: The jump between different energy levels in a molecule takes place so rapidly compared with the molecule's vibrational motion that immediately afterward the nuclei have approximately the same relative position and velocity as they had before the jump.

An optical transition, whether it is an emissive or an absorptive one, will tend to originate preferentially at the two points where the vibrational motion reverses itself, because it is in the vicinity of these points that the molecule spends most of its time. Intermediate points are passed through very rapidly. Thus according to the first part of the Franck-Condon principle the most favorable optical transitions can be approximately depicted by drawing vertical lines to other potential curves, upward or downward as the case may be, starting from the original end points. The lengths of the segments that result are proportional to the transition frequencies. Because the potential minimums for two different energy states may fall at different internuclear separations, the transitions originating at the two opposite end points may differ greatly in frequency. Vertical lines drawn from vibrational end points that intersect vibrational levels of different energy states at positions outside the boundaries of the potential curves of the latter states do not represent possible transitions, because of the second part of the Franck-Condon principle. Such transitions would require that the nuclei discontinuously gain a large amount of kinetic energy during the jump.

The vibrations of a dye molecule such as Rhodamine 6G are much more complicated than the vibrations of a simple diatomic molecule. Here there are many more atoms that can vibrate in various ways with respect to one another. For polyatomic molecules of this complexity there is really no simple interpretation of the generalized structural coordinate with respect to which the potential variation of an individual energy state is plotted. Nevertheless, the potential-well diagram still affords the best means for discussing, at least qualitatively, the



FOR COMPLEX ORGANIC-DYE MOLECULES there is no simple interpretation of the structural coordinate with respect to which the potential curve of an individual energy state is plotted. Nevertheless, the spectral narrowing and tunability of a dye laser are still best explained, at least qualitatively, by means of potential-well diagrams such as the ones shown in the illustration on this page. With the normal "broad band" reflecting mirrors inserted in the dye-laser cavity, stimulated emission takes place over a wide range of wavelengths corresponding to the sum of the emissions from all the molecules pumped to the first excited singlet state (*a, b*). The molecules in this case are thermally distributed among the continuum of vibrational states (*gray shading*). When a narrow-band filter that passes only shorter wavelengths is inserted into the optical cavity, stimulated emission can occur only within the band of wavelengths passed by the filter (*c*). This tends to deplete selectively the "population" of molecules in the lowest vibrational levels of the first excited singlet state, thereby upsetting the thermal distribution within the continuum of vibrational states. Molecules with more vibrational energy, however, quickly drop into the lower vibrational levels (*d*) and are thus in a position to contribute light at the shorter wavelength (*e*). A comparable argument would apply if filter were initially tuned to pass only longer wavelengths.

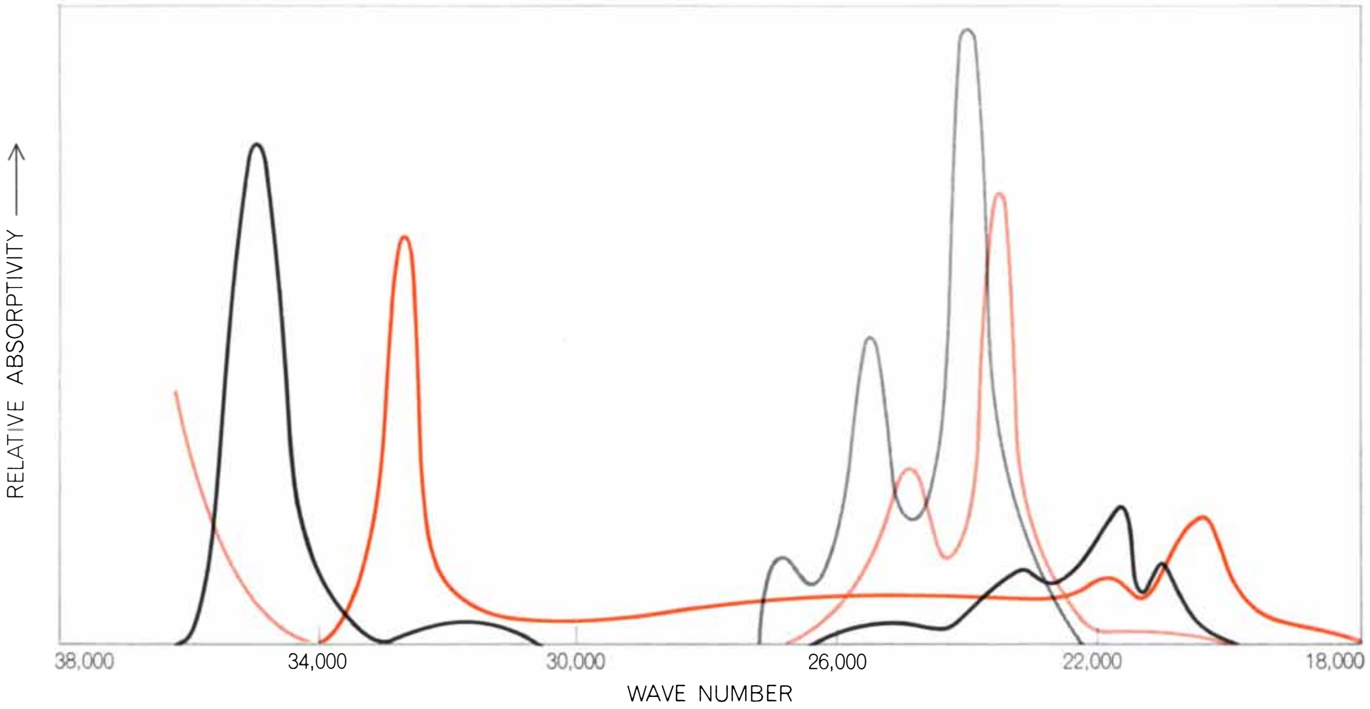


ENERGY-LEVEL DIAGRAM of a typical organic molecule shows the energy relation between this molecule's set of singlet states (*left*) and its set of triplet states (*right*). Some prominent vibrational levels, corresponding to observed subsidiary peaks in the molecule's absorption and fluorescence spectra, are indicated by the more closely spaced white horizontal lines. The diagram shown here was constructed on the basis of measurements for an organic-dye molecule called Acridine Orange by V. Zanker and E. Miethke of Germany.

spectral narrowing that occurs in a dye laser. For polyatomic molecules the set of discretely spaced vibrational levels in each energy state should be replaced by a continuous distribution of vibrational levels. If it is assumed that thermal equilibrium prevails within each such continuum to a first approximation, then only those levels that have vibrational energies equal to or less than the thermal energy of the molecule at a given temperature will be occupied. Moreover, the total population in each energy state will be more or less uniformly distributed within such a band.

When no selective feedback is present, stimulated emission will involve all the molecules present in the lowest excited singlet state. In the typical case the wavelengths emitted by molecules near the top of the occupied band will be longer than those emitted by molecules with less vibrational energy. Therefore the laser emission will cover a wide spectral range. If a narrow-band filter is inserted into the resonant cavity, allowing, say, only the shortest wavelengths to be reflected back and forth between the end mirrors, then laser radiation will be produced only at these wavelengths. That would deplete the population of the lower vibrational levels of the first excited singlet state, in effect "burning a hole" in the band of occupied states, if it were not for the fact that the tendency for thermal equilibrium prevails. Molecules from the top of the band quickly drop into the emptied lower vibrational levels, providing more molecules in a position to produce light in the original narrow band of frequencies [*see illustration on preceding page*].

So far we have considered laser emission from organic dyes in terms of transitions occurring between various levels belonging to the set of singlet states. It is well known, however, that all organic molecules possess in addition a set of energy states that are triplets [*see illustration at left*]. The long-lived phosphorescence of organic molecules, most easily observed at low temperatures, originates from the lowest of these triplet states. The slow decay of this emission reflects the fact that optical transitions between states of different multiplicity are in general highly unlikely. Molecules that have accumulated in the lowest triplet state can, however, make absorptive transitions to higher triplet states, removing energy at characteristic wavelengths from any beam of light that happens to fall on the sample. In particular, attenuation of a laser beam generated by a population inversion



ABSORPTION BANDS associated with transitions within a molecule's set of triplet states can seriously attenuate a laser beam generated by transitions within the molecule's set of singlet states. Fortunately a great deal of knowledge was available to the author concerning the magnitude and location of these triplet-triplet absorption bands. For example, the spectra of various anthracene derivatives, shown here, were measured by means of a flash photolysis technique by George Porter and Maurice W. Windsor in England. The vertical coordinate of each curve was multiplied by a certain factor in order to bring it into scale with the other curves.

within the set of singlet states can occur if there are enough molecules in the lowest triplet state. If a sizable percentage of all the molecules happen to be present in this state, the effect can be strong enough to prevent laser action completely.

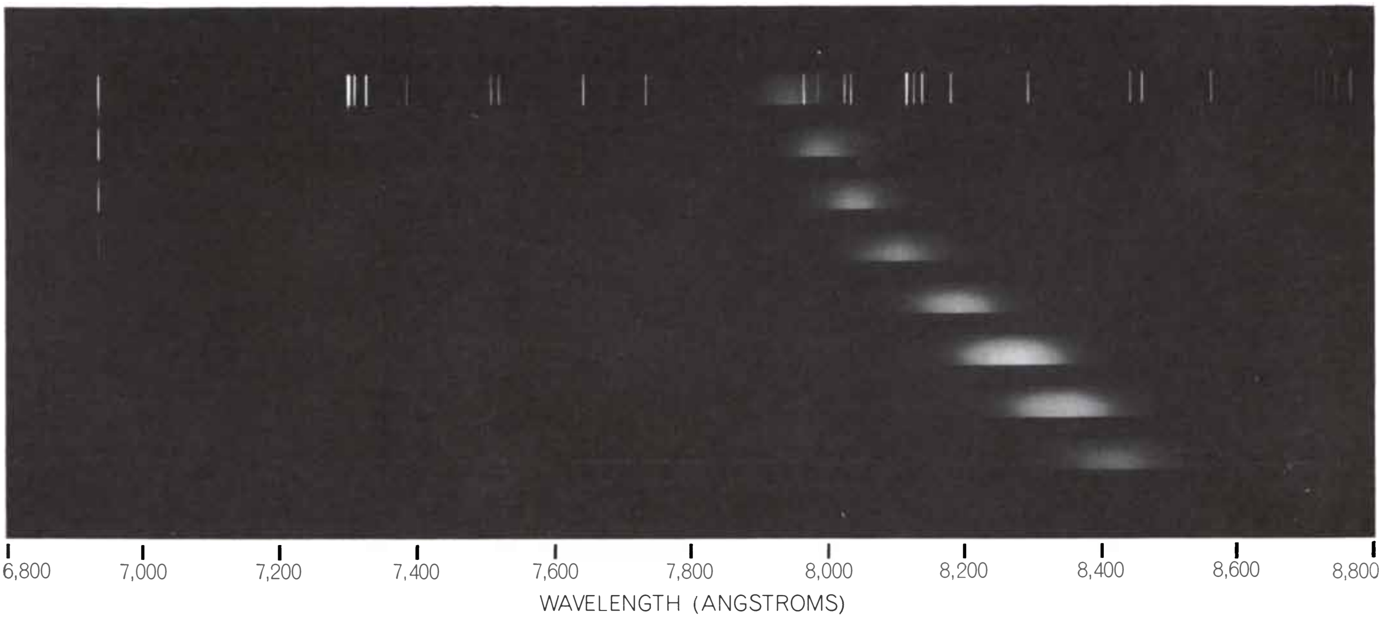
What is the pathway by which the molecules reach the triplet state? Invariably they cross over to this state by means of a nonradiative process from the lowest excited singlet state. The probability of intersystem crossing varies widely with molecular type. It depends on such factors as the resistance offered by the molecule to torsional bending, and the presence or absence of heavy atoms in the molecule. A comparatively low singlet-to-triplet crossover rate obviously obtains in those molecules with a high fluorescent quantum efficiency.

The problems created by having molecules accumulate in the lowest triplet state during the course of the pumping pulse had to be considered in early 1967 when we decided to try to build a flash lamp to replace the *Q*-switched solid-state laser that had up to that time been a necessary adjunct of the dye laser. The pulse duration of a *Q*-switched laser is only about 10 billionths of a second, so that the whole cycle involving excitation and stimulated emission within the set of singlet states could be completed before a significant population buildup occurred in the triplet state. In retrospect this is certainly one main reason why it has been possible to produce laser beams from literally dozens of fluorescent dyes when excitation is provided by a giant-pulse laser.

Many earlier studies had indicated that for highly fluorescent molecules the time constant for singlet-to-triplet crossover might be as long as a few hundred billionths of a second. For most molecules it is much shorter. From flash photolysis studies of the type perfected by George Porter, who shared the 1967 Nobel prize for chemistry, a great deal of knowledge was available concerning the magnitude and location of the triplet-triplet absorption bands [*see illustration above*]. With all this information at our disposal it was easy to calculate that with a very bright flash lamp having a rise time of a few tenths of a microsecond one should be able to pump selected dyes. We proceeded to build such a lamp. Our efforts were immediately rewarded. Laser beams were produced from about half a dozen highly fluorescent dyes that were excited by the specially constructed flash lamp.

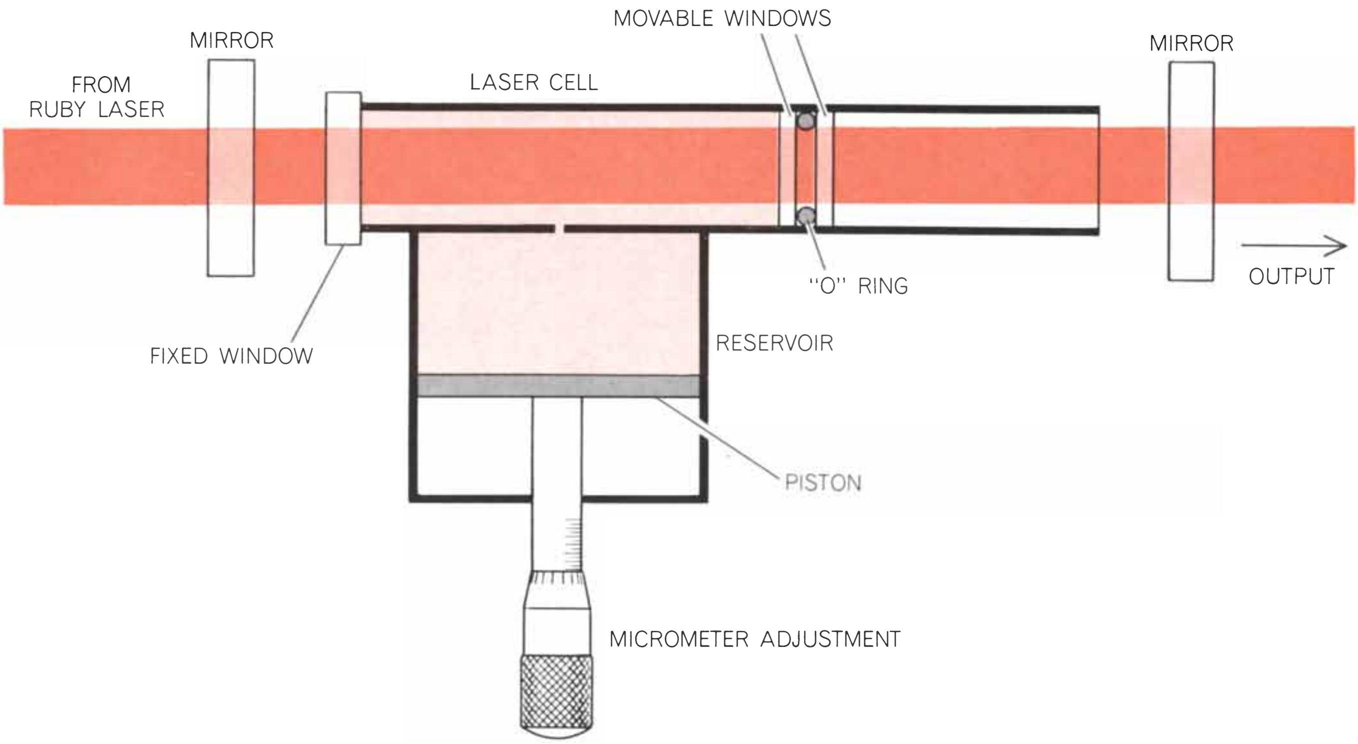
Recently it has been noted by various investigators that the pulse duration of the flash lamp is apparently not as important as we had originally thought, at least for two of the better-performing groups of dyes: the rhodamines and the coumarin derivatives. In fact, semicontinuous laser action is possible with these dyes, during which the output of the dye laser closely follows the shape of the applied pumping pulse. This effect has been observed for flash-lamp pulses of up to 10 microseconds' duration. The explanation of this phenomenon appears to involve the presence of dissolved molecular oxygen in the liquid solvents. The oxygen tends to quench the triplet state during collisions with excited dye molecules. After such collisions the dye molecules revert back to the ground singlet state, thereby preventing excessive accumulation of molecules in the triplet state. This fact, together with the unusually low intersystem-crossing rates that obtain in these particular dyes and low triplet-triplet absorption at the lasing frequencies, helps to make semicontinuous operation possible. Since special low-inductance flash-lamp circuitry is now no longer an absolute necessity, dye lasers of relatively simple construction can be built.

It is probably too early to assess how practical the organic-dye lasers will be. As important adjuncts to certain types of experiment, they seem bound to be used because of their versatility in output wavelength. It is now possible, for example, to populate selected energy levels of atomic and molecular vapors. This should lead to the development of certain laser devices not yet achieved, such as double-quantum light oscillators.



GROSS TUNING of an organic-dye laser can be accomplished by changing the concentration of dye in the laser cell. To obtain this photograph, which shows a series of images formed on the photographic plate of a grating spectrograph, the concentration of 3,3′-diethylthiatricarbocyanine iodide dye in the laser solution was halved after each pulse, starting from the bottom exposure. A giant-pulse ruby laser was used to end-pump the dye laser. The spectral line emitted by the ruby laser can be seen at the left in the top four spectra. The other lines in the top spectrum are reference lines produced by the second-order diffracted waves of a mercury lamp.

The dye laser has already been used to provide a broad continuous spectrum as a background for high-speed absorption spectroscopy. The usefulness of dye lasers in such diverse applications of laser beams as "welding" detached retinas and forming microelectronic components is currently being evaluated in a number of places. Their potential applicability to more everyday situations seems enhanced by a recent discovery by O. G. Peterson and Benjamin B. Snavely of the Eastman Kodak Company. They found that rods of Plexiglas, lightly doped with rhodamine dyes, will also emit laser beams under flash-lamp excitation. Finally, since the spectral, temporal and spatial characteristics of the beams emitted by lasers tend to convey new information about the molecules, atoms or ions that produce them, it is likely that organic-dye lasers themselves will be subjects of study for some time to come.



ANOTHER WAY to achieve gross tuning of an organic-dye laser is to vary the length of the resonating cavity. Lengthening the dye cell has the same effect as increasing the concentration of dye molecules in the dye cell. The particular hydraulic device portrayed here was built by Morton R. Kagan of the Federal Systems Division of the International Business Machines Corporation.

In hope of doing each other some good

Reaching and teaching the less bookish

There seems to be some problem as to who is willing to pay for science, let alone raise the ante. If the difference between science and technology gets to be more widely grasped, the problem may get worse. Cheer may portend, however, in that more of the population now goes to college and there encounters science.

Scientists who teach are therefore well advised to do a good job of it at levels of the human genetic and cultural pool which science must tap for sustenance but where it is not quite enough to suggest that elementary wave mechanics, for example, can be understood by devoting an afternoon to Heitler's 190-page little classic on the subject.

There seem to be more effective routes to the minds of a generation whose education began before kindergarten with Saturday morning cartoon shows. We made the film those shows came on, and we make film on which, in the opening words of a recent announcement by the Commission on College Physics, "The physics film underground is about to go legit."

The Commission begs for publicity for such extant classics of the physics teaching film as Bork's *Quantum Mechanical Harmonic Oscillator* and Sinden's *Force, Mass, and Motion.* It then proposes a "film publication system," referee-controlled, whereby the physics teaching community turns out films for each other. Most of the activity is to be at the advanced undergraduate and the graduate levels, for which few films now exist.

Aside from helping with the publicity, we can also help with the KODAK EKTAGRAPHIC MFS-8 Projector. It establishes a relationship between the student and the film that the teacher-filmmaker can put to good use. No longer does the film have to start at the beginning and run to the end. Even if the film wasn't conceived with this projector in mind, its edge can be marked to stop automatically at any frames to halt the action, make a statement, raise a question. When the student is ready, he presses a button to thaw the freeze and resume at 6 to 18 frames/sec, forward or backward as prescribed, until the next marked frame.

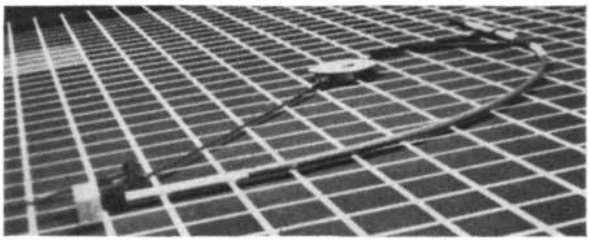
If gadgetry can help bring light to the less bookish of the populace, let's not consider it indecent.

To find out more about the KODAK EKTAGRAPHIC MFS-8 *Projector, ask Eastman Kodak Company, Motion Picture and Education Division, Rochester, N.Y. 14650.*

To find out more about the Physics Film Repository, ask the Director of the Commission on College Physics, University of Maryland, 4321 Hartwick Road, College Park, Md. 20740.

Here are a couple of shots the Commission has given us to show where you might stop the projector and ask for the vaulter's speed of approach from the energy stored in the pole:

The vault



The pole

Then have them go back to count frames and see how they made out.

A bit of aerial film

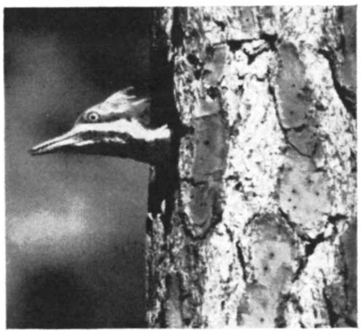
We have said much about aerial photography for scientific purposes and little about the minimum quantities in which our aerial film products are sold. The minimums may have been big enough to sink many a small scientific project before it ever got off the ground. Now we can report that even a single 100-foot roll of any of the following 70mm aerial films can be ordered for quick delivery from almost any camera shop:

- KODAK EKTACHROME AERO Film 8442, for color transparencies from higher altitudes.
- KODAK EKTACHROME MS AEROGRAPHIC Film 2448, with less contrast and therefore for low altitude; capable of being processed either to a transparency or to a negative that can be printed either as black-and-white or color, without the blanket orange that masks complementaries; tolerating more exposure error because of the chance for correction in the printing.
- KODAK EKTACHROME Infrared AERO Film 8443, the well-known "false color" film that extends color sensation to the near infrared.
- KODAK PLUS-X AERECON Film 8401, for plain black-and-white.

We offer no processing service for these films but can furnish names of firms who do. Write Eastman Kodak Company, Industrial Photo Methods, Rochester, N.Y. 14650.

The log-cock

He was known as the log-cock long ago, when birdwatchers had no such high-flown label as "pileated woodpecker" and did their watching for the family table and for the game markets in the towns. He doesn't taste very good. Nevertheless, his numbers declined. Then he came back, as the forest returned to poorer farmsteads, abandoned with the recognition of agriculture as a business. He can be watched again in much of North America by watchers good at watching.

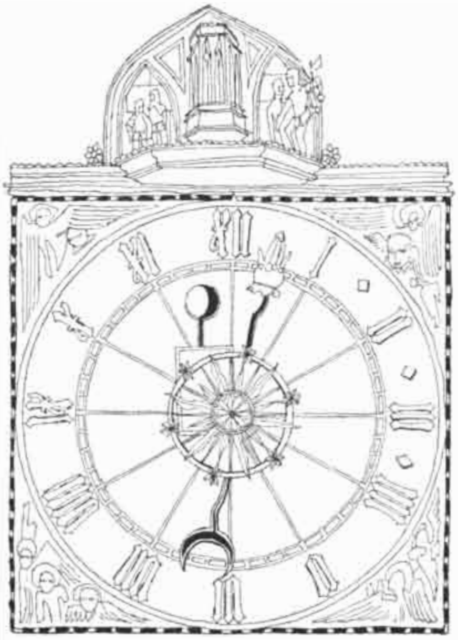


The behavior pattern that comes with his long, hairlike scarlet crest and his scarlet mustache makes him a living jackhammer. The chips that fly run 3, 4, even 6 inches in size. Rarely do he and his mate use for nesting one of the dead trees they have riddled in quest of ants. For a nest they select a special tree and spend a full month patiently and meticulously carving a huge chamber high up in it. The eggs are laid on the bed of chips. During daylight he and she take two-hour turns at incubating, but for the night he takes over alone.

The log-cock's world and man's remain in conflict in a minor way. A dead tree that has been impregnated with preservatives and replanted as a utility pole is still a dead tree to the log-cock. Computers may refine the figure, but $6 million is believed a fair estimate of the annual cost of the log-cock's assumption. We have reason to believe that if p-benzoquinone were added to the preservative recipe, he would be alerted to a difference. p-Benzoquinone is one of many chemicals that our manufacturing processes produce. Ingenuity in finding markets for them is admired in our marketers and gets them singled out as bright.

EASTMAN KODAK COMPANY An equal-opportunity employer

SCIENCE AND



Celestial Ammonia

Microwave radio signals characteristic of emission from ammonia molecules (NH_3) have been picked up from the general direction of the center of the galaxy by a radio telescope in California. The discovery marks the first time that molecules consisting of more than two atoms have been identified in interstellar space. Previously the most complex molecule detected in space had been the OH, or hydroxyl, radical [see "Radio Signals from Hydroxyl Radicals," by Alan H. Barrett; SCIENTIFIC AMERICAN, December, 1968].

The evidence for the existence of ammonia in a region of space populated by numerous clouds of gas and dust was obtained with a new 20-foot radio telescope at the University of California's Radio Astronomy Observatory near Hat Creek. The group responsible for the discovery consisted of Albert C. Cheung, David M. Rank, Charles H. Townes, Douglas D. Thornton and William J. Welch, all of the University of California at Berkeley. Their findings are reported in *Physical Review Letters.*

The radio data indicate that the ammonia molecules are quite abundant in a number of turbulent gas clouds in the constellation of Sagittarius, which is in the direction of galactic center. The actual distance of the clouds from the earth has not been determined. By comparing the relative intensities of two distinctive ammonia lines in the microwave-radio spectrum, however, the investigators were able to calculate the temperature of the molecules as being about 23 degrees Kelvin (degrees Celsius above absolute zero). They estimate the density of the interstellar ammonia gas to be one molecule per liter. The clouds in which the ammonia molecules were discovered have an overall density of a million molecules per liter, with the bulk of the matter probably consisting of molecular hydrogen (H_2). It appears that at least 1 percent of the available nitrogen in the region is contained in the form of ammonia.

According to the Berkeley group, it is unlikely that the ammonia molecules were formed by random atomic collisions. They suggest that the molecules might have been formed on particles of interstellar dust by the process known as surface catalysis. Once formed, the molecules could leave the dust particles by sublimation. The fact that the ammonia molecules exist inside interstellar clouds probably protects them somewhat from the ultraviolet component of starlight, which would otherwise destroy such molecules in a fairly short time.

In addition to hydrogen and nitrogen, both OH radicals and interstellar dust have been discovered in the region where the ammonia molecules were found. Other gaseous compounds such as water (H_2O), methane (CH_4) and even more complex organic substances may also be present in this region, and the search for them is being intensified.

Dual Immunology

Clinical evidence has been developed that bears out the experimental finding that there are two separate immunological systems, one of them dependent on the thymus gland and the other independent of it. The major function of the thymus as a source of cells involved in immunity was established only in 1961. Later experiments, particularly with chickens, made it clear that the varied immunological effects can be divided into two groups. First there are "cellular" immune responses such as delayed-hypersensitivity reactions and the rejection of skin grafts; these are mediated by small lymphocytes: white blood cells that originate in the thymus and are present in deep regions of the lymph nodes. Second there are "humoral" immune responses involving the synthesis of the immunoglobulins in the blood, which constitute the circulating antibodies; this synthesis is associated with proliferating germinal centers of lymphocytes in the lymph nodes and with plasma cells, which do not originate in the thymus. In the chicken this second system originates in an organ called the bursa of Fabricius; the equivalent of the bursa in mammals is not yet known.

In 1965 Angelo M. DiGeorge of the Temple University School of Medicine reported on several infants born without a thymus and the embryologically related parathyroid glands. Now a group at the Harvard Medical School has done a full evaluation of immune responses in two infants with DiGeorge's syndrome and has found that their immunological status reflects the dichotomy between the two types of immunity. The report by Roberto Kretschmer, Burhan Say, David Brown and Fred S. Rosen is published in *The New England Journal of Medicine.*

In both infants the thymus-dependent system was severely impaired. The children showed no delayed hypersensitivity in response to various antigens. One child completely failed to reject a graft of skin from an unrelated donor; the other rejected the graft only after a long delay. Biopsies taken from lymph-node tissue showed that the deep cortical regions associated experimentally with the thymus were poorly developed and contained few lymphocytes. The humoral system, on the other hand, was intact. The infants' blood serum contained normal amounts of immunoglobulins. When antigens were injected, specific antibodies were formed quickly and in large amounts. The biopsies showed active germinal centers and normal concentrations of plasma cells.

The authors point out that the defect in children born without the thymus gland is just the reverse of what is seen in children with congenital agammaglobulinemia, who lack plasma cells and humoral immunity but show normal cellular immunity. The immune defect caused by lack of a thymus gland can apparently be remedied by a thymus transplant.

Mild Intoxicant

Marijuana is a relatively mild intoxicant that seems to affect habitual users and those who are new to the drug differently. In a neutral laboratory setting smoking a large dose had few subjective psychological effects on naïve subjects, although chronic users became "high" on the same dose. Whereas the performance of the nonusers in simple tests was somewhat impaired by the smoking, the performance of chronic users was unimpaired or even improved. None of the subjects had any dangerous adverse reactions; the effects that were observed were of short duration.

These are among the findings of the first carefully controlled attempt to study the clinical and psychological effects of smoking marijuana. The investigation was carried out at the Boston University School of Medicine by Andrew T. Weil, Norman E. Zinberg and Judith M. Nelsen, who report their results in *Science*. Their objective was not to test popular convictions about the drug or to make sociological judgments but to collect "long overdue pharmacological data" and to establish the feasibility and safety of such experimentation.

The naïve subjects, nine men between 21 and 26, were cigarette smokers who had never tried marijuana. After a trial session at which they were taught to smoke properly, they were tested in three experimental sessions, at each of which they smoked two cigarettes. The cigarettes were of three kinds: high-dose (one gram of marijuana in each), low-dose (a quarter of a gram of marijuana plus tobacco) and a placebo (tobacco). Neither the subject nor the experimenter knew which type of cigarette was supplied at each session; the odor of marijuana was masked by mint leaves in all cigarettes and by a scented spray in the room. The eight subjects who were regular smokers participated in one session at which they smoked only the high-dose cigarettes.

When asked after each session what they thought they had smoked, eight of the naïve subjects could tell the difference between marijuana and the placebo. Most of them called the high dose a low one, however, and none called the low dose high. This reflected the generally unimpressive quality of their subjective reactions: some time distortion, very little euphoria, no visual or auditory distortions or confusion. Chronic users, on the other hand, said they were almost as high as they had ever been. Marijuana increased the heart rate in both groups moderately, had no effect on respiratory rate or pupil size but did cause reddening of the eyes.

The volunteers took several tests before and after smoking. On a written test (pairing digits and symbols) and on a psychomotor test (keeping a stylus in contact with a rotating spot) the scores of naïve subjects dropped significantly more after the low dose than after the placebo, and still more after the high dose. The performance of chronic users was good before the high dose and tended to improve after smoking. The users had worried about how they would perform after smoking and were surprised at how well they did; this situation is in sharp contrast, the authors point out, to the false sense of improvement people have with some other drugs that actually impair performance. The difference between the regular users' subjective "high" and their objective performance, and the apparent absence of neurological (as opposed to psychological) symptoms, suggest to the authors that the action of marijuana may possibly be confined to higher brain functions such as thinking and mood, without either stimulating or depressing the lower brain centers that control basic reflexes and coordination.

Global Pollutant

A family of industrial compounds known as polychlorinated biphenyls, widely used as insulators in electrical devices and as extenders in plastics and surface coatings, has recently been detected in wildlife at levels approaching the concentration of DDT and related insecticides. Chemically similar to the insecticides, the biphenyls are fat-soluble and thus concentrate in the fatty tissues of fishes, birds and other animals. According to a recent article in *Nature*, "[the various] chlorinated hydrocarbons, which came into general use in the 1940's, may now be the most abundant synthetic pollutants present in the global environment."

The article discusses the hypothesis that many species of birds, notably the peregrine falcon, have suffered a decline in population because the chlorinated hydrocarbons interfere with calcium metabolism and lead to the production of eggs with thin shells. There is evidence that chlorinated hydrocarbons induce the formation of certain enzymes in the liver that destroy the female sex hormone estradiol, which in turn regulates the withdrawal of calcium from bone while the egg is developing. The levels at which this happens are far below the levels at which the compounds are regarded as being toxic.

The peregrine falcon is now extinct in the eastern U.S. In California the number of breeding peregrines has been reduced in recent years by at least 80 percent. A peregrine eggshell collected in 1968 in Lower California was 34 percent thinner than average shells collected in the same area in 1947. One unhatched and abandoned egg of a peregrine falcon found in Lower California contained nearly five milligrams of chlorinated hydrocarbons of the DDT type. It also contained about .5 milligram, or about 10 percent as much, of polychlorinated biphenyls. Farther north, around San Francisco Bay, the amount of polychlorinated biphenyls compared with DDT in the organs of peregrine falcons was found to exceed 50 percent. Presumably there is widespread dissemination of polychlorinated biphenyls in the San Francisco area because of the incineration of materials containing these compounds and the direct discharge of industrial wastes into local waters. The biphenyls, which are highly resistant to degradation, have also been found in European wildlife.

The authors of the paper in *Nature* are R. W. Risebrough and P. Reiche of the University of California at Berkeley, S. G. Herman of the University of California at Davis, D. P. Peakall of Cornell University and M. N. Kirven of the San Diego Natural History Museum.

Superconducting Hydrogen

Metallic hydrogen, a form of the element that has never been observed but is nonetheless believed to exist, may be a superconductor at elevated temperatures. This possibility was recently discussed in *Physical Review Letters* by Neil W. Ashcroft of Cornell University. The highest temperature at which any metal or alloy is known to be superconducting is about 20 degrees Kelvin (degrees Celsius above absolute zero). Applying the existing theory of superconductivity to the probable characteristics of metallic hydrogen, Ashcroft concludes that it should be a superconductor at a temperature substantially higher.

Although hydrogen is normally a gas, it is the first member of the group of elements that includes the well-known alkali metals: lithium, sodium, rubidium and cesium. Because none of the alkali metals becomes superconducting even when it is cooled nearly to absolute zero, little attention had been paid to hydrogen as a possible superconductor even in its hypothetical metallic state. The alkali metals evidently fail to become superconducting partly because their crystals do not provide a satisfactory coupling between electron waves and the waves of crystal-lattice vibrations called phonons. Ashcroft's analysis suggests, however, that in metallic hydrogen the electron-phonon coupling may be favorable.

It is believed that hydrogen is a major component of the planet Jupiter and that at some depth in the planet's interior the pressure is so great that solid molecular hydrogen is converted to solid metallic hydrogen. It is estimated that this transition takes place at a pressure of about one megabar (one million atmospheres, or about 15 million pounds per square inch). Pressures of .6 megabar have been achieved in the laboratory, making it feasible to try to create the metallic form of hydrogen. There are theoretical reasons for believing that, if metallic hydrogen can be made, it will continue to exist when the pressure is reduced to one atmosphere. If metallic hydrogen is found to be superconducting, it would not only be of great technical interest but also it might help to explain why Jupiter has a strong magnetic field even though it seems to be deficient in metals such as iron.

The Varnishing Luthier

The influence of varnish on the acoustics of the violin has been the subject of much debate. In a recent book on the celebrated luthier Antonio Stradivari, for example, it is argued that of the three categories (1) wood, (2) dimensions and construction and (3) varnish the last is the most important and the first the least. Now an amateur investigator in Asbury Park, N.J., has completed a comprehensive series of tests on the acoustical effects of violin varnish and has come to the conclusion that the acoustical virtues of varnish have been greatly exaggerated.

The amateur is John C. Schelleng, retired director of radio research at the Bell Telephone Laboratories. The results of his current work appear in *The Journal of the Acoustical Society of America*. According to Schelleng, violin varnish falls in a class of "amorphous polymers of high molecular weight below their glass-transition temperature." Like the other components in a vibrating system, varnish produces effects arising from its mass, stiffness and internal friction. The mass added by varnish to a wooden violin part is not negligible; Schelleng calculates that a layer of varnish .005 inch thick would increase the mass of a violin top plate by about 10 percent. This in itself "would cause a lowering of taptone frequencies of 5 percent, which is the larger part of a semitone and not to be casually ignored."

In contrast to the effects of mass,

which are immediate, the effects of stiffness develop gradually. When a strip of wood is varnished, the result (following an initial drop in frequency owing to the added mass) is a rise in frequency as the volatile components of the varnish evaporate. Moreover, this rise continues beyond the time when tackiness disappears and may not be complete after a long period of aging. Because the effect of stiffness eventually predominates over the effect of mass and might ultimately be a cause of concern, much of Schelleng's work has been devoted to determining the elastic modulus of various varnishes in terms of the change in the frequency of the vibrating surfaces on which the varnishes were tested.

For example, he found that the "real" elastic modulus per unit density of a film of hard varnish on a substrate of cross-grain spruce was 2.5×10^{10} centimeters squared per seconds squared after an aging period of one and a half years. In contrast, the corresponding value for a soft varnish after one year was 1.6×10^{10}. Surprisingly he found that a commercial heavy-duty floor varnish was in no way acoustically inferior to the two violin varnishes tested; its elastic modulus falls between the hard and the soft types.

Since further acoustical tests with an actual violin were, in Schelleng's words, "beset with many uncertainties owing to the complicated nature of the vibrations and the mathematically bizarre shape of the instrument," he contrived a simple "pseudofiddle" consisting of rectangular plates of spruce and maple, each having the area and approximate thickness of the violin plate and a ratio of length to width of 2 : 3 (an average ratio in the violin). With this device he conducted a variety of acoustical measurements, none of which, he points out, "confirm the popular view of violin varnish as a major contributor to acoustical excellence." Schelleng suggests to the practicing luthier that the "secret of varnish" may well be "a secret of varnishing techniques for providing adequate but not excessive protection and acceptable appearance with the least possible material."

Saved Swan

The trumpeter swan, a rare species that once numbered fewer than 100, has been declared out of danger by the Department of the Interior. The trumpeter (*Olor buccinator*) is the heaviest bird in North America; adult males may reach 30 pounds. A nonmigratory waterfowl, it once occupied a wide range in the western U.S. and Canada. The trumpeter's lumbering flight made it easy prey; hunters pursued it for feathers and flesh until 1918, when most waterfowl came under government protection in both countries. By then the bird had been hunted to the point of extinction in the U.S. In spite of more than a decade of protection, the only trumpeters left by 1932—a total of 69—were confined to the Yellowstone and Red Rock Lakes regions of Montana and the Jackson Hole area of Wyoming.

The trumpeter swan's return began with the establishment of the Red Rock National Wildlife Refuge in Montana in 1935. By 1939 an increase in numbers made it possible to start placing trumpeter colonies in other wildlife refuges. Today between 4,000 and 5,000 of the swans are found from eastern Washington and Oregon to western Minnesota and South Dakota. The Canadian population of trumpeters has reached even larger proportions, and an additional 3,000 now inhabit southeastern Alaska. The trumpeter swan thus joins the bison, the white-tailed deer and the pronghorn antelope in the ranks of North American animal species saved from extinction by conservation programs.

Gift of Wonder

The Tower of the Winds, one of the few buildings of the Hellenistic period that survive in Athens, attracts tourists because of its allegorical figures of the eight winds and because its roof reputedly bore the world's first weathervane. Joseph V. Noble of the Metropolitan Museum of Art in New York and Derek J. de Solla Price of Yale University have concluded that beyond this the tower is a monument to Greek mathematics and astronomy. In an investigation of its original functions they find that in addition to its role as a wind indicator the tower housed a remarkable 24-hour clock.

Designed and built by the Greek astronomer Andronicus of Cyrrhus in the first century B.C., the tower stands north of the Acropolis in the area that later became the Roman marketplace. Each of its eight walls served as a sundial, and a ninth dial was cut into the curved surface of a smaller tower that stood against the main tower's south wall. Water from a nearby spring kept a reservoir in the outbuilding constantly filled.

Writing in the *American Journal of Archaeology*, Noble and Price note the significance of this constant water supply. A full reservoir is the key requirement for water clocks of the inflow type. With a constant head of pressure, the flow of water from a faucet near the base of the reservoir is also constant. The faucet can be regulated so that the water flowing from it will exactly fill another tank in 24 hours, at the same time raising a float inside the tank a fixed distance. A marker attached to the float indicates the hours.

With the water clock inside and the sundials outside, visitors to the tower could learn the hour by day or night and in clear or cloudy weather. Andronicus still had to decide exactly how the clock would show the hour. Tradition required that the day be divided into 12 equal hours, even though the time between sunrise and sunset changes with the seasons. One way to solve this problem would be to make a set of hour indicators with different scales and to change the indicators every week or so. Although Andronicus could have done this, Noble and Price point to details of the building's interior that suggest the astronomer adopted a form of display more suited to the grandeur of his overall scheme.

Such a system is described in detail by Andronicus' contemporary, the Roman architect Vitruvius. The clock's float was connected by a line to a counterweight and the line passed around a horizontal shaft. As the float rose the shaft rotated, as did a circular metal plate attached to its end. The plate bore a map of the heavens; holes along the line of the ecliptic made it possible to move a representation of the sun every other day or so in duplication of its annual movement. A complete rotation of the map every 24 hours simulated the diurnal motion of the heavens. In front of the rotating disk a grid of curved reference wires presented the hours; as the sun's image passed each wire it gave the time as well as any sundial.

Noble and Price believe the interior of the tower must have been a dazzling display. They conjecture that Poseidon was a central figure behind twin fountains, and that Hercules and Atlas held the wire grid before a bright disk that slowly rotated to duplicate the movement of the constellations overhead. "We live in an era in which we accept science and technology as commonplace," Noble and Price conclude, "and we expect them and our architecture to be efficient and functional. Athens... was a place of wonder and beauty, and it was a time to marvel at the achievements of mathematicians and astronomers—a time to build and admire a Tower of the Winds."

A SERIES OF INSTRUCTIONAL FILMS

Creative glass blowing

with JAMES E. HAMMESFAHR and CLAIR L. STONG. Produced by Willard Films, Inc., in association with W. H. Freeman and Company

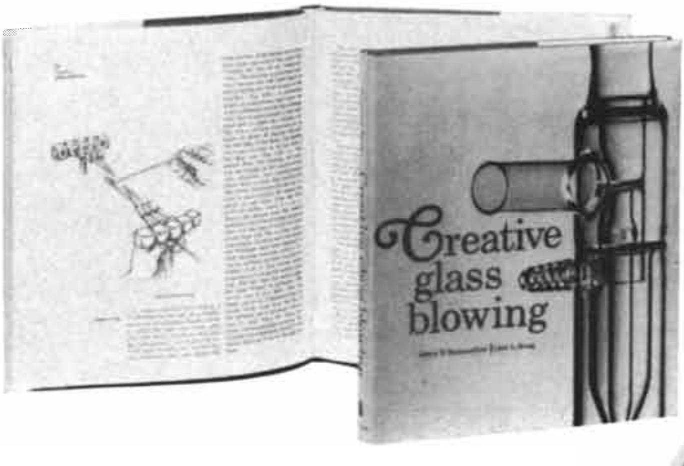
1968, five 16mm sound-and-color films, total running time 46 minutes, $100 (£42) each, $475 (£200) the set.

This series of instructional motion pictures is intended to demonstrate the basic operations of glass blowing for students, scientists, technicians, hobbyists, and others. Prepared by a descendant of a long line of professional glass blowers in collaboration with an experienced science writer who is well known to readers of SCIENTIFIC AMERICAN, the series demonstrates how to perform basic operations from rounding a sharp edge and sealing glass parts to blowing bulbs and "crocheting" with molten glass. Each technique is explained and illustrated step by step, with many close-up views of the equipment, the object being worked, and the finished product.

Useful in formal courses in glass blowing, these films will also be valuable to laboratories, businesses, clubs, and libraries. Each film is delivered in a durable case, ready for showing with 16mm projection equipment.

FILM 1: Adjustment of gas burners, and three basic operations (8½ minutes); FILM 2: Bending tubes, flaring, and pulling a point (9¾ minutes); FILM 3: Seals and constrictions (10½ minutes); FILM 4: Glass blowing (9½ minutes); FILM 5: The art of "crocheting" with molten glass. Wirework (7¾ minutes); Total running time 46 minutes.

These films were produced especially for use with the book CREATIVE GLASS BLOWING by James E. Hammesfahr and Clair L. Stong. Foreword by Charles H. Greene, State University of New York, College of Ceramics at Alfred University. 1968, 196 pages, 147 illustrations (9 plates in full color), (68-14225), $8.00 (74/-)



W. H. Freeman and Company
660 Market Street, San Francisco, California 94104
Warner House, Folkestone, Kent, England

Teaching avionic systems to get along in close quarters.

• New computerized antisubmarine system doubles previous target detection and identification capabilities • New armed helicopter flies and fires aided by fully integrated computer • Latest all-weather landing system controls planes all the way to touchdown.

Within the limited confines of airframes, Lockheed avionics experts are closely integrating increasing numbers of increasingly complex electronic systems. By thus "teaching" diverse systems to be compatible, previously impossible aircraft capabilities are becoming routine. Some brief examples follow.

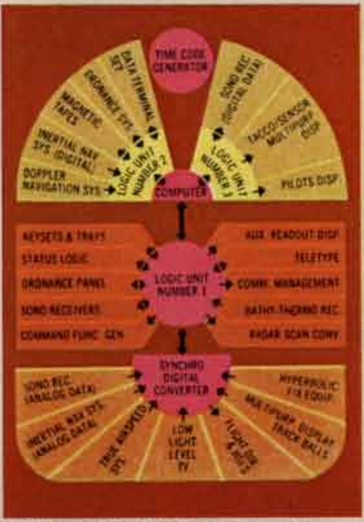
Advanced Sub Hunter. Nuclear submarines—faster, quieter and deeper-running—are becoming ever more elusive game for U.S. Navy sub-hunting aircraft. To keep ahead, Lockheed is developing the most sophisticated version yet of the P-3 Orion.

Designated P-3C, this electronics-packed plane has the first general-purpose digital computer for automatic ASW (antisubmarine warfare) data processing. Besides many subsystem improvements, other sharpened capabilities come from interfacing the computer with existing subsystems, maximizing their effectiveness. Totally, the P-3C's is the fastest, most accurate ASW tactical data retrieval, transmission and display system yet devised.

An example of the integration problems solved involves the MAD (Magnetic Anomaly Detection) gear. This

LOCKHEED
LOCKHEED AIRCRAFT CORPORATION

sensor detects aberrations in the Earth's magnetic field—such as those caused by large metal bodies. Although initial design provided the most magnetically clean tail environment possible, the gear still must operate surrounded by hundreds of magnetic fields generated by other on-board subsystems. For instance, fields are induced by transmitters. And small localized radio frequency currents generated in the plane's skin create tiny circulatory currents, inducing weak fields. Enabling the MAD gear to maintain maximum sensitivity, these disturbances are neutralized by compensation. Result: Most aircraft systems can be operated while flying MAD patterns, with confidence that any submarine in range can be detected.



P-3C, simplified ASW data flow diagram.

When all the P-3C's electronic parts are fitted together, its data processing capability is expected to more than double the present ability to detect, classify and localize targets. And the MTBF (mean time between failure) for certain systems may be 5 to 7 times greater.

Although the P-3C has about twice the P-3B's black boxes, they are condensed into the same space by miniaturization and electromagnetic interference control techniques. And next, as 1 of 2 Contract Definition contractors for the VS(X) (new Navy carrier-based ASW plane), Lockheed will equal the P-3C's avionics capability in about one-fifth the fuselage volume.

Fully Integrated Armed Compound Helicopter. The U.S. Army's winged AH-56A Cheyenne is the first production helicopter using Lockheed's Rigid Rotor and the first manned Army craft with fully integrated avionics. One gives inherent stability and superior handling; the other puts these to maximum use for battle.

The heart of Cheyenne's avionics system is a computer central complex. It includes 3 data processing units, a signal transfer unit and a digital interface unit. Integrated with it are the various subsystems. Assuring compatibility of all subsystems—the substance of avionics integration—comes through careful component interfacing.

The central complex, besides processing information related directly to sensors, navigation, control and data display, computes for the weapon system. Example: When the gunner sights a target, the computer is fed data by a laser range finder, flight velocity from a doppler radar, stabilization information from an inertial platform, plus inputs from other sensors. Then it adjusts for the weapon's ballistics using precisely stored information, aims and fires the gun with deadly accuracy.

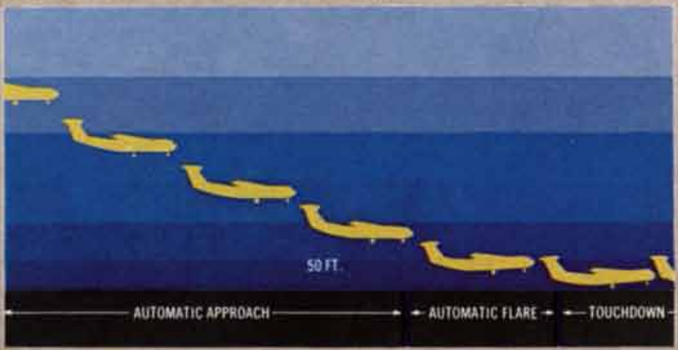
Some other Cheyenne avionics systems include: Terrain following and avoidance radar for safe automatic low-level flight. Station-keeping radar for automatic close-formation flying in any weather. And FLAWS, a Fault Location and Audio Warning System that monitors critical avionics and flight systems, beeps a warning and pinpoints malfunctions on a display panel.

Advanced avionics such as these, properly mated, will make Cheyenne one of the most effective weapons in the Army's arsenal. And, with extensive use of microelectronics, Cheyenne's avionic functions fit into one-third the space required by previous technology.

First Fully Automatic Landing System. Typical AWLS (All-Weather Landing Systems) guide a plane only to within 100 ft. or so of the runway, then return control to the pilot. Now Lockheed has developed a fully automatic system. Complete with automatic flare, it inclines the plane to touch down at the proper angle.

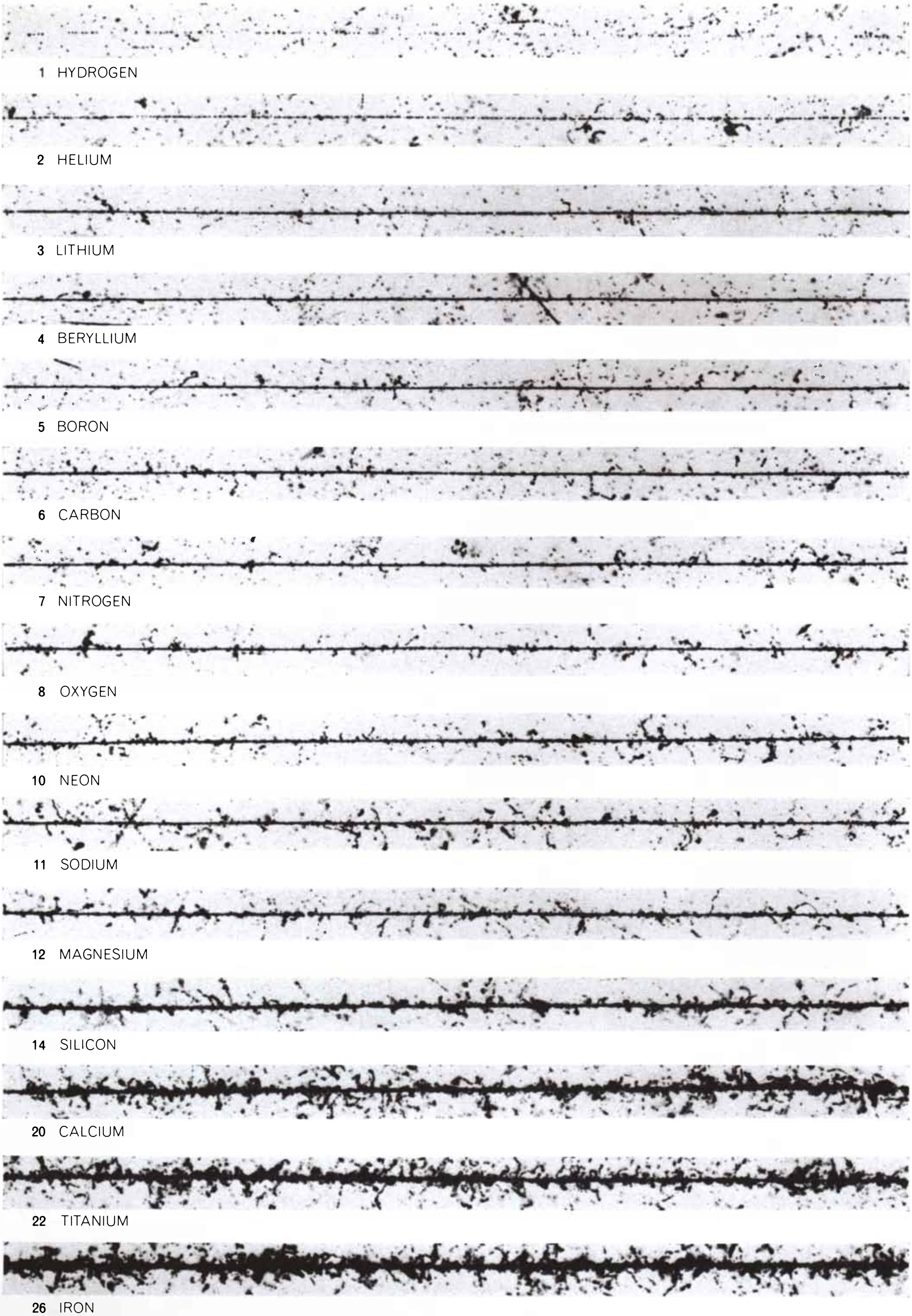
Lockheed's AWLS is completely integrated, rather than devised through the "building block" approach. Also, through microminiaturization and high-density packaging, the number of circuit components per cu. in. was increased by up to 50%. It was initially developed jointly by Lockheed, the U.S. Air Force and the FAA for use on Lockheed-built C-141 StarLifter transports. Besides automatic piloting and flare-computing, it can give the pilot an instant position fix any time, automatically control the throttle, and guide the aircraft to smooth touchdowns. If a go-around is necessary, it gives the pilot proper commands. For added safety, a test and logic computer was developed for automatic in-flight system testing, subsystem monitoring, failure warning and fail-safe disengagement of faulty components.

This AWLS is the first fully automatic military system certified by the FAA for Category II approaches (100-ft. ceiling and 1,200-ft. runway visibility), with further FAA approval to continue the approach automatically through touchdown. Demonstrating its capability, the system brings huge C-141s in for perfect landings within 300 ft. of a designated touchdown point and within 12 ft. of a runway center line. Lockheed's latest test program, recently completed, will aid the FAA in establishing equipment criteria for certification of Category III landings (near zero runway visibility).



Automatic landing sequence. Not shown in scale.

The activities mentioned here are only a few of Lockheed's current projects in avionics R&D. If you are an engineer or scientist interested in this field of work, Lockheed invites your inquiry. Write: K. R. Kiddoo, Lockheed Aircraft Corporation, Burbank, California 91503. An equal opportunity employer.


1 HYDROGEN
2 HELIUM
3 LITHIUM
4 BERYLLIUM
5 BORON
6 CARBON
7 NITROGEN
8 OXYGEN
10 NEON
11 SODIUM
12 MAGNESIUM
14 SILICON
20 CALCIUM
22 TITANIUM
26 IRON

The Astrophysics of Cosmic Rays

These energetic particles have come to be regarded (along with the stars, planets, gas and dust and electromagnetic radiation) as one of the main components of the universe

by V. L. Ginzburg

What are the main components of the universe? Fifteen years ago most astronomers would have summed them up by this list: the stars, the planets, the interstellar gas and dust and electromagnetic radiation (chiefly light). Hardly anyone would have mentioned cosmic rays. To be sure, the existence of the fast particles raining on the earth from interstellar space was well known, but there was little reason then to regard the cosmic radiation as a significant "element" in the makeup of the universe. During the past 15 years, however, we have come to recognize that the cosmic rays are indeed a weighty and energetic factor, ranking with the stars as a principal component of the cosmos.

Until 1953 study of cosmic rays was limited to observation of the particles themselves, on their arrival here at the earth. It was recognized then that these particles, traveling as they do at velocities close to the speed of light, emit electromagnetic radiation of a peculiar kind when they are deflected by magnetic fields in space. Their presence could be detected and much else about them learned from observation of this radiation. As a result the study of cosmic rays now reaches out into the universe as far as the most powerful optical and radio telescopes do.

COSMIC RAY TRACKS made by a variety of high-energy nuclei appear in the nuclear-emulsion photographs on the opposite page. The elements represented range from hydrogen to iron; preceding each element is its atomic number: the number of positive charges in its nucleus. The cosmic ray nuclei collided with the silver bromide grains in the emulsions, leaving the grains developable. The photographs were made by investigators at Bristol University in England.

In these few years we have learned that cosmic rays are truly a universal phenomenon, not only present throughout the space of the solar system, of our galaxy and of other galaxies but also associated with the life processes of stars, with supernova explosions, with radio galaxies (galaxies that are "bright" at radio wavelengths) and with quasars. They are, in fact, detectable almost everywhere in the universe within reach of our instruments. Moreover, we have found that the magnitude of this radiation is such as to make the cosmic rays a decisive factor in the energy balance and the dynamics of such systems as radio galaxies and the expanding gaseous envelope of supernovas.

Studies of the cosmic ray flux on the earth and in distant reaches of our galaxy indicate that the energy density of the cosmic rays in the system averages approximately one electron volt per cubic centimeter. This is of the same order as the average density of the energy of the magnetic field of the galaxy and of the thermal motion of the interstellar gas. The cosmic rays themselves constitute a gas of particles moving at relativistic velocities (close to the speed of light) that exerts a pressure proportional to its energy density.

It is clear, therefore, that the cosmic rays must play an important role in the dynamics of the interstellar gas. The main force in space—gravitation—loses its preeminence, since in many places the pressures of the cosmic rays and of the magnetic field are no smaller and no less important. In addition it must be reckoned that cosmic rays play a central role in solar flares, supernova explosions and the explosions of the entire central region or nucleus of galaxies that are believed to account for radio galaxies. The flux of cosmic rays produced in these events is so great that it constitutes to a considerable degree the very nature of the events.

Chemical Composition

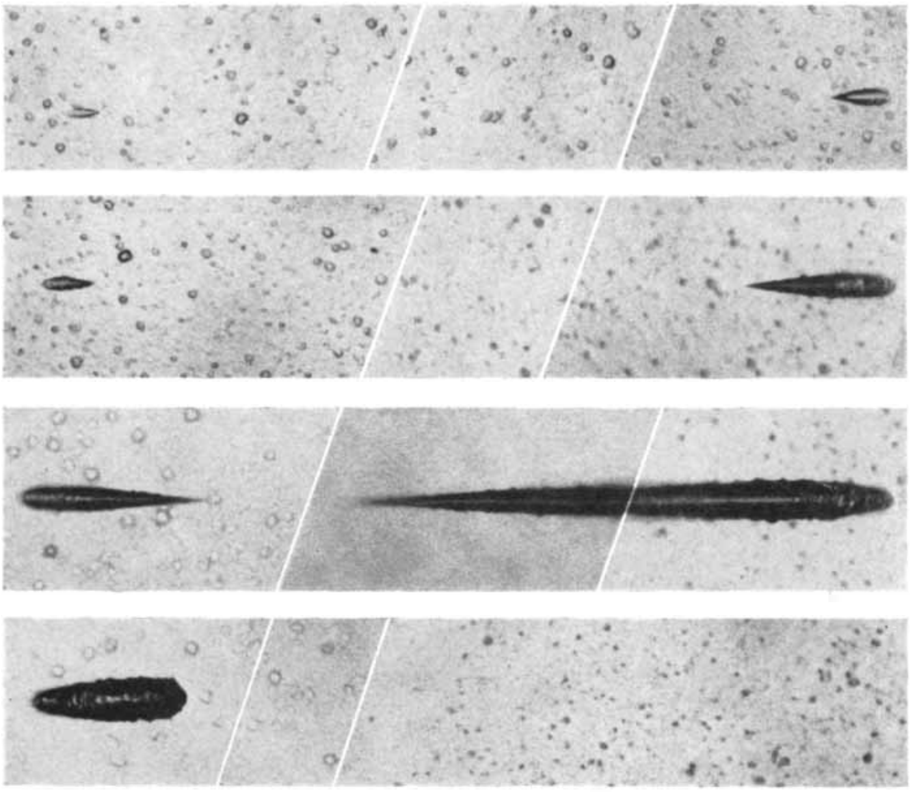
The term "cosmic ray" is a misnomer, but one with entirely creditable historical antecedents. It was reasonable 60 years ago to ascribe to some unknown radiation the discharge of an electroscope by the arrival of a charged and highly energetic particle. Although there is no universal agreement on the minimum kinetic energy a particle must have to be called a cosmic ray, I shall arbitrarily take this minimum to be 100 million electron volts. We shall consider only the primary cosmic rays, as they are observed outside the earth's atmosphere before they collide with atmospheric matter and are transformed into showers of secondary particles. In the pristine primary state they retain their elemental identity as the nuclei of this or that species of atom stripped of their electrons. Rockets and artificial satellites are now collecting information on the primaries, and no doubt the future of cosmic ray measurements will belong to these extraterrestrial observing vehicles. So far, however, most of our information has come from balloon flights, which at altitudes of 40 kilometers or more are above 99 percent of the earth's atmosphere. These missions not only obtain reliable samples of the primary rays but also bring their records back to the earth.

The fundamental measurement that interests us is the intensity, or rather the intensities, of the cosmic ray flux. We want to know not only the total intensity but also the intensities of particular components of the radiation. That is to say, we want to analyze the chemical composition and the energy distribution of the particles. The intensity is measured in terms of the number of particles traversing a square centimeter each second per unit of solid angle. This quantity should be distinguished from flux, which is measured in terms of the number of particles per square centimeter per second without regard to direction. Such a distinction is not very helpful, however, because it appears that the flux of cosmic ray particles in space is isotropic: approximately the same in all directions. The measurement of flux in any plane of orientation therefore yields a reliable estimate of intensity (provided that allowance is made for the effect of the earth's magnetic field in bending the particles' paths).

Let us consider first the chemical composition of the observed flux of cosmic rays. By far the most abundant component is hydrogen. Protons (hydrogen nuclei) account for about 90 percent of the total intensity. All but 1 percent of the balance is made up of alpha particles (helium nuclei) carrying the same energy per nucleon, that is, for each of their component protons and neutrons. To analyze the composition in more detail we must focus on a particular energy range, say particles with a total energy of more than 2.5 billion electron volts per nucleon. The total energy (E) includes the particle's kinetic energy (E_k) and its intrinsic "rest" energy, or $E = E_k + mc^2$. We do not have enough data to measure the individual intensities of all the elements heavier than helium; we usually have to consider them in groups. A table of the proportions of the various elemental groups in the primary cosmic ray flux arriving at the earth has been compiled [*see illustration on page 57*].

The first striking fact is the relative abundance of the cosmic rays in the group of three elements just beyond helium in the periodic table: lithium, beryllium and boron. These elements are comparatively rare in the earth and the stars. Yet in the cosmic rays the nuclei of this group are about equal in number to the total of all the nuclei of the elements of atomic number 10 and higher. The abundance of the three elements in the cosmic rays is roughly 100,000 times greater than their average abundance in the universe as a whole.

The nucleus of the rare isotope of helium—helium 3, which has only one neutron instead of the usual two—offers another striking case. Whereas in natural helium the ratio of helium 3 to the common isotope helium 4 is less than one to 3,000, in the cosmic rays the ratio is of the order of one to 10.



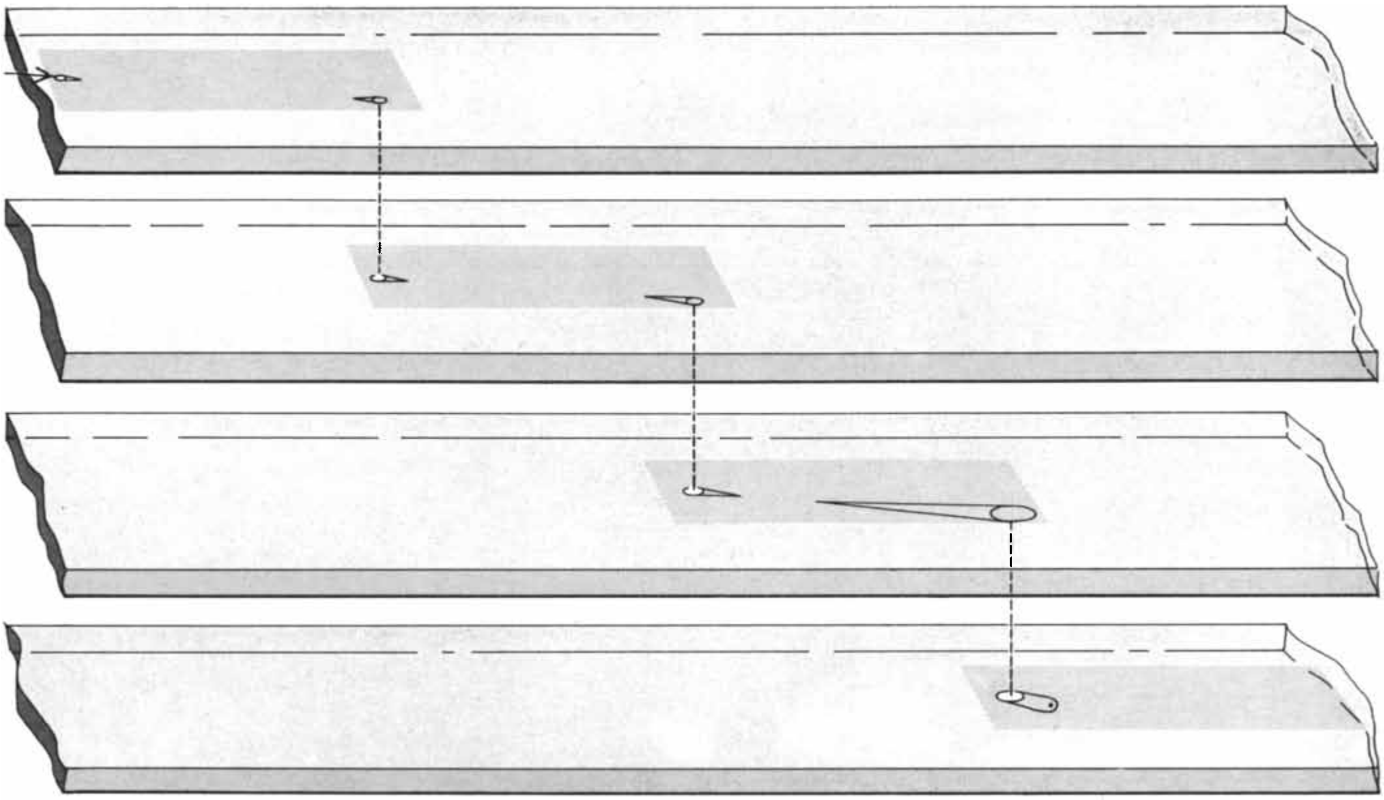
PLASTIC COSMIC RAY DETECTOR used to record the track of a low-energy calcium ion is shown in the photographs at left. The drawings at right show how the track was detected. The detector, which consists of a stack of Lexan polycarbonate sheets, each 250 microns thick, was flown by balloon above most of the earth's atmosphere. Cosmic ray particles passing through the sheets ionized atoms along their path. After the sheets were recovered they were immersed in a special etching solution, which attacked the plastic

How are we to explain the disproportionate abundance of these rare nuclei (and of others that might be mentioned) in the cosmic rays? It is not likely that the sources from which the cosmic rays originate are so disproportionately rich in the rare nuclei. This suggests the hypothesis that the cosmic rays acquire their distinctive elemental composition during their wanderings through the gas of interstellar space.

Since the high-energy particles travel through space and collide with nuclei in the interstellar gas, transmutation of the cosmic particles must be a fairly common event. Many of the collisions result in nuclear reactions that split heavy nuclei into lighter ones, including those of lithium, beryllium and boron. We know this because the probabilities of various types of nuclear transformation have been established more or less accurately by experiments in accelerators and by other evidence. Knowing these probabilities, and assuming that the original source of the cosmic rays contained no more than the average abundance of nuclei of the three elements in question, we can make a rough calculation of the "thickness" of matter the cosmic rays had to traverse to give rise to the observed number of these nuclei. Such a calculation shows that the observed skew in the distribution of elements would be occasioned by the collisions accumulated by an average particle in penetrating a cubic centimeter packed with two to four grams of matter, that is, with a density two to four times that of water.

From the computed thickness it is possible to estimate the average lifetime of the cosmic rays, defined as the time they spend wandering between their sources and their detection here on the earth. For this purpose the cubic centimeter becomes a tunnel, a square centimeter in cross section, packed with matter at the average density of matter in space and so extended across vast reaches of space. In our galaxy the density is about one atom per 100 cubic centimeters, or 2×10^{-26} gram per cubic centimeter. To accumulate a sufficient number of collisions in this thin medium, the cosmic rays must travel distances up to 2×10^{26} centimeters. At the relativistic speed of 30 billion centimeters per second they must wander for 100 to 200 million years.

This is a reasonable cosmic ray lifetime, and the figure is not confuted by other considerations. It may even find in-



along the ionized track more rapidly than elsewhere. The lengths of the resulting hollow, etched cones increase with the ionization rate of the particle. The last cone (*in bottom sheet*) has a rounded tip where the calcium nucleus came to rest. The sheets were photographed from directly above, with the camera refocused at several depths in each sheet; the resulting photographs were then assembled to form the composites shown here. This technique is particularly suitable for detecting heavily ionizing cosmic ray particles, since the chemical reactivity along the particle tracks in Lexan increases exponentially with ionization rate rather than linearly, as is the case with nuclear emulsions. The experiments were carried out by P. B. Price, R. L. Fleischer and D. D. Peterson of the General Electric Company and C. O'Ceallaigh, D. O'Sullivan and A. Thompson of the Dublin Institute for Advanced Studies.

dependent confirmation when we have learned more about the relative abundance of certain isotopes in the cosmic rays and can use the known decay time of their parent elements to design a cosmic ray clock. When measuring time by this clock, incidentally, we must allow for the slowing of time associated with relativistic motion.

The distribution of elements in the cosmic rays thus offers clues to the nature of their sources and to their longevity. In my opinion, which is not shared by all, the data are at least not in contradiction with the assumption that the relative abundance of the elements at the sources of cosmic rays is normal, nor with the conclusion that the elemental identities of these particles reflect nuclear transformations induced in the course of their wanderings through space.

The Energy Spectrum

Next we consider the energy spectrum of the cosmic rays: the relative intensities, or proportions of particles carrying various energies. In the earth's vicinity the total intensity of the cosmic rays (including all particles with a kinetic energy of at least 100 million electron volts) is about .3 particle per square centimeter. This corresponds to a concentration of only 1.5 particles per 10 billion cubic centimeters, which is 10 or 11 orders of magnitude lower than the concentration of gas molecules in the interstellar space of our galaxy. The great kinetic energy carried by the particles, however, gives the cosmic ray gas a pressure or an energy density comparable to that of the interstellar gas, as I have already noted.

Can we take the cosmic ray intensity measured near the earth as being representative of the average intensity in our galaxy? There is a good reason for deciding that we cannot. The cosmic ray flux in the solar system is considerably influenced by the "solar wind." This stream of particles from the sun drives cosmic rays of lower kinetic energy out of the system, so that many of them do not reach the earth at all. We have definite evidence of this effect. During the periods when the sun is most active, the cosmic ray intensity measured at the earth decreases noticeably; it is substantially less then than the figure I mentioned above, which applies to the time in the sun's 11-year cycle when its activity is at a minimum (as it was in 1954 and 1965). In fact, the solar wind holds down the cosmic ray intensity in the vicinity of the earth at all times. As the energy spectrum shows, the weaker or softer cosmic rays have the highest intensity; their abundance is so high they account for the major portion of the total energy density of the cosmic ray flux. It is precisely this portion of the total flux that is pushed out of the solar system. We may conclude, therefore, that the cosmic ray energy density is considerably greater—perhaps three times greater—in interstellar space.

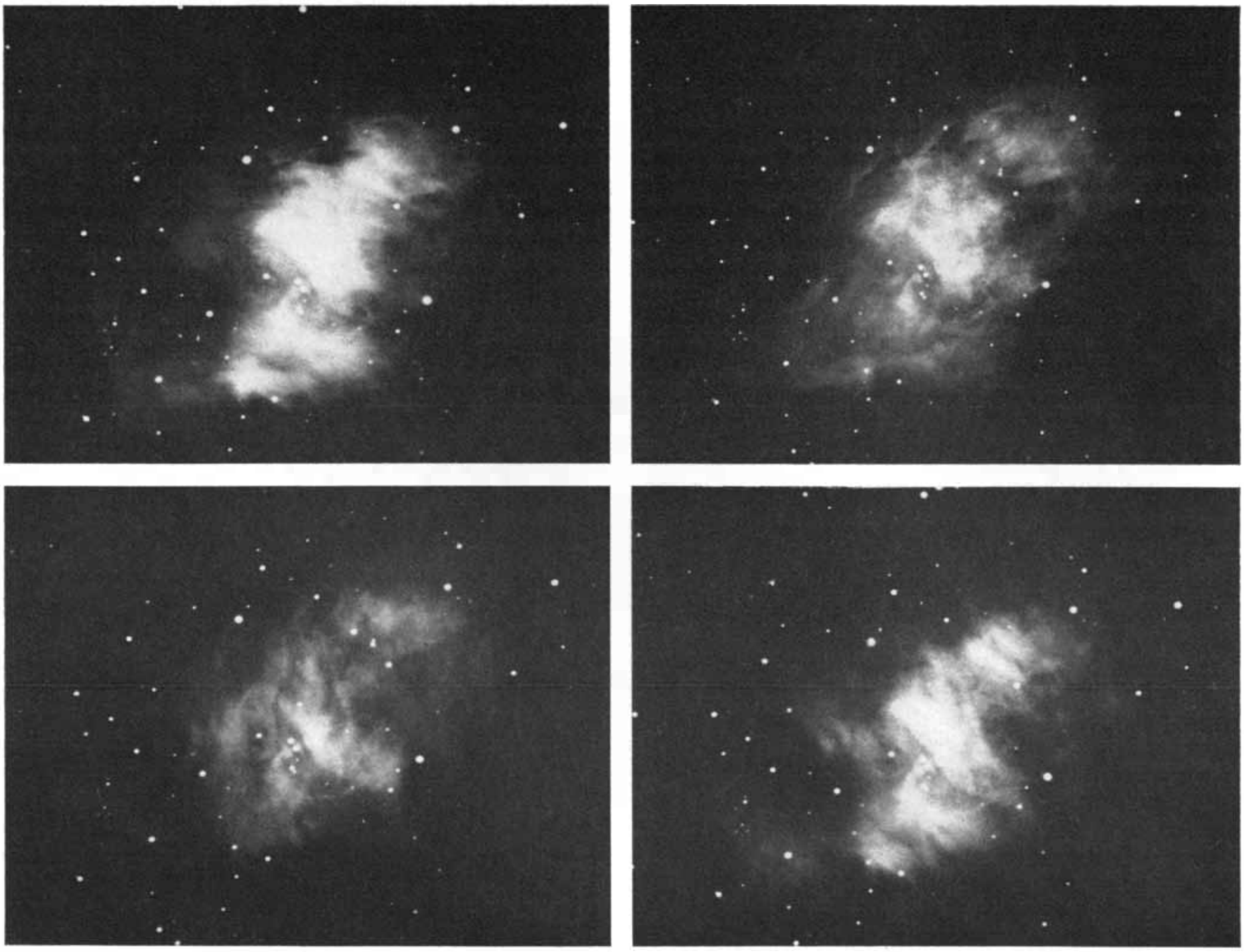
The solar wind has relatively little effect, however, on cosmic ray particles of high kinetic energy: a billion electron volts or more. We may assume that the energy spectrum of the high-energy cosmic particles near the earth is probably typical of the spectrum outside the solar system.

Considering only particles that possess a total energy (kinetic plus rest energy) of more than a billion electron volts, we find that intensity decreases as the energy increases. In other words, the number of nuclei declines at higher levels of energy. This relation is not straightforward but somewhat irregular [*see illustration on page 58*]. Analyzing the spectrum further in terms of chemical composition, we note that in the range of energies above a billion electron volts protons account for 37 percent of the total intensity, helium nuclei for 27 percent and the rest of the elements for 36 percent.

The most energetic particles (most probably protons) detected in the cosmic rays have energies of the order of 10^{20} electron volts, which is equivalent to 100 million ergs. A single proton carrying that energy could produce a flash in a small electric lamp! By way of comparison, experimental physicists have been working with particles of 3×10^{10} electron volts produced by accelerators at the Brookhaven National Laboratory in the U.S. and the European Organization for Nuclear Research (CERN) in Switzerland; the world's largest accelerator, which has just gone into operation at Serpukhov in the U.S.S.R., has attained 7×10^{10} electron volts; the first machine of the next generation (which will be at Weston, Ill.) is being designed at 2×10^{11} electron volts, and it will be a decade before accelerators reach the next order of magnitude. One can understand why physicists climb high mountains to study the cosmic rays. Only there or in balloons or artificial satellites can the properties of ultrahigh-energy particles be investigated directly.

These particles are so rare that a large detection system is necessary to capture a useful number of them. For instance, the intensity of cosmic particles with an energy of more than 10^{15} electron volts outside our atmosphere is about three particles per 10 square centimeters per day. The detection system must be not only large in area but also thick enough to stop the extremely energetic particles. Satellite vehicles designed to intercept and record ultrahigh-energy particles must be very massive; the four satellites of the "Proton" class so far launched for this purpose by the U.S.S.R. weighed up to 17 tons each. Effective results from such vehicles lie in the future. Meanwhile we must depend mainly on what we can learn about ultraenergetic cosmic particles from the showers of secondary particles they produce in the atmosphere, the secondaries being caught by very large systems of counters spread over square miles on the ground.

Study of the overall intensity of cosmic rays may uncover important clues to their place or places of origin. As I have mentioned, the flow of the cosmic rays in space outside the influence of the earth's magnetic field appears to be highly isotropic—about the same in all directions. It is not, however, perfectly so: in a direction toward the center of the galaxy the intensity of flow seems to be slightly greater (somewhat less than 1



EVIDENCE of the presence of cosmic ray electrons in the Crab nebula is contained in these four photographs, which were made with polarized-light filters in four different orientations. The polarization of the light from the Crab nebula indicates that the mechanism responsible for the light emission is synchrotron radiation, which is produced by the gyration of cosmic ray electrons in the magnetic field of the nebula (*see illustration on page 56*). According to the author's view, supernova explosions such as the one that caused the appearance of the Crab nebula in A.D. 1054 are the most probable source of almost all the cosmic radiation in our galaxy.

percent) than in other directions. The data need to be refined and verified. Even such a small anisotropy, however, would have great significance. Suffice it to say that cosmic rays produced in the galaxy must flow out of it and must therefore show a flux from the center of the system. On the other hand, if cosmic rays observed on the earth originate primarily in intergalactic space, as some workers believe, then the anisotropy should indicate a flux from the periphery of the galaxy.

Electrons and Positrons

About 1 percent of the cosmic ray particles are not nuclei but electrons and their positively charged complement, positrons. It was not until 1961 that James A. Earl of the University of Maryland established the presence of these particles among the primary cosmic rays. They have since been studied with increasing interest by groups in the U.S. (notably by Peter Meyer and his colleagues at the University of Chicago), in western Europe, in the U.S.S.R., in India and in Japan. One fact clearly established is that electrons outnumber positrons by more than 10 to one, particularly at the higher energies. Here we have a clue to the probable origin of these particles.

The cosmic ray electrons and positrons could have one of two origins: they could be launched along with protons and other nuclei from the same primary sources, or they could have a secondary origin in the collisions between the nuclei of the cosmic rays and those of the interstellar gas. In the latter case one would expect to find a predominance of positrons. Such collisions give rise to pi mesons, which decay rapidly into mu mesons, which in turn break down into electrons, positrons and neutrinos; in the ultimate debris positrons even outnumber electrons. On the other hand, the observed predominance of electrons argues that they come from the same sources as the nuclei; electrons can be expected to outnumber positrons there, and such expectation can be reversed only with the help of complicating, farfetched assumptions. Here I permit myself to recall that as early as 1963, even before the conclusive measurement of the electron-positron ratio had been made, calculations from theory by S. I. Syrovatskii and me, and by other workers in the field, had pointed to the conclusion that most of the cosmic ray electrons are truly primary in origin.

It remains a fair assumption, of course, that the positrons (and a corresponding minority of the electrons) are generated by nuclear reactions in the travels of the cosmic rays. Some preliminary data from studies of the positron energy spectrum suggest, indeed, that they are produced in the course of wanderings by the cosmic rays through the same thickness of interstellar matter as that required to explain the increased abundance of rare nuclei observed in the rays.

As in the case of the nuclear components of the cosmic rays, the electron-positron component declines in intensity with increasing energy of the particles. The curve plotted from the work at different energy levels by American, Indian, Soviet, Japanese and western European workers shows, however, a kink at the energy of two to three billion electron volts [*see illustration on page* 59]. The data must still be confirmed, and local distortion, if any, by the solar system remains to be determined. If the kink is real, then this may lead to important conclusions concerning the origin of the cosmic rays.

Radiation from Cosmic Rays

There are still many gaps in our information about the flux of cosmic rays arriving at the earth. Even when we have filled in these blank spots, however, such geocentric knowledge by itself will not tell us where the cosmic rays come from. The difficulty in the way of this effort—the Achilles heel of cosmic ray astrophysics—is the isotropy of the flux. The best evidence available, including even the demonstration of some small anisotropy, will support only indirect inferences about the sources: their location, number, strength and so on. It is as if optical astronomy were limited to study of a composite spectrum of all the celestial bodies taken together and yet were challenged to deduce the nature and history of individual stars and galaxies.

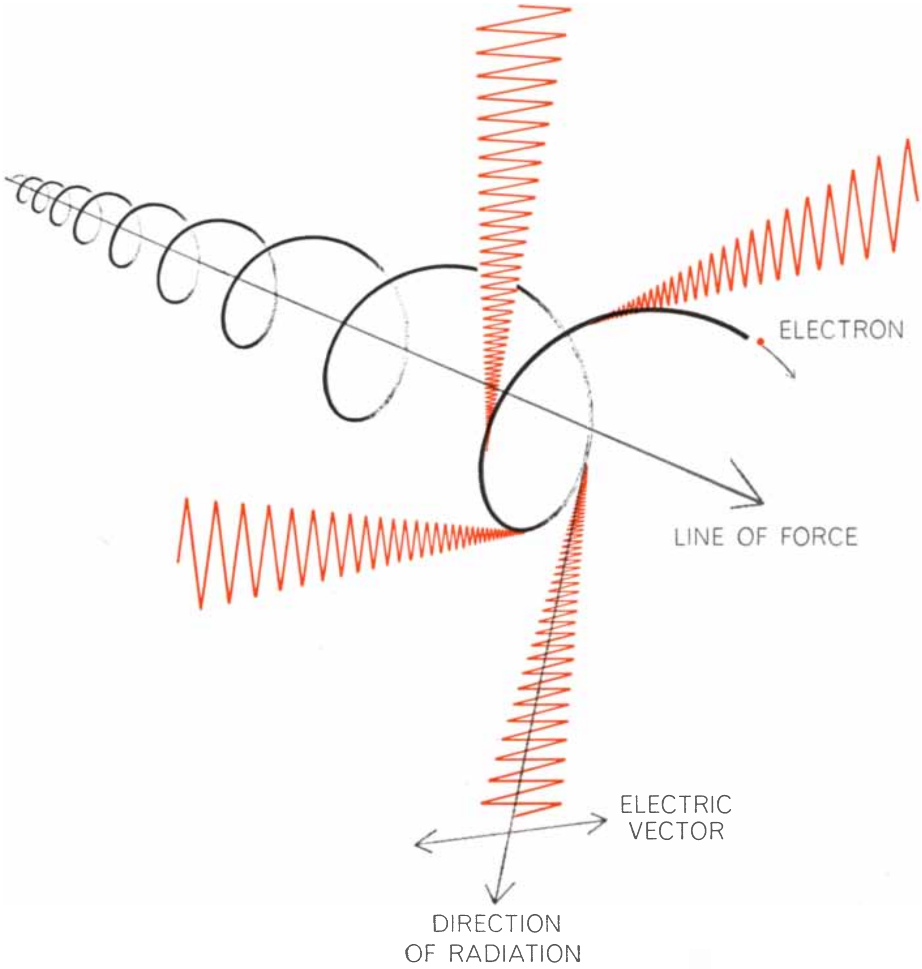
Light travels in straight lines, and the telescope yields an image of the light source. Cosmic rays, in contrast, are charged particles and travel on trajectories that are deflected in interstellar magnetic fields and are also disordered by interaction with the interstellar gas, or "plasma," of charged particles. By the time they reach the earth the cosmic rays have been caused to "forget" almost completely the direction in which they were emitted from their sources. Significant progress in the astrophysics of cosmic rays has come principally in the brief period since it became possible to obtain information about cosmic rays far from the earth in the distant reaches of our galaxy and in other galaxies.

How can earthbound astrophysicists obtain information about cosmic rays far from the earth? The asking of this question in the early 1950's brought an immediate, fruitful answer, as so often happens in the history of science. Because I was one of a number of participants in this episode (a number no longer large and bound to decrease with time) I should like to recount it here.

When powerful radio emissions were first discovered, about 20 years ago, to be coming from discrete sources in the sky, many astronomers argued that they must be emanating from "radio stars." In ignorance of contemporary developments in physics some of these astronomers turned theorist and suggested a number of farfetched mechanisms to account for the radio emissions. Several astrophysicists (Hannes Alfvén and A. N. Herlofson of Sweden, K. O. Kiepenheuer of Germany and, after them, myself in the U.S.S.R.) then came forward with an explanation in terms of a well-established and familiar (to physicists) physical process. This is the synchrotron radiation.

Charged particles—particularly electrons—produce radiation when, already traveling at relativistic velocities, they are deflected from straight-line flight and so are accelerated still closer to the limiting velocity of light. In high-energy accelerators, for example in a synchrotron, relativistic particles are driven to relativistic velocities and held in deflection on circular orbits by magnetic fields. When radiation from these particles was observed, it was found to have peculiar properties. For one thing, the radiation is practically continuous across the breadth of the electromagnetic spectrum and not limited to a discrete wavelength as the light emitted by the quantum jump of an electron bound to its atom is. This peculiar characteristic was observed also in the emissions from the radio stars. Astrophysicists accordingly proposed that these objects might be clouds of relativistic electrons—the product of violent stellar events—being deflected by magnetic fields at their source.

Not until 1953 did G. G. Getmantsev, Ya. Ye. Gordon and I persuade our astronomical colleagues to abandon the radio-star hypothesis. Later on Gordon was able to show how the synchrotron mechanism explains the continuous optical spectra of solar flares, and I. S. Shklovskii did the same for the optical emission of the Crab nebula. Another



SYNCHROTRON RADIATION is emitted by electrons spiraling along a line of force in a magnetic field. The radiation can be in the visible or radio part of the electromagnetic spectrum; the wavelength depends on the velocity of the particle and the strength of the magnetic field. Radiation produced by the synchrotron mechanism is highly polarized, with its electric vector perpendicular to the line of force and to the direction of radiation. It is important to note that although cosmic rays themselves travel on erratic paths from their sources to the earth, they generate electromagnetic radiation that propagates in straight lines. Thus it was the postulation of the synchrotron mechanism in the early 1950's that opened the way to the study of cosmic rays in the remote corners of the universe.

strong piece of evidence for the synchrotron hypothesis was the observation that the optical and radio emission from the Crab nebula is polarized; Gordon and I had suggested on theoretical grounds that observers would find this to be so.

Once it was established that radio emissions from distant sources in the galaxy could be construed as evidence of the presence of high-energy electrons under the influence of a magnetic field, it became possible to answer the question: Can cosmic rays be observed at distances far from the earth? The relativistic electrons that constitute a component of the cosmic rays are acted on by the often relatively strong magnetic fields at their source and by the weak magnetic fields in interstellar space. Under certain conditions they can be expected to give forth radio emissions that will reach the earth and signal the presence and even the intensity of cosmic rays in distant regions of our galaxy and in other galaxies.

From measurement of the intensity of the synchrotron radiation coming from a particular region it is possible to estimate the intensity of the electron component of the cosmic rays in that region. This requires, however, the making of some assumptions about the strength of the magnetic field in the region. By various methods the magnetic field in some regions of our galaxy has been shown to have an average energy density of about a trillionth of an erg per cubic centimeter. The average energy density of the cosmic rays in the galaxy, according to available measurements, appears to be of the same order. From this and various theoretical considerations it seems reasonable to assume that the energy density of cosmic rays in any region tends to be approximately equal to the density of the magnetic field. It follows that, if we can measure the intensity of synchrotron radiation from a distant region, and if we assume that the energy intensity of the relativistic electrons represents 1 percent of the total cosmic ray energy, we can make a reliable estimate of the overall cosmic ray intensity in that region.

Cosmic rays also induce the generation of electromagnetic radiation by other processes. Collisions of cosmic rays with nuclei in the interstellar gases, as I have mentioned, produce pi mesons; a percentage of these (the neutral pi mesons) decay almost instantaneously to two gamma rays. Such radiations can help to fill out the picture gained from synchrotron radiation.

Thus, although cosmic rays themselves travel on erratic paths from their sources to the earth, they generate electromagnetic radiation that propagates in straight lines. This knowledge now makes it possible to study cosmic rays in remote corners of the universe and even to isolate and identify discrete sources, much as the astronomer studies individual stars.

Cosmic Ray Sources in Our Galaxy

We are therefore in a position to consider the nature of the sources and the mechanisms that generate cosmic rays. One obvious possibility is the type of stellar explosion known as a supernova. In our galaxy a supernova explodes about once every 30 years. We see relatively few of these explosions, because the light from most of them is absorbed on its way to the earth by the interstellar dust in the galaxy. The only supernovas in recent times that were clearly visible when they occurred were the object now visible as the Crab nebula, the explosion of which was observed in 1054, the Tycho Brahe supernova observed in 1572 and the Johannes Kepler supernova observed in 1604. Additional supernovas have been detected, however, by other means. The most remarkable was an explosion in the constellation Cassiopeia, which would have been observable from the earth 250 years ago but was not discovered until 1948, when radio telescopes picked up its great emission of energy. It proved to be the "brightest" radio source in the sky in the band of wavelengths around one meter (apart from the sun, which on occasion "shines" even brighter in radio telescopes). The visible light of the Cassiopeia supernova is so faint, however, that it can barely be observed with the most powerful optical telescopes.

Supernova explosions have not yet been fully explained. Most probably the phenomenon consists in the rapid collapse of an unstable star, which possibly then degenerates into a neutron star. The collapse splashes out an appreciable part of the star's energy and mass, forming an explosively expanding envelope of particles. The envelope of the Cassiopeia supernova has a mass several times greater than the mass of the sun and is expanding with a speed of up to 7,000 or 8,000 kilometers per second. Even if the envelope had only the mass of the sun, its kinetic energy would amount to 5×10^{50} ergs, which is about 10 orders of magnitude greater than the sun's entire energy output in a year. It is no wonder that a supernova in the first weeks of its outburst can be brighter than an entire galaxy.

A supernova envelope generates powerful synchrotron radiation. The explosion must therefore give rise to some form of cosmic rays—at least relativistic electrons and probably protons and other nuclei as well. From the amount of radio energy emitted by supernovas we deduce that on the average their cosmic ray electrons have an energy in the neighborhood of 10^{48} ergs. The Crab nebula, which has been the most thoroughly studied, is known to emit synchrotron radiation and X rays (which may arise from the synchrotron effect or possibly from processes in the hot plasma). The nature of its energetic radiation gives evidence that the Crab contains electrons with energies of a trillion electron volts and more. These electrons rapidly lose their energy; it is not likely, then, that they trace their origin and energy back to the original explosion. The presence inside the nebula of a very compact source of long-wave radio emission suggests that something is left there from the explosion of the star and that this something continues to generate cosmic rays.

In addition to the supernovas such as the Crab nebula there are other sources of synchrotron radiation at radio wavelengths in our galaxy. One of these sources is the galaxy as a whole, including an "envelope" surrounding it. This entire region, wider and much thicker than the optical disk, or Milky Way, produces a general galactic radio emission that can be attributed to high-energy electrons wandering in the galactic magnetic fields. Tracing the radio emission, one can estimate that the electrons fill a "radio disk" approximately 2,500 light-years thick and 100,000 light-years in diameter. In 1952, even before the radio disk had been recognized, the Soviet astronomer S. B. Pikel'ner suggested that the Milky Way is surrounded by a roughly spherical halo filled with cosmic rays and rarefied gas. There is as yet no firm evidence for the extension of the radio disk into a spherical halo, but the arguments in its favor are strong. Cosmic rays flowing out of the plane of the galaxy would drag interstellar gas and magnetic fields with them, thus "rounding out" the system. In fact, certain relatively strong radio signals have been received from outside the radio disk. Whether these come from an extended halo around our galaxy or from intergalactic space has not yet been determined; the question may soon be resolved by more specific information on the possible variation of the intensity of the signals with frequency and direction. Meanwhile a spherical radio halo has been detected around the Great Nebula in Andromeda, the large spiral galaxy close to our own.

We receive strong radio emissions from still another source in our galaxy: the core, or central region. Rather powerful, synchrotron-generated radio signals come from that center. By observation at infrared wavelengths (which penetrate the interstellar dust) we find that the total optical radiation of the core is 20 million times greater than that of the sun. This leads to the conjecture that occasionally (perhaps once every 10 or 100 million years) the core may explode, emitting large amounts of cosmic rays, or that the core may generate cosmic rays continuously.

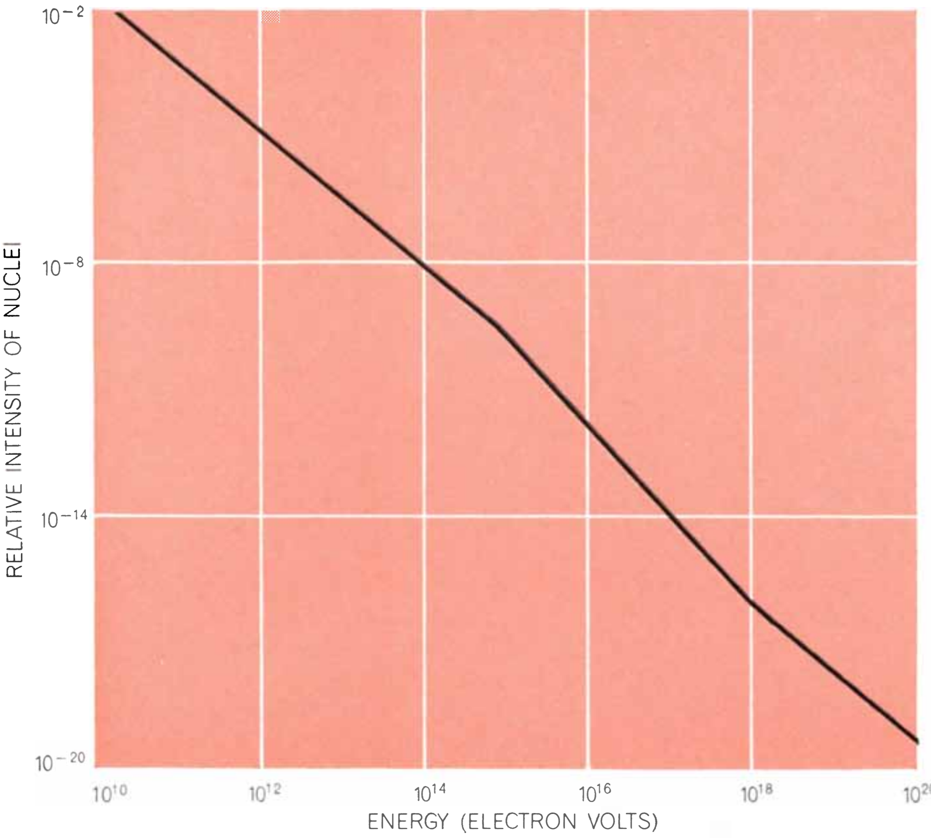
From the radiant energy generated by cosmic rays we have thus traced the particles themselves to some major sources in our galaxy and developed the general plan of their distribution in our local universe. They are certainly produced in supernovas and are possibly generated, by processes less well understood, in the galactic core. Cosmic rays fill out the radio disk and probably the larger region of the halo. In the radio disk the cosmic ray density is about the same as the density near the solar system; in the halo it is somewhat smaller.

Cosmic Rays outside the Galaxy

It would be very strange if our galaxy were the only one containing cosmic

TYPE OF NUCLEUS	ATOMIC NUMBER	RELATIVE INTENSITY	RELATIVE PREVALENCE IN COSMIC RAYS	RELATIVE PREVALENCE IN UNIVERSE
PROTONS	1	1,300	650	3,000-7,000
ALPHA PARTICLES	2	94	47	250-1,000
LIGHT NUCLEI	3-5	2	1	10^{-5}
MEDIUM NUCLEI	6-9	6.7	3.3	2.5-10
HEAVY NUCLEI	10-19	2	1	1
VERY HEAVY NUCLEI	20-29	.5	.26	.05
VERY VERY HEAVY NUCLEI	$\leqq 30$	$\sim 10^{-4}$	$\sim 10^{-4}$	$\sim 10^{-4}$

CHEMICAL COMPOSITION of the observed flux of primary cosmic rays arriving at the earth is given in this table. Not enough data are available to measure the individual intensities of all the elements heavier than helium; hence these are considered in groups according to their relative atomic weights. As the table shows, protons (hydrogen nuclei) account for about 90 percent of the total intensity. Alpha particles (helium nuclei) make up another 9 percent of the intensity, which leaves only 1 percent for all the other elements. The disproportionate abundance of certain nuclei in cosmic rays compared with their average abundance in the universe as a whole is brought about not by a disproportionate abundance of these elements at the sources of cosmic rays but rather by nuclear transformations of the cosmic ray particles induced in the course of their wanderings through space.



ENERGY SPECTRUM OF COSMIC RAY NUCLEI shows that in general the number of such nuclei detected on the earth decreases as the energy increases. In the range of energies lower than about 10^{14} electron volts protons account for 37 percent of the total intensity, helium nuclei for 27 percent and the rest of the elements for 36 percent. The irregularities in the slope may reflect a number of different mechanisms of generation.

rays. In fact, if we take radio emission to be a sign of the presence of cosmic rays, there is definite evidence not only that these rays exist in other galaxies but also that they are much more prominent in some of those galaxies than they are in our own.

The "normal" galaxies (the class to which ours belongs) generally show a radio luminosity that is considerably smaller than their optical luminosity. The radio output of our galaxy, for example, is some 3×10^{38} ergs per second, which is hundreds of thousands of times less than its output in the visible band. On the other hand, there are galaxies that radiate more strongly in the radio band than in the optical band. One of the brightest radio galaxies, known as Cygnus A, is five times brighter in radio emission than in optical emission. All the radio galaxies are of the optically bright elliptical type, which sets them apart physically from spiral galaxies such as ours. The bright elliptical galaxies number only one in 1,000 in the total population of galaxies. They are correspondingly spaced out thinly in the heavens (some 60 million light-years apart on the average).

The cosmic rays of the radio galaxies embody fantastic amounts of energy. The total energy of the cosmic rays filling the space of the radio galaxy Cygnus A, for example, is in the neighborhood of 10^{61} ergs, which is seven orders of magnitude greater than the energy of the sun's rest mass! Since elliptical galaxies rotate very slowly compared with spiral systems such as our own, it seems that their transformation into radio galaxies can be attributed to the gradual accumulation of huge masses of material at their core. Presumably this accumulation passes some critical point and the core is collapsed by gravitational forces and explodes. It is likely that magnetic fields also play an important role in the collapse and in the formation of cosmic rays.

In addition to the radio galaxies, it seems clear that the recently discovered objects called quasars must be recognized as another powerful source of cosmic rays. The quasars, whose nature surely presents one of the most interesting and important problems in astronomy, are prodigious emitters of radio energy. I shall not attempt to discuss here the details of the much argued question of whether the quasars are nearby (perhaps having been ejected from the core of our own galaxy) or are objects receding from us at very great, or "cosmological," velocities and distances [see "The Problem of the Quasi-stellar Objects," by Geoffrey Burbidge and Fred Hoyle; SCIENTIFIC AMERICAN, December, 1966]. My own view is that the arguments for the hypothesis that they lie near our galaxy are farfetched and physically unlikely, at least on the basis of our present knowledge. It seems to me that the argument for the quasars' remoteness is on firm ground. Their large red shifts, for example, must be taken as evidence of large recession velocities. Not one of the approximately 100 so far observed shows a shift toward the violet that would indicate motion toward us; this would be expected of at least one out of 100, if they were local objects. If the quasars are indeed remote objects, most likely they are either compact collections of stars or unstable superstars—bare nuclei of galaxies, so to speak—with a mass some 100 million times greater than the mass of the sun and with strong magnetic fields.

For our purposes it is sufficient to note that the radio emission from quasars and at least part of the intense optical emission must be essentially of synchrotron origin. If the quasars are very distant, it must also be supposed their number in the universe is small, and this assumption has a bearing on the problem of the density of cosmic rays in intergalactic space.

One can plausibly assume that cosmic rays leak into intergalactic space from the various galactic sources: normal galaxies, radio galaxies and quasars. How much cosmic radiation might such sources deliver to outer space? Estimates suggest that at most the total delivery could not exceed an amount that would give intergalactic space a cosmic ray energy density of about 10^{-15} erg per cubic centimeter, which is about a thousandth of the density of cosmic rays within our galaxy. Some investigators believe the intergalactic density might be considerably greater than this estimate. It is therefore important to try to obtain a direct measure of the cosmic ray intensity in intergalactic space.

The magnetic field in intergalactic space is too weak to deflect relativistic electrons and so generate a detectable amount of synchrotron radiation. Fortunately, however, there are processes that might give rise to X rays and gamma rays, signaling the presence of cosmic rays.

In 1965 Arno A. Penzias and Robert W. Wilson of the Bell Telephone Laboratories discovered that the space of the universe is bathed with a diffuse radiation that is assumed to persist following the "big bang" expansion of the universe from an original fireball [see "The Primeval Fireball," by P. J. E. Peebles and David T. Wilkinson; SCIENTIFIC AMERICAN, June, 1967]. This radiation fills intergalactic space and has a thermal spectrum with a temperature of 2.7 degrees Kelvin. The photons, or quanta of electromagnetic radiation, at this temperature have an average energy of 6×10^{-4} electron volt (which means they have a wavelength in the millimeter band). Relativistic electrons moving in such a field would generate X rays. Recently X radiation has indeed been detected from intergalactic space, and it turns out that this radiation has a diffuse component that arrives uniformly from all directions. Assuming that it is generated by the cosmic ray electrons, the intensity of the radiation provides a basis for estimating the intensity of the electron component of the intergalactic cosmic rays. That intensity turns out to be not more than a thousandth of the intensity of the cosmic ray electrons in our galaxy. This is in good agreement with the estimate based on the possible rate of delivery of cosmic rays from galactic sources.

The thermal intergalactic radiation interacts not only with the electrons in cosmic radiation but also with the protons and heavier nuclei. In the relativistic coordinate frame in which these particles—with energies of 10^{20} electron volts or higher—are at rest the photons of the thermal radiation appear as rather hard gamma rays. Through photodisintegration the nuclei break down to pi mesons. Both experimental and theoretical knowledge of these processes indicate that neither protons nor other nuclei can reach the earth from the remote and relatively empty depths of intergalactic space. This statement will be subject to verification soon, when apparatus capable of registering extensive showers of particles generated in the earth's atmosphere by particles with an energy greater than 10^{20} electron volts is put into operation in Australia.

The space outside galaxies of course is filled with optical radiation from stars. This starlight has an energy density close to 10^{-14} erg per cubic centimeter. There is also a certain amount of gas (almost completely ionized); a tentative but still far from verified estimate suggests that the concentration of the gas may amount to several atoms per million cubic centimeters. The interaction of cosmic rays with optical radiation and gas produces gamma rays. Gamma ray counters flown on satellites may open this window onto intergalactic space.

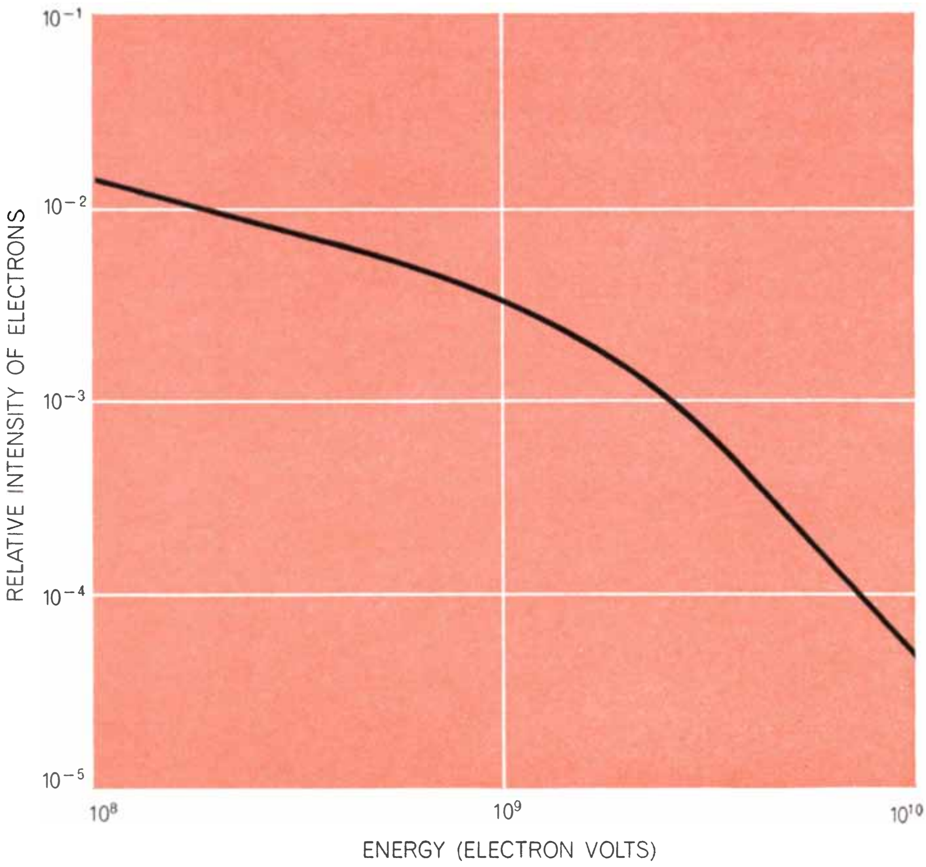
Models of the Origin

Having established the ubiquity of cosmic rays and even identified some sources, we come now to the question of origin. Where and by what processes are cosmic rays generated? How are they accelerated in the galaxy and beyond its limits? What volume do they fill?

These questions are presented, in the first instance, with respect to the sample of the cosmic rays we observe on the earth. To make the sample more representative we shall ignore the relatively soft component of the radiation traceable to the sun. We shall also ignore the particles of ultrahigh energy (above 10^{18} electron volts). We are concerned with the history of the main bulk of the cosmic ray particles that constitute one of the principal features of the cosmos as we now know it. Fortunately it is possible to reconstruct much of the cosmic rays' history without full understanding of the processes from which they spring. In the same way one can calculate the trajectory of a shell from its velocity at the muzzle of the gun, without knowing the manner in which it may have been accelerated in the barrel.

Several models, or hypotheses, of the origin of the cosmic rays observed on the earth are under serious consideration today. They can be divided into two basic categories: those that maintain the cosmic rays are produced in our galaxy and those that argue they come into our galaxy from outside. Before discussing the models I should state my own position. From 1953 to this day I have believed the most probable is the "quasi-stationary galactic model with halo," which I shall describe below. It cannot yet, however, be regarded as proved, and the alternatives deserve full discussion.

Any model proposing that the cosmic ray flux we observe comes from outside the galaxy must assume that the intensity of cosmic rays outside is at least as high as that within the galaxy. The water level in a pool fed from a lake cannot be higher than the level in the lake unless it is boosted by a pump. As far as we know there is no pump effective enough to drive cosmic rays into our galaxy from the space outside. It is almost equally



ENERGY SPECTRUM OF COSMIC RAY ELECTRONS also shows a decline in intensity with increasing energy of the particles. In this curve, however, a kink has been discovered at an energy of two to three billion electron volts. If the kink is shown by further measurements to be real, it may lead to important conclusions about the origin of the cosmic rays.

difficult to show how all of intergalactic space, out to billions of light-years from our galaxy, could be filled with cosmic rays at an energy density about equal to the energy density in the galaxy (about 10^{-12} erg per cubic centimeter). The known sources (galaxies, radio galaxies and quasars) could not begin to furnish the necessary supply, nor could such a huge population of high-energy particles persist in space from the early coalescence of matter into galaxies eight billion or more years ago. The input of cosmic rays into the vast volume of intergalactic space from all the present known sources is estimated to supply no more than a thousandth of the amount that would be necessary to maintain a cosmic ray intensity equal to the intensity in our galaxy. In any case, there can be little doubt that intergalactic space contains few electrons of cosmic ray energy, because relativistic electrons lose their energy by interaction with the thermal radiation. Consequently we must assume that the high-energy electrons in the cosmic radiation within our galaxy come not from intergalactic space but from within the galaxy. To maintain the extragalactic model thus requires the complicating assumption that the components of the cosmic rays in our galaxy come from different sources—the electrons from within the galaxy and the nuclei from outside.

Other models propose that the cosmic rays come to us from some localized source outside our galaxy comparatively close to us, such as Centaurus A, the nearest radio galaxy (10 million light-years away). The case for these models is improved by the higher probability that relativistic electrons could reach us, but they are open to the same objections concerning energy balance as the models are that picture delivery from intergalactic space in general.

All in all, the models proposing that our galaxy's content of cosmic rays comes from outside suffer from the defect that there is no direct observational evidence whatever in favor of them. The absence of demonstrated evidence for a scientific hypothesis is generally taken as very weighty testimony against it. Nevertheless, in astronomy one must proceed with caution and with respect for the ingenuity of the theorist. As long as a hypothesis has not been proved false it can be discussed.

A Galactic Model

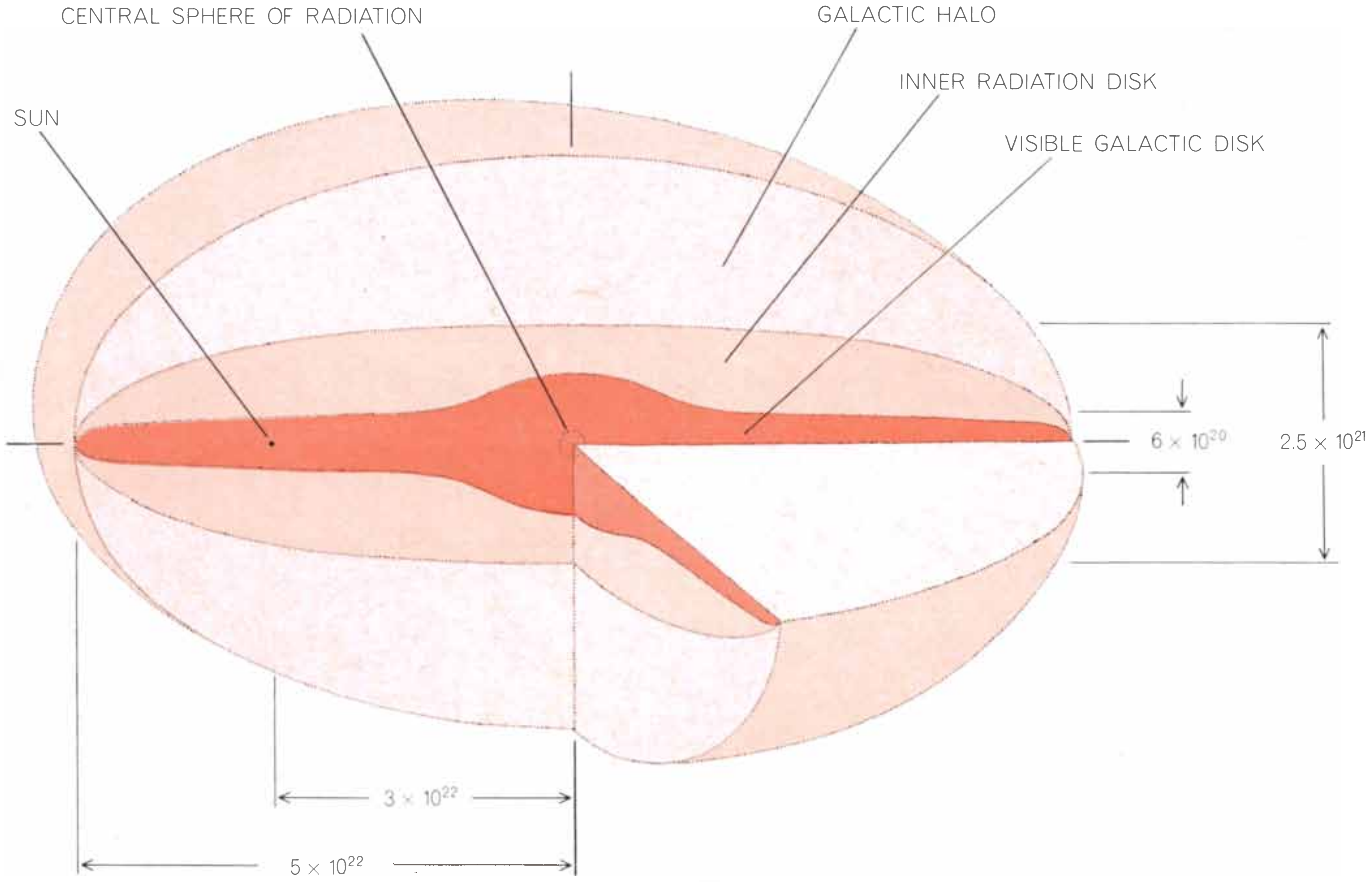
Let us consider now the model that seems to me the one best supported by the available evidence. This model argues that the cosmic rays filling our galaxy are produced within the galaxy and that they more or less uniformly pervade not only the stellar disk but also the radio disk and the extended halo. The supernova explosion is postulated as the principal source of the cosmic rays; such explosions would maintain the flux in a steady state, or more precisely in a quasi-stationary state, through intermittent replenishment, making up for cosmic rays that disappear by degeneration of their energy and by escape from the galaxy.

What rate of replenishment is required? Assuming that the galaxy and its halo roughly constitute a sphere with a radius of between 3×10^{22} and 5×10^{22} centimeters, the total volume is approximately 10^{68} cubic centimeters. Since the observed average density of cosmic rays in the galaxy appears to be about 10^{-12} erg per cubic centimeter, this means that the total energy of the cosmic rays in the system amounts to about 10^{56} ergs. We have noted that the typical lifetime of a cosmic ray in the system is estimated to be a few hundred million years—approximately 10^{16} seconds. Consequently to maintain the total energy at 10^{56} ergs fresh cosmic rays must be supplied at the rate of about 10^{40} ergs per second.

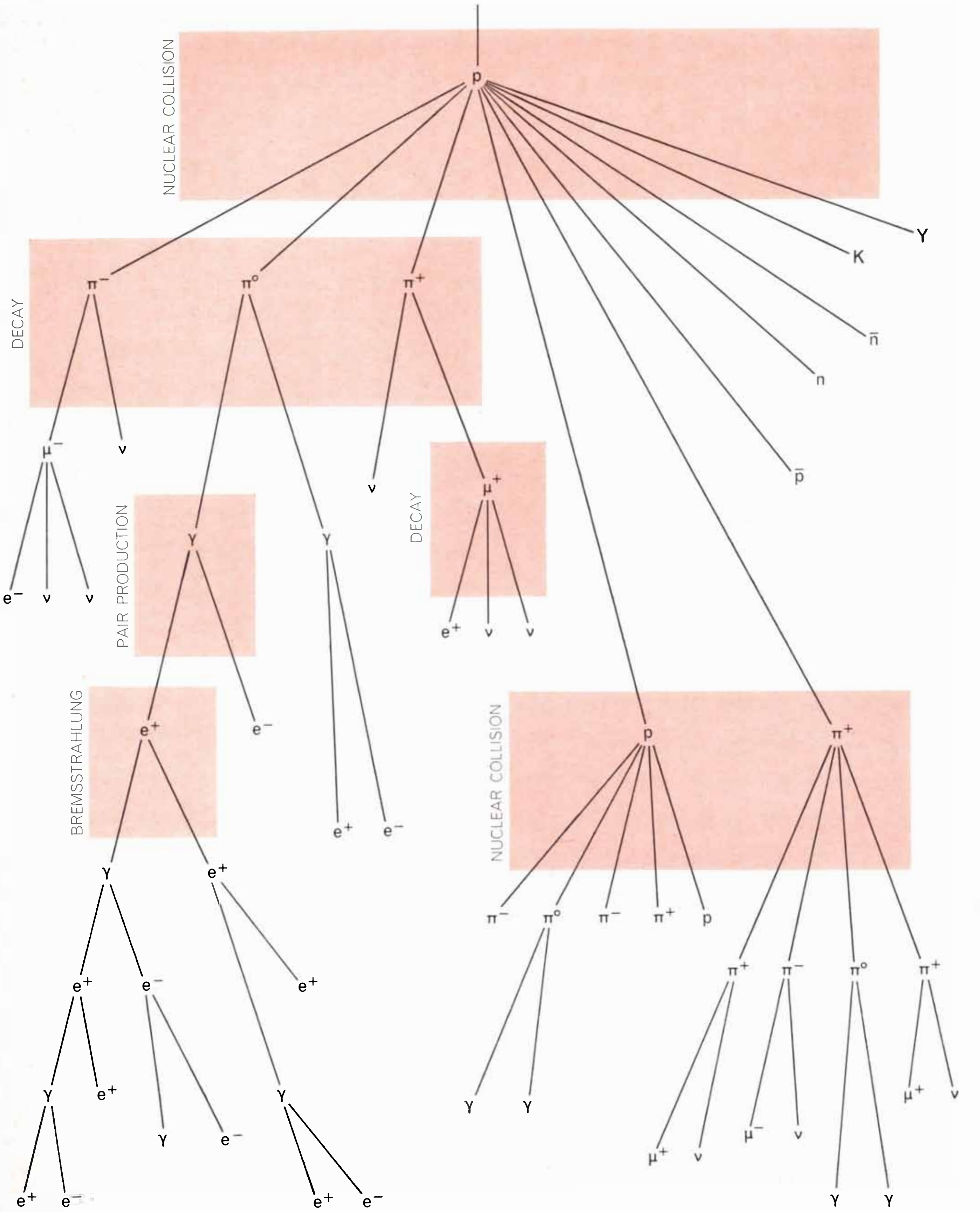
Could a cosmic ray output of this order of magnitude be maintained by the ordinary (nonexploding) stars of the galaxy? If all the several hundred billions of stars in our system generated cosmic rays at the same rate as the sun (about 10^{24} ergs per second), the total production would be only about 10^{35} to 10^{36} ergs per second. Compared with the required 10^{40} ergs per second this is too small by four or five orders of magnitude. Some stars, to be sure, are much more active than the sun, but there are not a great number of these and they could not raise the total cosmic ray output to the necessary level. Furthermore, the cosmic rays from the sun are significantly different from the typical cosmic ray flux in the galaxy in chemical composition and in energy spectrum.

How much cosmic ray production might be expected from explosions of the galaxy's core? Such explosions, if they occur, cannot be very powerful; if they were, our galaxy would be a radio galaxy. Still, comparatively small-scale explosions of the core, taking place every few tens of millions of years, might sustain a cosmic ray production corresponding to the steady rate of 10^{40} ergs per second. The difficulty with this supposition is that the relativistic electrons in the cosmic rays would not survive as high-energy particles over the intervals between explosions. As we have seen, the presence of relativistic electrons in the cosmic radiation is a touchstone by which we detect and measure this radiation in regions of the galaxy far from the earth.

Thus we must fall back on the supernovas as the most probable source of most of the cosmic radiation in our galaxy. Each supernova explosion produces an estimated release of 10^{51} to 10^{53} ergs of energy on the average, and it is estimated that about 10^{49} ergs of this is converted into cosmic rays. Since supernova explosions in the galaxy occur on the average about every 30 years (10^9 seconds), the estimates lead to the conclusion that they can produce cosmic rays



MODEL OF THE GALAXY currently favored by astrophysicists includes, in addition to the visible disk, or Milky Way, a much broader "radio disk" that produces a general galactic radio emission attributable to high-energy electrons, and also a roughly spherical "halo" filled with cosmic rays and rarefied gas. Powerful, synchrotron-generated radio emissions from the core, or central region, of the galaxy have given rise to the conjecture that the core occasionally explodes, emitting large amounts of cosmic rays, or that it generates cosmic rays continuously. Radio data also suggest that in the radio disk the cosmic ray density is about the same as the density near the solar system, whereas in the halo the density is probably a little smaller. Dimensions are indicated in centimeters.



COSMIC RAY SHOWER develops in the earth's atmosphere as a result of a collision of a primary cosmic ray particle, usually a proton, with an oxygen or nitrogen nucleus (*top*). The products of the initial collision include neutrons (*n*), protons (*p*), neutral pi mesons (π^0), charged pi mesons (π^+ and π^-), antiprotons and antineutrons ($\bar{p}$ and $\bar{n}$), heavy mesons (*K*) and hyperons (*Y*). Neutral pi mesons decay to gamma rays (γ), which in turn materialize into positive and negative electrons (e^+ and e^-). Charged mesons may strike other atmospheric nuclei or decay into mu mesons (μ^+ and μ^-) and neutrinos (ν). Electrons passing through the local electric fields of atmospheric nuclei radiate part of their energy into gamma rays in the process known as bremsstrahlung.

on a continuing basis at the rate of 10^{40} ergs per second. This is precisely the order of magnitude required. Of course, no special significance should be attached to such precision of agreement between estimates; one of the laws of cosmic physics is expressed by the equation $1 = 10$. Nonetheless, the supernovas must be regarded as leading candidates for the honor of being the main source of galactic cosmic rays.

In principle, the much smaller explosions called novas may also make a contribution to the cosmic radiation. Novas occur several thousand times more frequently than supernovas. No radio emission has been observed from them, however, so that it is probable their production of cosmic rays is small.

Other intragalactic models have been proposed. One suggests that the cosmic rays were generated in a single large explosion of the galactic core at some time in the past. This model encounters several objections, in particular the fact of the continuing presence of relativistic electrons. Another model holds that the cosmic rays fill only the radio disk, denying the existence of a larger halo. In that case we must assume that the cosmic particles have a shorter lifetime than they would in the extensive halo, and this leads to difficulties in explaining the required rate of generation and other problems.

The model I have described as being the most likely does not, I am convinced, involve any serious difficulties or contradictions with existing evidence. Nevertheless, it still lacks confirming evidence. Needed at this point is some direct indication that the postulated halo does indeed exist and some definite sign that protons and other nuclei, as well as electrons, are accelerated to cosmic ray velocities in supernova explosions.

As for the volume of space occupied by cosmic rays, this may soon be resolved by radio observations. It will be much more difficult to find evidence of the presence of cosmic ray nuclei in the supernova explosions. There is no synchrotron effect by which they can be detected. Certain possibilities are nonetheless being explored. For example, cosmic ray nuclei may produce neutral pions in a supernova envelope, and this event could be identified by observing the decay of the pions.

The Question of Acceleration

The question of how the cosmic rays are accelerated would make an article in itself—and would come to no conclusion in the present state of knowledge. I shall venture only a few remarks on the subject here. The key to the eventual answer undoubtedly lies in the fact that nearly all matter in space—from atoms to entire stars—is ionized. The particles in space thus constitute a plasma. Highly mobile and continuously in motion, this cosmic plasma generates electric fields, electric currents (the cosmic plasma has tremendous conductivity) and magnetic fields, whose motion in turn also induces electric fields. It is therefore clear that in the conditions of the cosmos the acceleration of particles is a perfectly normal and universal phenomenon.

Only a very small fraction of the particles are accelerated to the extremely high energies of cosmic rays. This separation of the cosmic rays from the rest of the galactic gas comes about through a statistical mechanism of a kind first proposed by Enrico Fermi in 1949. Most of the particles, moving about in the weak, random fields, are alternately accelerated and decelerated and consequently do not reach high energies. A "lucky" few (even fewer than the lucky people who win at roulette!) happen to fall in with a moving field and, if they remain in phase with the field long enough, are raised to colossal energies.

Particles may be accelerated to cosmic ray velocities by processes occurring in the life cycle of stars. My colleague Syrovatskii has pointed out that when the configuration of certain magnetic fields is changed—for example the field in the region of a pair of sunspots—an entire layer of plasma can be accelerated. Particle acceleration is possible also on the fronts of powerful shock waves propagating from the central region of a star to its surface, as was proposed in 1960 by Stirling A. Colgate and M. H. Johnson at the Lawrence Radiation Laboratory of the University of California.

This still leaves us with the task of describing what happens in a supernova explosion. Choice of the correct model of the explosion and the primary acceleration of the particles would be facilitated by study of their chemical composition and of their energy spectrum.

Analysis of the behavior of the plasma in space does help to explain the isotropy of the cosmic rays. I have already mentioned the effect of the diverse fields in space in randomizing the directions of the particles as they wander through the medium. There is another mechanism of randomizing that is inherent in the plasma itself. The movement of a beam of particles through a plasma generates waves that within a short time (cosmologically speaking) spread out the beam. Hence the beam becomes unstable and soon loses its integrity. This mechanism alone guarantees that the cosmic rays, however directional they may be at their origin, will eventually become practically isotropic almost everywhere.

A Question of Time

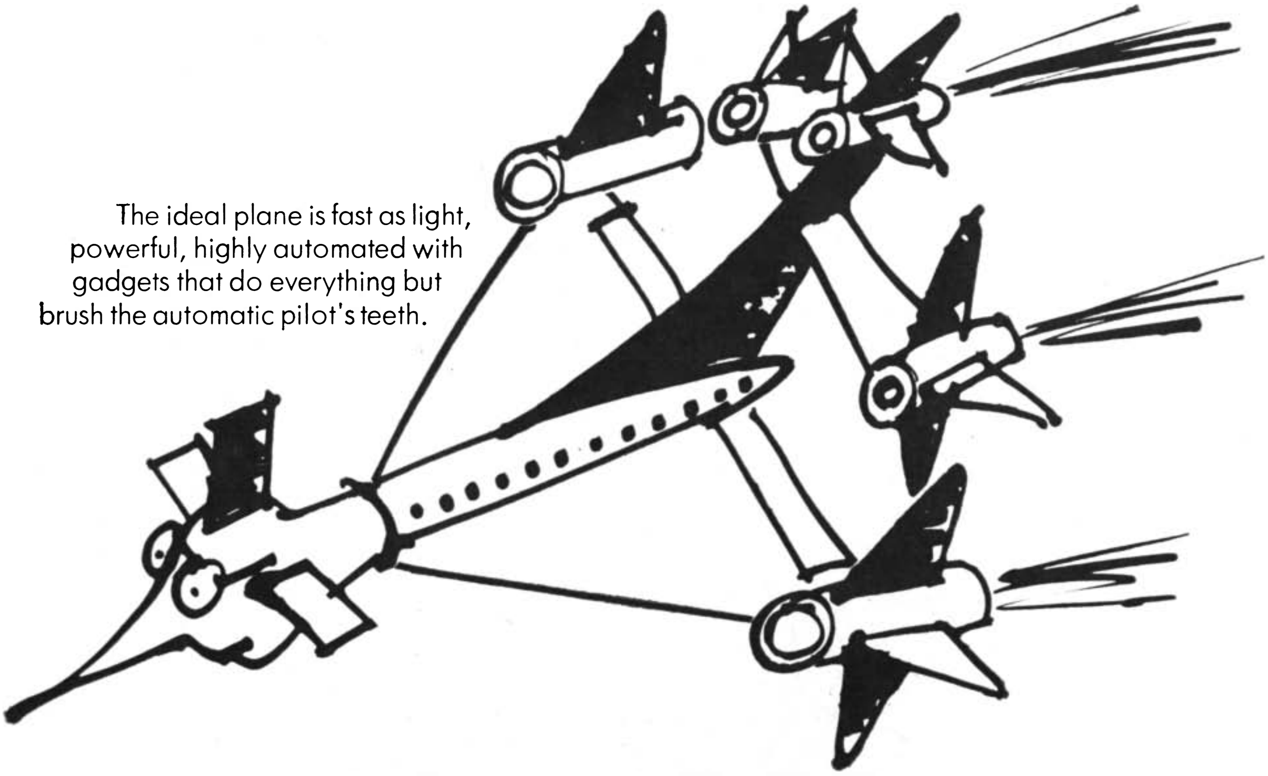
In seeking to arrive at a satisfactory model of the origin of cosmic rays we are of course severely handicapped by the remoteness of the sources that hold the answers to the problem. It is disappointing that in 15 years of work we have not yet been able to obtain a convincing check, pro or con, on the validity of the galactic model I have put forward in this article. The difficulty lies not in the model but in the lack of means for acquiring the necessary information. Indeed, the paucity of firm information on matters cosmological fosters a temptation to propose spectacularly new, but not necessarily plausible, hypotheses. The fact that radical ideas such as the creation of new matter out of nothing or the ejection of quasars from galactic cores are extensively discussed in the scientific literature and at conferences is a reflection of the present state of astronomy, characterized by a general uncertainty with respect to a number of fundamental questions.

The situation is changing, however. New techniques are being developed and new channels for acquiring information are opening up. It seems to me that very soon the area of astronomy in which one can recklessly give rein to fantasy will be moved back by millions of light-years.

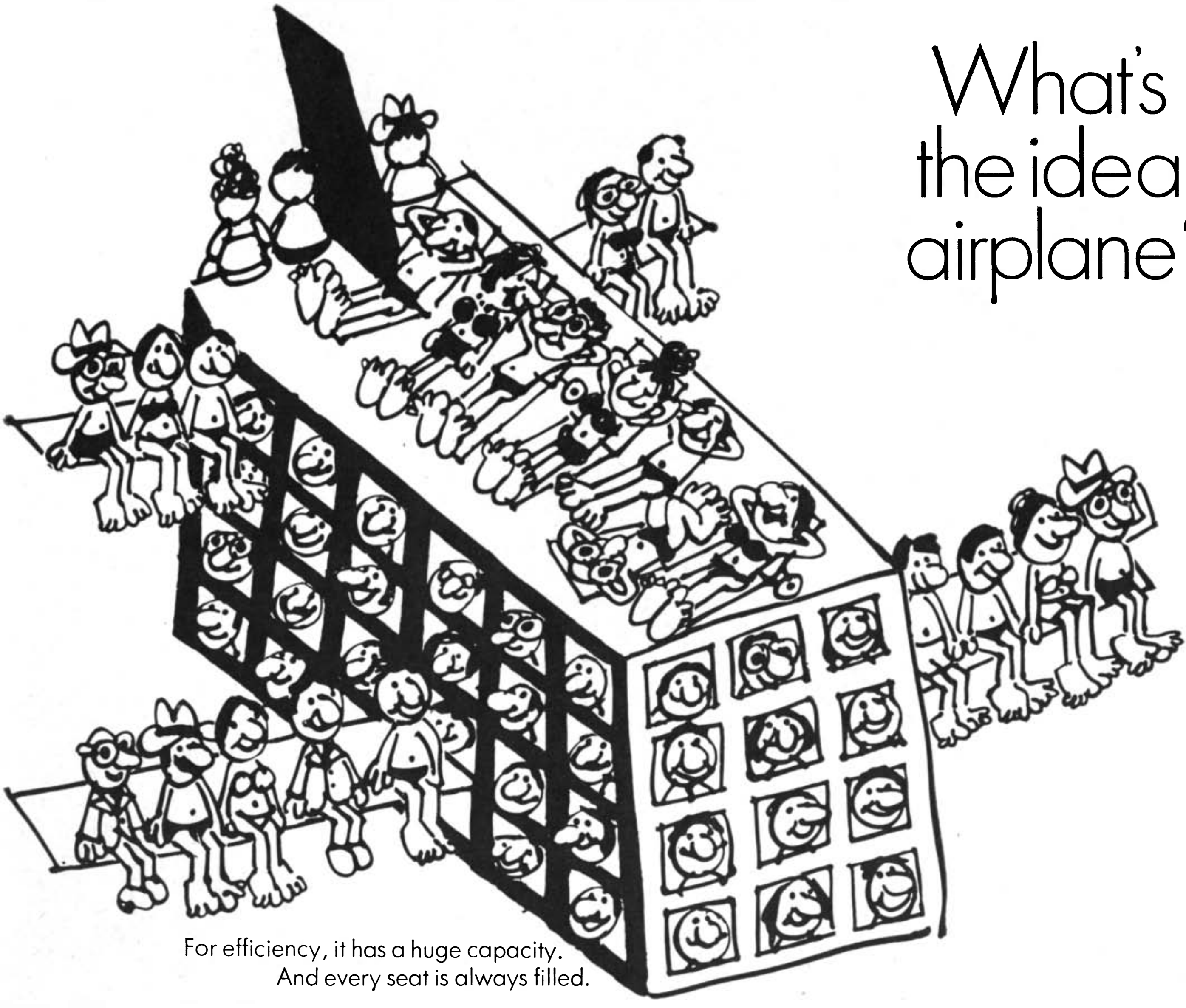
As for the problem of the origin of the cosmic rays, I believe a modest amount of progress in the acquisition of new evidence will suffice to provide a verdict on the model. These needs are: determination of the age of the cosmic rays near the earth from radioactive isotopes, more precise measurement of the energy spectrum of the electron component, clarification of the direction of the slight anisotropy in the galaxy, determination of the shape and dimensions of the galactic halo and measurement of the flux of cosmic rays in intergalactic space.

At a symposium on the structure of the galaxy held in the Netherlands in the fall of 1966 I remarked that I hoped to see the verification of the galactic model of the cosmic rays during my lifetime. Hannes Alfvén immediately rejoined: "I hope you will live very long." I shall be glad if Professor Alfvén turns out to be a good prophet about my longevity. As for the cosmic ray model, I take the risk of predicting that its fate will be decided within the next five to 10 years.

The ideal plane is fast as light, powerful, highly automated with gadgets that do everything but brush the automatic pilot's teeth.



What's the ideal airplane?



For efficiency, it has a huge capacity. And every seat is always filled.

The Biochemistry of Anxiety

Patients with anxiety neurosis show an excessive rise in lactate, a normal metabolic product. A double-blind experiment has shown that anxiety symptoms and attacks can be induced by infusions of lactate

by Ferris N. Pitts, Jr.

The patient feels very sick. He is tired and apprehensive, his heart pounds and his breathing is labored. From time to time he is overcome by fright and the conviction that he is seriously ill or even about to die. Still, his doctor says: "There is nothing wrong with you." This is a description of someone with an anxiety neurosis, a chronic disorder that affects perhaps 5 percent of the U.S. population. Most physicians have been unable to recognize it, let alone treat it; its cause has seemed to be obscure and somehow "psychogenic." Yet in our laboratory at the Washington University School of Medicine we have been able to produce the symptoms of anxiety neurosis and even acute anxiety attacks in susceptible patients by chemical means: we administer enough lactate, a normal product of cell metabolism, to raise the blood lactate level about as high as it is in strenuous physical exercise or other heavy physiological stress. This is the first time anxiety attacks have been produced in any group by any specific stimulus. Our findings have led us to a tentative hypothesis about the biochemical mechanism that gives rise to anxiety symptoms and also seem to explain a new method of treating this hitherto intractable condition.

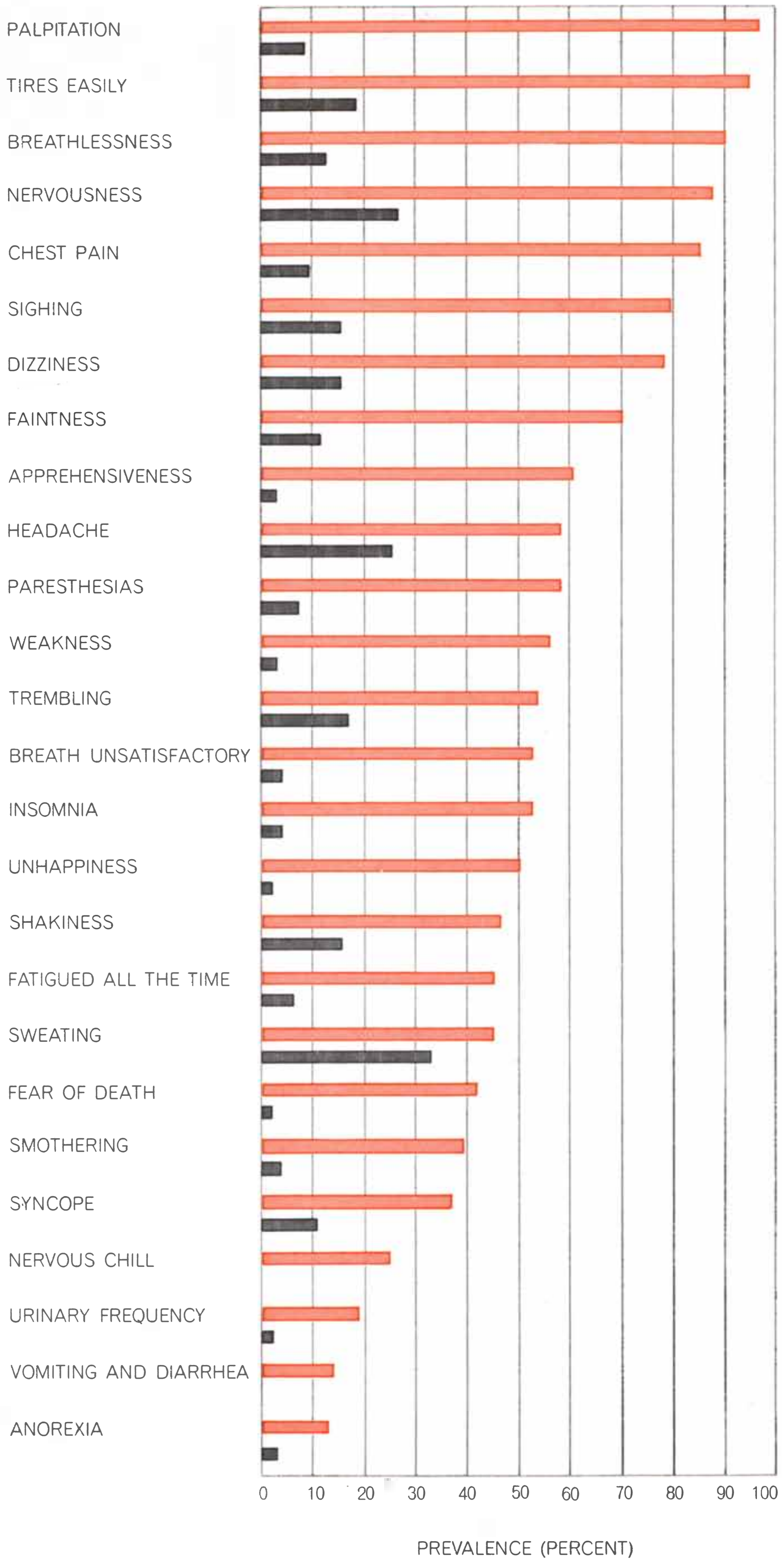
Anxiety neurosis is a chronic familial illness characterized by feelings of tenseness and apprehension, breathlessness and shortness of breath, palpitation, nervousness, irritability, chest pain and chest discomfort, easy tiring, dizziness, numbness and tingling of the skin, trembling and faintness—and by acute anxiety attacks: abrupt spells of intense fear of impending doom that come on without any apparently appropriate stimulus. The attacks are associated with symptoms of smothering and palpitation and often result in fear of heart attack, cancer, insanity or some other grave disorder. The condition most often arises between the ages of 15 and 35; the symptoms persist with fluctuating intensity for many years without in any way reducing longevity or increasing susceptibility to other diseases. The symptoms are frightening and the fatigue is intense, and so the anxiety neurotic quickly seeks medical attention.

Physical examination reveals no abnormality; laboratory tests are usually normal. The physician is faced with treating an individual who has many subjective physical complaints and great fear of serious illness but who gives no evidence of such illness. Quite probably the physician, who has received little or no training in recognizing the various psychiatric conditions on the basis of reported symptoms, does not even know what questions to ask in order to define the disorder. Most physicians either send these patients away after telling them there is nothing wrong or prescribe a sedative, and then forget the whole matter or blame the patient by labeling him a "crock"—medical slang for a neurotic complainer.

The patient is nonetheless certain that his symptoms signal a distressing condition; he comes to believe his disease is either so serious that the doctor cannot tell him the truth or so early in its course as to be unrecognizable. Naturally the patient often seeks other medical opinions, and the more active and determined the patient is the more doctors he sees. Family physicians and internists are consulted about breathlessness and heart palpitations, ophthalmologists about blurred vision, neurologists about dizziness and numbness, otolaryngologists about "a lump in the throat" and psychiatrists about the subjective anxiety and its behavioral consequences. Psychotherapy has little effect on the symptoms of anxiety neurosis, although it may influence the patient to accept his condition.

The mutual frustration of physicians and patients over anxiety neurosis is common because the magnitude of the problem is so great. The 10 million Americans with the disease outnumber by 40 to one the 250,000 practicing physicians. The high prevalence of the disorder, together with the fact that anxiety neurotics see physicians frequently, accounts for the fact that between 10 and 30 percent of the patients of most general practitioners and internists have anxiety neurosis.

The disorder has had many names. The first written description was given by Alfred Stillé, a Civil War military surgeon, in 1863; he called it "palpitation of the heart." Some of the other terms suggested have been muscular exhaustion of the heart, nervous exhaustion, neurasthenia, irritable heart and neurasthenia with abortive and larval anxious-state, effort syndrome and neurocirculatory asthenia; the term anxiety neurosis was introduced in 1895 by Sigmund Freud. Early clinical descriptions were sketchy and imprecise, but in 1871 Jacob M. DaCosta listed nearly all the symptoms in a report on more than 300 cases seen in a Union Army hospital during the Civil War. DaCosta pointed out that the disorder could not be new because he had located complete case reports of the syndrome in British army records from the Crimean War and incomplete descriptions in other military hospital records from campaigns in the preceding two centuries. He emphasized that although the disorder had been recognized and defined by military surgeons



SYMPTOMS of anxiety neurosis among 60 patients (*colored bars*) and 102 controls (*black bars*) were reported by Mandel E. Cohen and Paul Dudley White of the Harvard Medical School. Paresthesia is tingling skin, syncope is fainting and anorexia is loss of appetite.

evaluating soldiers unable to take the field, it was not caused by military life, since most soldiers had developed the disorder before joining the army and many civilian patients also exhibited it. DaCosta was also the first to demonstrate the familial nature of anxiety neurosis, and described a pair of affected twins. As a result of his report (which was remarkably rigorous in organization and content, even compared with many papers published in medical journals today) the disorder was long known as DaCosta's syndrome. In many ways that is still the best term, since it is the only one that does not imply the cause is known or implicate any one organ system.

Physicians disagree as to how many distinct conditions are described by the various diagnostic terms and how the terms overlap and interrelate. The fact is that it seems impossible to differentiate DaCosta's syndrome from neurocirculatory asthenia or either of them from anxiety neurosis or any other of the terms. The standards for the diagnosis of anxiety neurosis have been the least stringent, but if one does a systematic psychiatric examination of a person labeled an anxiety neurotic (for whatever reason) and is able to rule out the presence of other psychiatric conditions, the patient will report enough of the symptoms associated with neurocirculatory asthenia to justify that diagnosis also. In short, although the symptoms of anxiety neurosis are subjective and the disorder may represent a group of symptoms caused by several different specific factors or diseases, we still have no reliable way of subclassifying the group of patients with anxiety neurosis on any clinical grounds. The symptoms characteristic of anxiety neurosis [*see illustration at left*] are also seen, in different percentage distributions, in many psychiatric conditions and in the course of many medical conditions. It is important for physicians to learn the complex differential diagnosis of anxiety symptoms if each patient is to be given the best treatment.

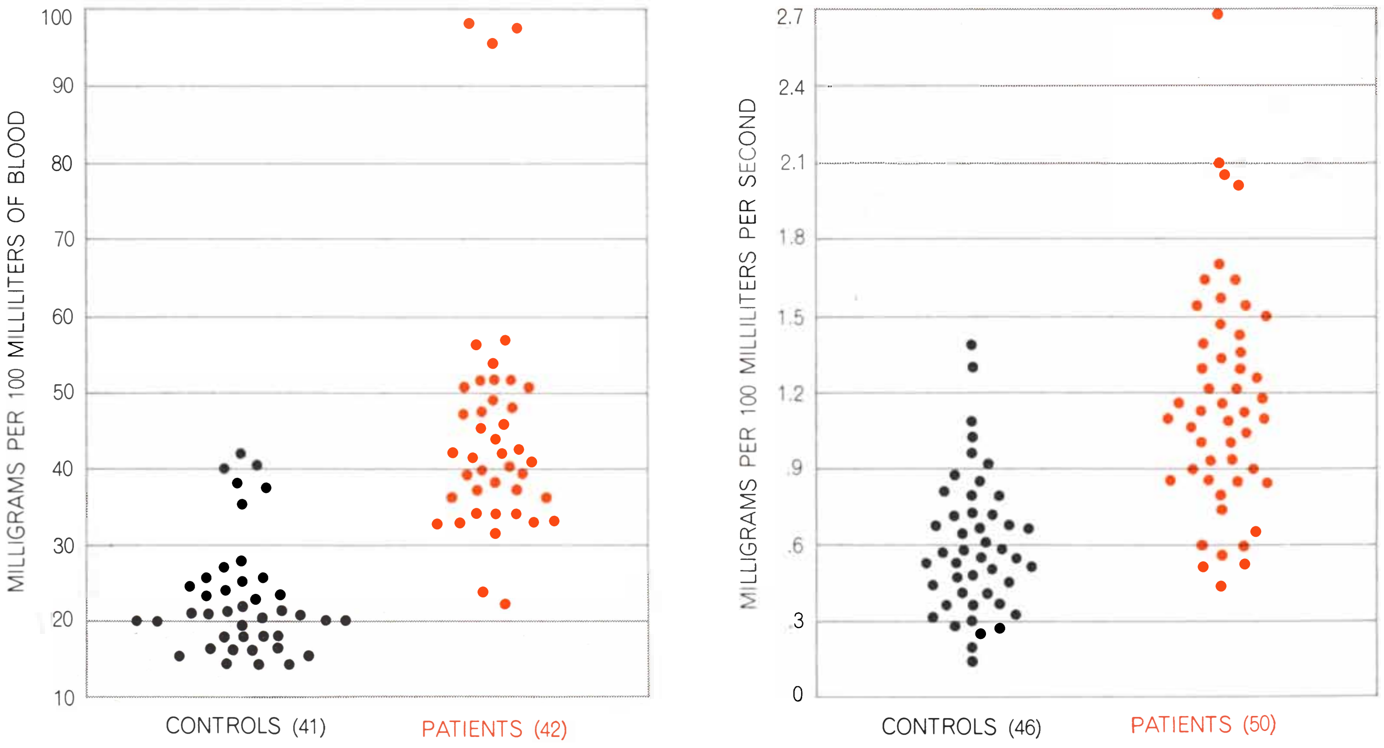
The familial nature of anxiety neurosis was demonstrated some years ago in a systematic study by Paul Dudley White and his colleagues at the Harvard Medical School. They found that the incidence of the disorder in a random control sampling of the general population was 4.7 percent, but that among relatives of patients it was several times higher. With one parent affected, 48.6 percent of the children suffered from anxiety neurosis; with two parents affected, 61.9 percent of the children suffered from the disorder. With neither parent affected but with one child suffering from anxiety neurosis, 27.9 percent of the other children in the family were affected, whereas the incidence among children in the general population sample was about 4 percent. These data demonstrated that some kind of associational factors operate in the transmission of anxiety neurosis and suggested that the factors are hereditary, but the number of subjects was too small to establish the precise type of transmission.

Most studies among civilians reveal an excess of women with anxiety neurosis, with about two female patients for every male. The Harvard group's family study showed that the deficit of males is probably only apparent; when the number of males in a family who were alcoholics and also had anxiety symptoms was added to the number with anxiety symptoms alone, the sum equaled the number of females with anxiety symptoms. In other words, alcoholism may often be symptomatic of anxiety neurosis in men, and when it is, the alcoholism makes it difficult to diagnose anxiety neurosis.

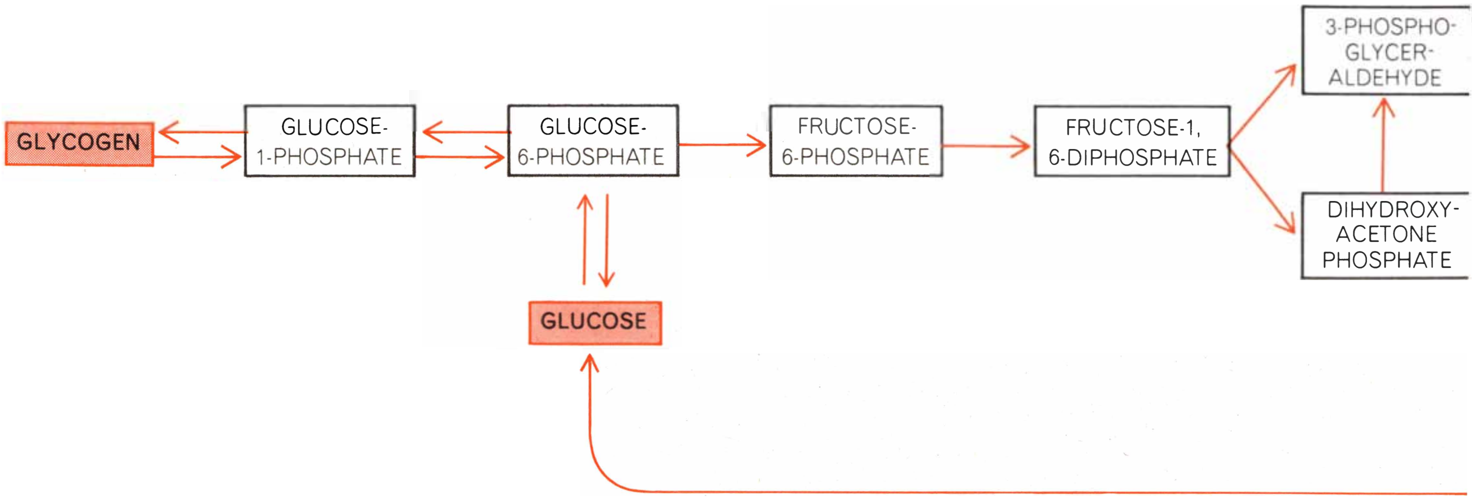
Some of the symptoms of anxiety neurosis resemble those produced by physical exertion, and indeed most patients report that physical activity can bring on or intensify their symptoms. These facts led medical investigators to evaluate various physical functions in anxiety neurotics. They found that, compared with normal controls, anxiety neurotics react sooner to increasing levels of noise, light or heat. They cannot maintain a strong handgrip as long. Their breathing rate increases more in response to discomfort (a tightening blood-pressure cuff, for example). They sigh more and breathe faster when carbon dioxide is added to the air they are inhaling. In response to light exercise they show more of an increase in pulse and breathing rates, utilize inspired oxygen less efficiently and develop a higher level of lactic acid in the blood.

The rise in lactic acid (or lactate, to speak of the ionic form of the substance) has been of particular interest. Lactate is the end product of anaerobic glycolysis, the process by which cells break down glucose (or glycogen, its storage form) and extract energy from it. When muscle cells do work, they convert large quantities of glycogen to lactic acid, some of which is subsequently oxidized to carbon dioxide and water but most of which diffuses into the blood and is eventually resynthesized into glucose in the liver. A rise in blood lactate is therefore a normal result of exercise. It has been shown, by four investigations in four countries over the past 25 years, that the rise in blood lactate with exercise is excessive in anxiety neurotics. The effect was first noted by White and Mandel E. Cohen at Harvard [*see illustration below*]. It was independently confirmed by Maxwell S. Jones of the Mill Hill Emergency Hospital in London, by Eino Linko of the University of Turku in Finland and by Alf G. M. Holmgren and his associates at the Royal Caroline Institute in Stockholm. The appearance of anxiety symptoms evoked in patients by the exercise appeared to be concomitant with the extremely rapid rise in lactate; nonpatients serving as controls did not develop anxiety symptoms with exercise and showed only the expected normal increase in lactate. In the anxiety neurotics the rise in lactate (per unit of work per unit of time) was about what is seen in patients with such serious medical conditions as arteriosclerotic or rheumatic heart disease.

It occurred to me that perhaps the lactate ion itself could produce anxiety attacks in susceptible people. We conducted a pilot study of nine patients, with nine nonpatients as controls. In all the patients and in two of the controls typical anxiety attacks developed with lactate infusions that were sufficient to raise the venous lactate level to between 12 and 15 millimoles per liter, a range that



BLOOD LACTATE was measured by Cohen and White in anxiety neurosis patients and in normal controls before and after moderate exercise (walking on a treadmill) and heavy exercise (running on a treadmill). When results are plotted for each subject, it is clear that the lactate level was significantly higher in patients than it was in controls after the walk (*left*) and, for the same duration of running, after the run (*right*). Mean values are 21 for controls and 44.6 for patients (*left*), .6 for controls and 1.48 for patients (*right*).



LACTATE is the end product of anaerobic glycolysis, the process by which glucose (or glycogen, its storage form) is broken down by cells in the absence of oxygen, as in the case of muscle cells during exercise. This occurs in a number of steps, each catalyzed by

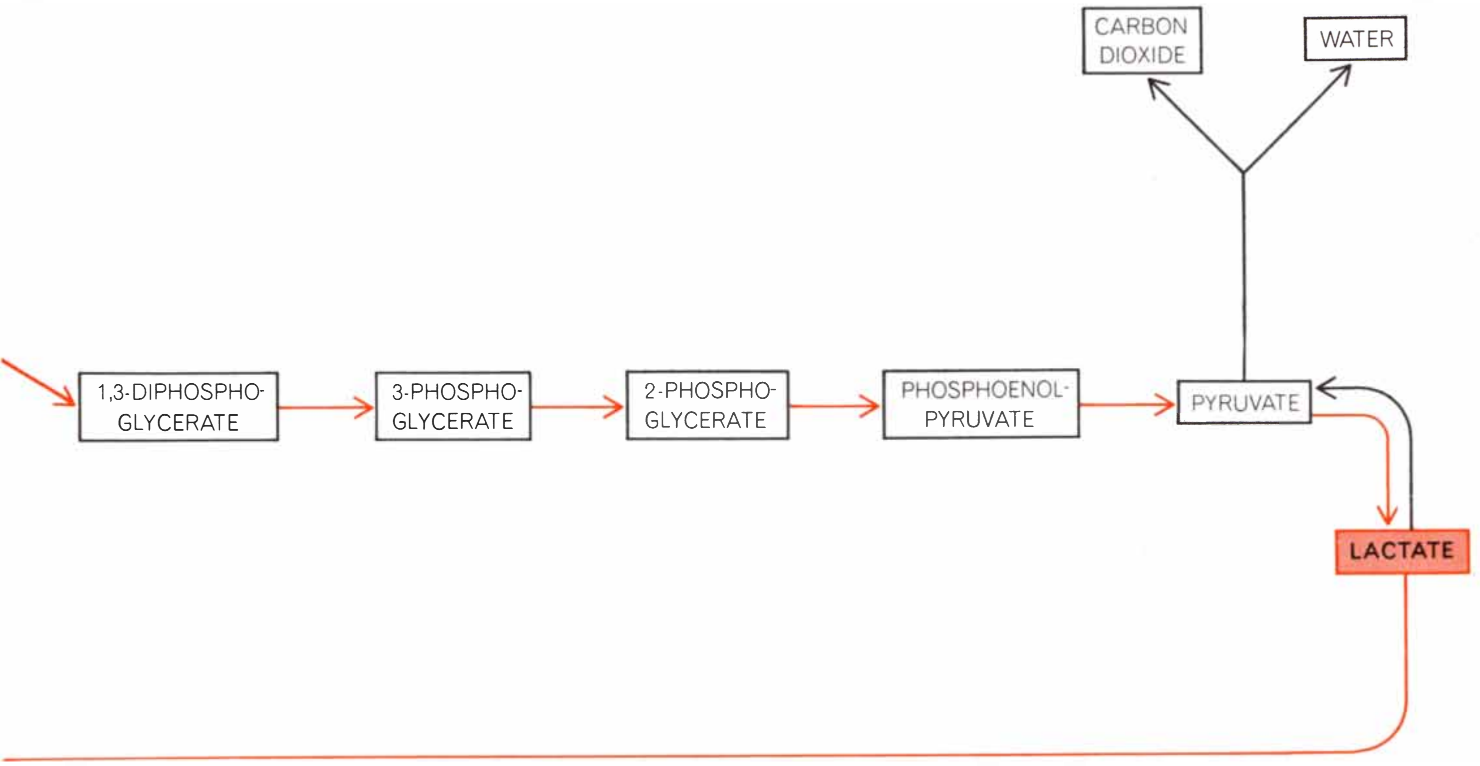
is normally attained only with maximum muscular exertion or after the administration of adrenalin. Such attacks did not develop in patients or controls with either of two control infusions.

We went on then to perform a more elaborate double-blind experiment. On the basis of rigid criteria we selected a group of 14 patients who could definitely be classified as anxiety neurotics, and we picked a carefully matched group of 10 normal subjects to serve as controls. Each of the 24 subjects received 10 milliliters per kilogram of body weight (about half to three-quarters of a quart) of each of three experimental solutions by intravenous infusion at three experimental sessions five to 10 days apart, with the various solutions administered in carefully randomized order. The experimenter, my colleague James N. McClure, Jr., at that time was unaware of the contents of each infusion, the medical history of the subjects or the purpose of the experiment. He gave the infusion, recorded the subject's behavior and comments and took blood and urine samples. Then the subjects were questioned intensively about their symptoms.

The three infusions were solutions of sodium lactate, of sodium lactate with added calcium and of glucose in sodium chloride. The control solution of sodium lactate with calcium was selected for a specific reason. It had seemed to me that many of the symptoms of anxiety neurosis were identical with those seen in hypocalcemia, a condition in which the level of calcium ions in the blood is low. The lactate ion has a weak but definite ability to complex with ionized calcium, binding it into a physiologically inactive form. It seemed possible, therefore, that the excess lactate in anxiety neurotics might operate by binding calcium, which plays an important role in the transmission of nerve impulses. The calcium in my control infusion was about enough to saturate the binding capacity of the added lactate, so that the lactate would presumably leave the calcium level in the subjects' blood and tissue fluids unaltered. The second control solution, glucose, was chosen simply because its normal metabolic destiny is lactate and it would therefore not introduce any new biochemical effect.

After his third session each subject was asked to rate the three infusions in order of the severity of their effects. McClure, the "blind" observer, did the same thing for each of the subjects. All 24 subjects were able in effect to identify the three solutions, reporting that the sodium lactate had caused the most symptoms, the glucose very few symptoms or none at all and the sodium lactate with added calcium an intermediate number of symptoms. This result had a high statistical significance: the probability that the 24 subjects would correctly rank all three solutions by chance was one in 10,000. McClure did almost as well. He correctly ranked all three solutions for 11 of the 14 patients and for seven of the 10 controls, a performance that would be achieved by chance only five times in 10,000 trials. (His only error was in reversing the two lactate solutions in three members of each group.)

The most striking outcome of the experiment was that the infusions produced anxiety attacks. This is the first time, to my knowledge, that such a result has been achieved with a chemical, physiological or psychological stimulus. Thirteen of the 14 patients and two of the 10 controls had typical acute anxiety attacks during the lactate infusion. (The difference was statistically significant, showing that patients have a characteristic response to lactate.) The anxiety neurotics likened the effect of the lactate to their "worst attacks." One commented: "Heart pounding, mouth dry, vision blurred, dizzy, headache, and all just like my sick spells, even breathing tight and like mint." Another reported: "Have palpitations, tightness-lump in throat, trouble breathing, shuddering sensation all over, can't stop shaking feeling, hard to focus my eyes and things are blurred, I'm very apprehensive and jumpy, this all began with this experiment." None of the



a different glycolytic enzyme, with energy extracted along the way. The lactate diffuses into the blood, is carried to the liver and there reconverted to glucose. When oxygen is available, pyruvate is oxidized to carbon dioxide and water through aerobic respiration.

subjects in either group had such attacks with either of the control infusions. In other words, the addition of calcium did markedly reduce the effect of the lactate on the anxiety neurotics.

When individual anxiety symptoms are considered, the results again show a strong effect of lactate, a mitigating effect of calcium and a difference in the response of patients and controls to lactate [*see illustration on next page*]. It is noteworthy that with the lactate infusion all subjects in both groups experienced paresthesia, a numbness and tingling of the skin that is usually caused by a low level of calcium in the tissues. With the lactate-plus-calcium infusion only a small minority of the subjects reported paresthesia, and none of them did with the glucose infusion. Significantly more patients than controls reported experiencing nearly all the other symptoms with lactate, but with the two control infusions there was no significant difference in the extent to which each symptom was reported by the two groups. These observations hold true for the cumulative total of symptoms as well as the individual reports. Of the 294 possible symptoms (21 symptoms for each of 14 subjects), the anxiety neurosis patients reported experiencing 190, or 64.6 percent, during lactate infusion, 25.5 percent with lactate plus calcium and 4.4 percent with glucose. Of 210 possible symptoms, the control subjects reported experiencing 34.3 percent during lactate infusion, 17.1 with lactate plus calcium and 2.9 percent with glucose. Analysis of these figures shows that the anxiety neurotics developed significantly more symptoms than the controls did with lactate but not with the control infusions.

There were marked aftereffects—significant symptoms lasting more than 24 hours—from the lactate infusion in patients but not in controls; there were no marked aftereffects for either group from the control infusion. One patient reported, for example: "I was sick, weak and dizzy for several days and couldn't get out of bed to go to school the next day. I was still very weak two days later and gradually recovered over several days."

Let me summarize the findings. A 20-minute infusion of lactate into a patient with anxiety neurosis reliably produced an anxiety attack that began within a minute or two after the infusion was started, decreased rapidly after the infusion but was often followed by from one to three days of exhaustion and heightened anxiety symptoms. Such patients did not have anxiety attacks and had many fewer individual symptoms when calcium was added to the lactate infusion. Patients had almost no symptoms when they were infused with glucose in saline solution. Nonpatient controls had many fewer and less severe symptoms in response to lactate; they had only a few symptoms in response to lactate with calcium and almost none with glucose. The patient group differed from the controls significantly only in the case of the lactate infusion. Clearly the patients were responding to a specific effect of the lactate, not to any psychological aspects of intravenous infusion.

Our conclusion is that a high concentration of lactate ion can produce some anxiety symptoms in almost anyone, that it regularly produces anxiety attacks in patients but not in controls, and that calcium ion largely prevents the symptoms in both patients and controls. Together with earlier findings on abnormal lactate metabolism in anxiety neurotics, we believe, our experiments demonstrate that the lactate ion may operate in a very specific way to produce naturally occurring anxiety symptoms. We have developed a theory, which is still in a preliminary stage, that anxiety symptoms may ultimately be expressed through a common biochemical mechanism: the complexing of calcium ions by lactate ions. If this binding occurs in the intercellular fluid at the surface of excitable membranes such as nerve endings, an excess of lactate could interfere with the normal functioning of calcium in transmitting nerve impulses.

What is the source of the excess lac-

ANXIETY SYMPTOMS were produced in anxiety neurosis patients (*left*) and in nonpatients (*right*) as shown here. The bars indicate the number of subjects who reported each symptom during the infusion of lactate (*solid color*), lactate with added calcium (*light color*) and glucose in salt solution (*gray*). The lactate produced paresthesia in all the subjects. The other symptoms were produced significantly more often in the patients than in the nonpatients by the lactate but not by either of the two control infusions.

tate? The difference between patients and nonpatients is not one of lactate "tolerance," or ability to clear lactate from the blood; in all our subjects the excess lactate from the infusions was removed normally by the liver in 60 to 90 minutes. According to our theory, anxiety symptoms could occur in normal people under stress as a consequence of excess lactate production resulting from an increased flow of adrenalin, which is known to stimulate anxiety symptoms as well as to step up lactate production. The anxiety neurotic would be someone particularly subject to this mechanism because of chronic overproduction of adrenalin, overactivity of the central nervous system, a defect in metabolism resulting in excess lactate production, a defect in calcium metabolism or a combination of these conditions.

Such a mechanism is still far from being clearly established, but the theory is entirely compatible with a new and apparently effective treatment for anxiety neurosis. Adrenalin steps up lactate production by acting on metabolic receptor sites on the cell surface to activate the cell's glycolytic enzyme system. A new drug, an adrenalin analogue called propranolol, has recently become available that blocks these metabolic sites and also sites (the β-adrenergic receptors) at which adrenalin exerts its nerve-stimulating effect. In the past two years investigators in London and in South Africa have conducted double-blind experiments in which propranolol is alternated with an ineffective placebo and have shown that propranolol can reduce or eliminate anxiety symptoms.

We have, then, evidence of the biochemical physiology of the anxiety symptoms that are characteristic of anxiety neurosis; we also have a seemingly effective and possibly specific treatment, a treatment that the new knowledge of the biochemistry of anxiety would lead one to expect to be effective. Much further work needs to be done to answer some important questions. Does the infusion of lactate cause anxiety symptoms and attacks in various other groups of patients characterized by anxiety or is there more than one mechanism for expressing these symptoms? Does adrenalin infusion produce anxiety symptoms in anxiety neurotics and other anxious patients and, if so, is the production of anxiety correlated with the production of blood lactate? Can propranolol block anxiety symptoms that have been produced in susceptible patients by the infusion of lactate or adrenalin?

Subsistence Herding in Uganda

The Karimojong drink the milk and blood of their cattle but rarely eat meat. Why do they not adopt the successful dairying and ranching practice of advanced nations? The answer is rooted in human ecology

by Rada and Neville Dyson-Hudson

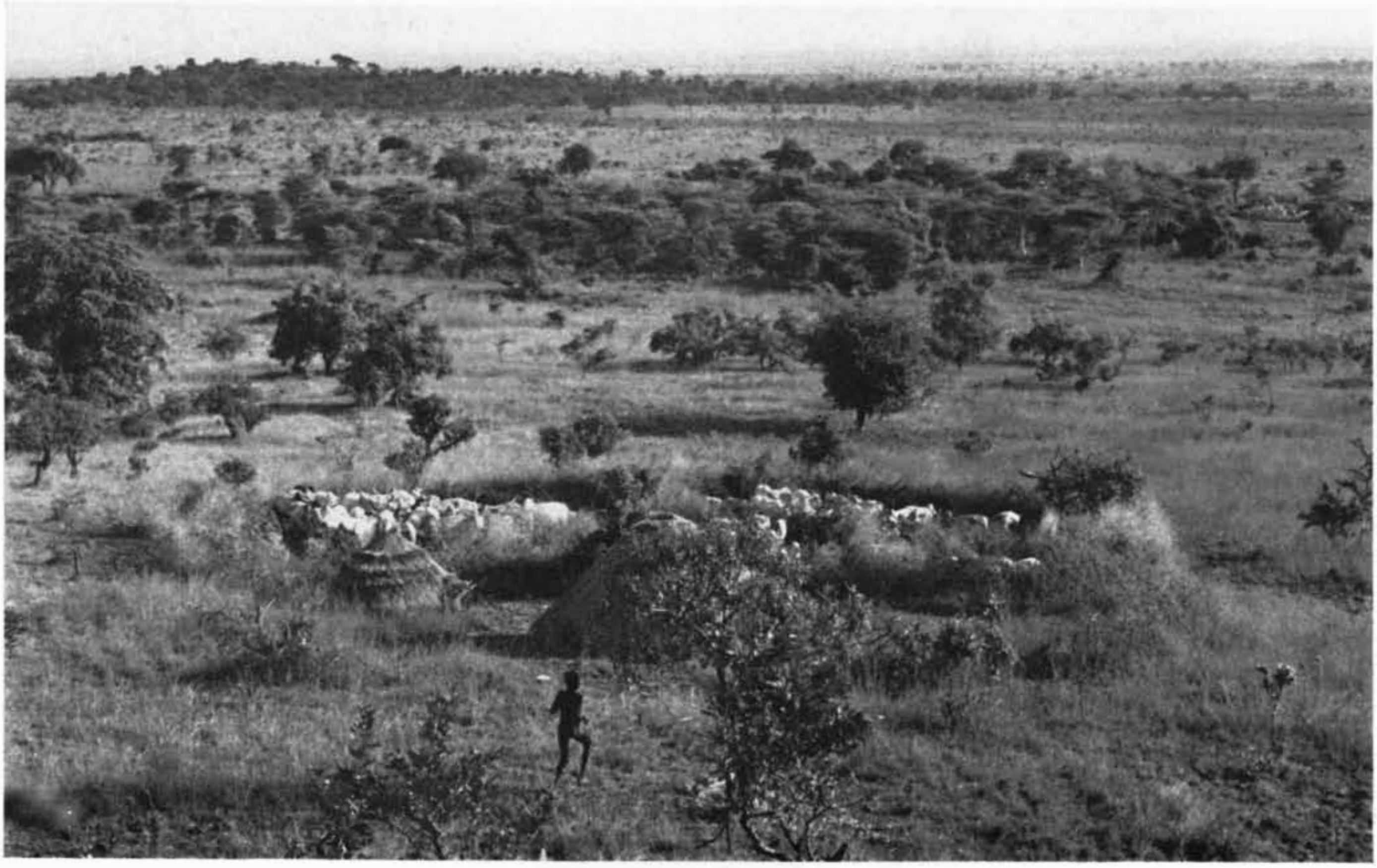
Wide areas of Africa are savanna grassland. It is a habitat most suited to grazing animals, and where it is exploited by man it is most often used for raising livestock. As a result livestock are a major natural resource in many African nations; in some countries (such as Mauritania and Chad) they may be the only significant economic resource in sight. Yet in Africa livestock have proved to be an exceedingly difficult resource to exploit economically on a national scale.

The reason for the difficulty is a simple one. Traditional African systems of livestock exploitation, in spite of their many variations across the continent, have one thing in common: the people who operate them survive not by ranching or by dairy farming but by subsistence herding. The common aim of ranchers and dairy farmers is the conversion of herbage (either naturally available or grown for the purpose) into marketable produce, and their objective is achieved by associating small numbers of people with large herds of livestock. In subsistence herding large numbers of livestock are associated with large numbers of people, and the aim, within the limits of the available technology, is the production not of a marketable surplus but of a regular daily supply of food. In short, in market-oriented livestock systems the herds support the minimum population needed for livestock care; in a subsistence-oriented livestock system the herds support the maximum population that can be regularly fed from their produce. Indeed, in subsistence systems continuity of food supply is so emphasized that live-animal products (milk, milk fats and often blood tapped from live animals) are the ones most utilized, with terminal products (meat and the blood of recently slaughtered animals) used only to mark special occasions, to make the best of accidental livestock death or to stave off famine.

The contrast between the market orientation of the rancher or dairy farmer and the continuous-feeding orientation of the subsistence herder is so pronounced that it has frustrated many well-intentioned advisers to African nations. The obvious inefficiency, in market terms, of traditional livestock systems has even prompted the argument that the African savannas can best be exploited by wild-game cropping rather than by domestic animal husbandry. The absence of market rationality in traditional herding systems is beyond dispute: herd structure, husbandry practices and the explicit comments of the herders themselves all confirm it. Too often, however, the absence of market rationality in traditional herding systems is taken to be the absence of rationality of any kind. Tribal herders are given no credit for intent and design in their livestock operations. Quite commonly innate cultural backwardness or mere ecological ignorance is invoked to explain the nature (and remarkable persistence) of traditional herding systems. It is a commonplace among conservation-minded world travelers that the tropical herdsman is thoughtlessly bent on ruining his environment. Such misinterpretations are possible only because of a shortage of hard data on the actual day-to-day operation of traditional herding systems. In the present age of the economic planner's dominance in developing nations these misinterpretations may bring hardship to many of Africa's tribal groups.

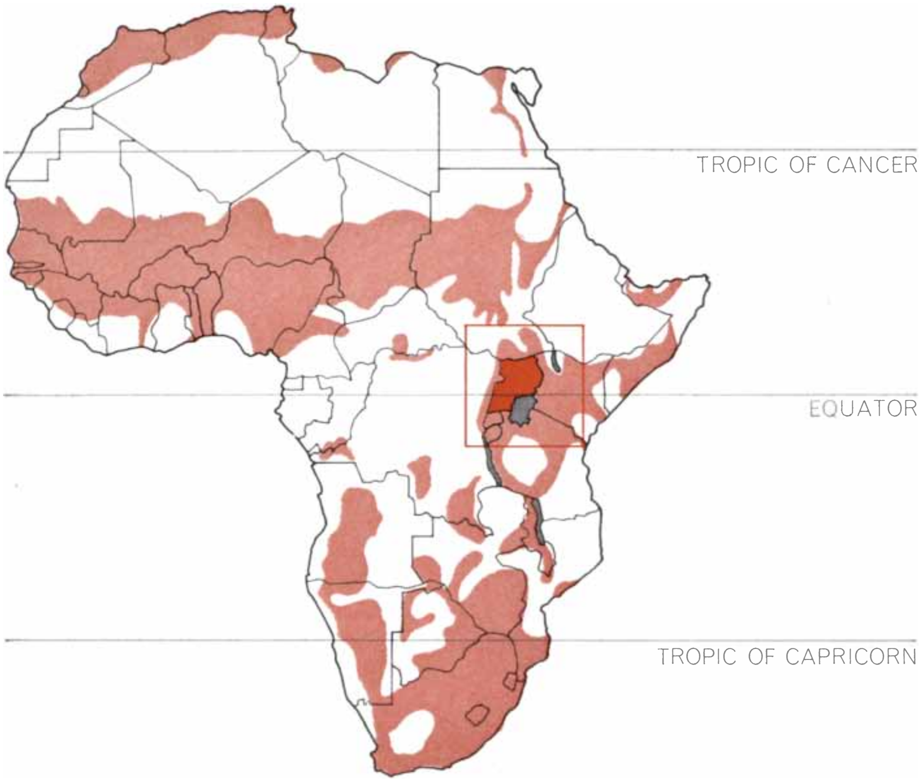
Let us take as an example a single East African tribe: the Karimojong, who live in the southern part of the Karamoja District in Uganda. The Karimojong, to be sure, are only a tiny fraction of Africa's population—about 60,000 persons. They occupy an infinitesimal part of its land—about 4,000 square miles of semiarid plain in northeastern Uganda. Nonetheless, in their emotional and economic commitment to herding as the best means of survival in an uncertain environment they represent a significant part of the African continent and its peoples. Moreover, in their livestock practices they clearly represent the skills and rationality of traditional African livestock production, which have too often been misunderstood (or simply overlooked) by observers raised in a different tradition and oriented toward other goals.

To be rigorous, in fact, we must begin with a much smaller example than even a single tribe, because the Karimojong will not give outsiders information about their livestock any more than an American businessman would open his financial records to a stranger. The minimum example from which we start is the herd of one Karimojong man named Loput, whose herding movements were tracked, whose herd structure was tallied and whose livestock yields were regularly sampled over a 13-month period. For purposes of comparison less complete yield measurements were obtained from two other herds, and the herding movements were tracked over a two-year period for seven homesteads that together formed a residential community of some 250 people. Beyond this the assessment of the representative nature of the herd data for the tribe as a whole depended on direct questioning and independent observation during close but casual interaction with many tribesmen. Corroboration in some respects, and a wider frame of reference, were provided by detailed records for native cattle kept as a dairy herd at Karamoja District

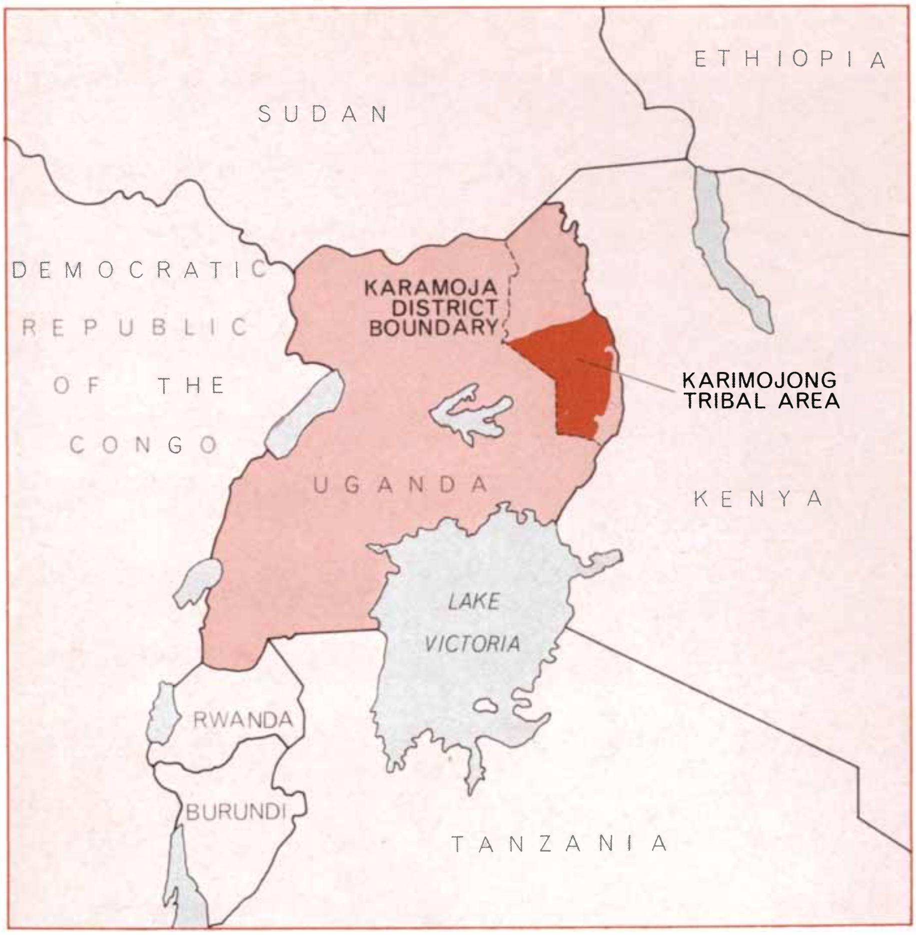


CATTLE CAMP in the western highlands of the Karimojong tribal area in northeastern Uganda has thornbush corrals for the animals and rough huts of straw for the herdsmen. Grazing is abundant in season here, and a camp like this may be occupied for many weeks.

HOME SETTLEMENT of a Karimojong herd owner is a large stockade with a separate compound for each wife. A corral for cattle is at upper right, a circular pen for goats and sheep at center. The structures on stilts outside the stockade are bins for grain storage.



DISTRIBUTION OF CATTLE in Africa (*light color*) includes stock in areas north of the Sahara and in the far south. Extensive rangelands occupy a region from south of the Sahara to and below the Equator. Uganda, where the authors' study was conducted, is in dark color.



KARIMOJONG TRIBAL AREA lies near the border between Uganda and Kenya in northeastern Uganda, occupying half of the Karamoja District. Although its year can be divided into a wet and a dry season, rainfall is erratic and grazing and water are highly variable.

headquarters and by livestock censuses conducted by the Uganda Veterinary Department. The statistical shortcomings of such an investigation are obvious, but the detail provided by intensive investigation compensates by yielding many insights that cannot be derived from superficial extensive investigations. It is perhaps worth noting that even the minimum example from which we start was the result of almost three years of field study, including more than two years of close daily association with Loput, who was moved to adopt us into his own family group.

Understanding Karimojong herding operations means understanding that, to the Karimojong, cattle mean many things. Cattle are property, and accordingly they represent variable degrees of wealth, of social status and of community influence. They are a man's legacy to his sons. They can be exchanged to symbolize formal contracts of friendship and mutual assistance. The transfer of cattle from the groom's family to the bride's is needed to validate a marriage. The sacrifice of cattle is a vital feature of religious observances. The focus of Karimojong aspirations is the acquisition of cattle, and disputed cattle ownership is at the root of most Karimojong quarrels. Cattle are considered proper objects of man's affection, and this conviction is an integral part of each man's life cycle. As a boy he is given a specially named male calf to identify himself with, to care for and to decorate, to commemorate in song at dances and beer parties, and to incorporate into the style of his most formal name as an adult. Interesting and important as all these elements are, they are cultural elaborations of one central fact: cattle are the major source of subsistence for the Karimojong. First, last and always the role of cattle in Karimojong life is to transform the energy stored in the grasses, herbs and shrubs of the tribal area into a form easily available to the people.

The Karimojong do practice subsistence agriculture in addition to livestock husbandry; they also collect wild fruits and berries and occasionally hunt wild game. Because of the uncertainties of the environment this method of exploitation helps to ensure a continuity of food supply that a single food source could not. The most reliable food source is nonetheless livestock, herded by men who may build their rough camps anywhere on the Karimojong tribal land. In most years there are localized rainstorms in some part of the tribal land, and the livestock can be moved to where grass and water are available. Occasionally, however, there are major droughts of four months or more over all the tribal land, and the shortage of grazing and water reduces to a very low level the yield of those livestock that do survive. There are also epidemics of livestock disease that can decimate the herds, and the neighboring tribes, particularly the Suk and the Turkana, are in a perpetual state of war with the Karimojong, so that a man's entire herd may be stolen. For the Karimojong to live entirely on their herds would be risky.

Subsistence agriculture is practiced primarily by the women, who live in the relatively comfortable permanent settlements in the center of the Karimojong tribal land. Agriculture too is perilous; a short local drought of three or four weeks during the growing season (a frequent occurrence) severely damages the crops, and they cannot be moved to areas of better rainfall. Nonetheless, excellent crops can be harvested all over the tribal land in certain years, and in certain areas in most years. Sorghum, the major crop, is used to supplement the blood and milk from the livestock. Wild game and bush foods, although they enabled the few Karimojong surviving after the major livestock and human epidemics of the 1890's to reestablish themselves as a major tribe, are not now sufficiently abundant to be more than an occasional supplement to the basic Karimojong diet of livestock and agricultural products.

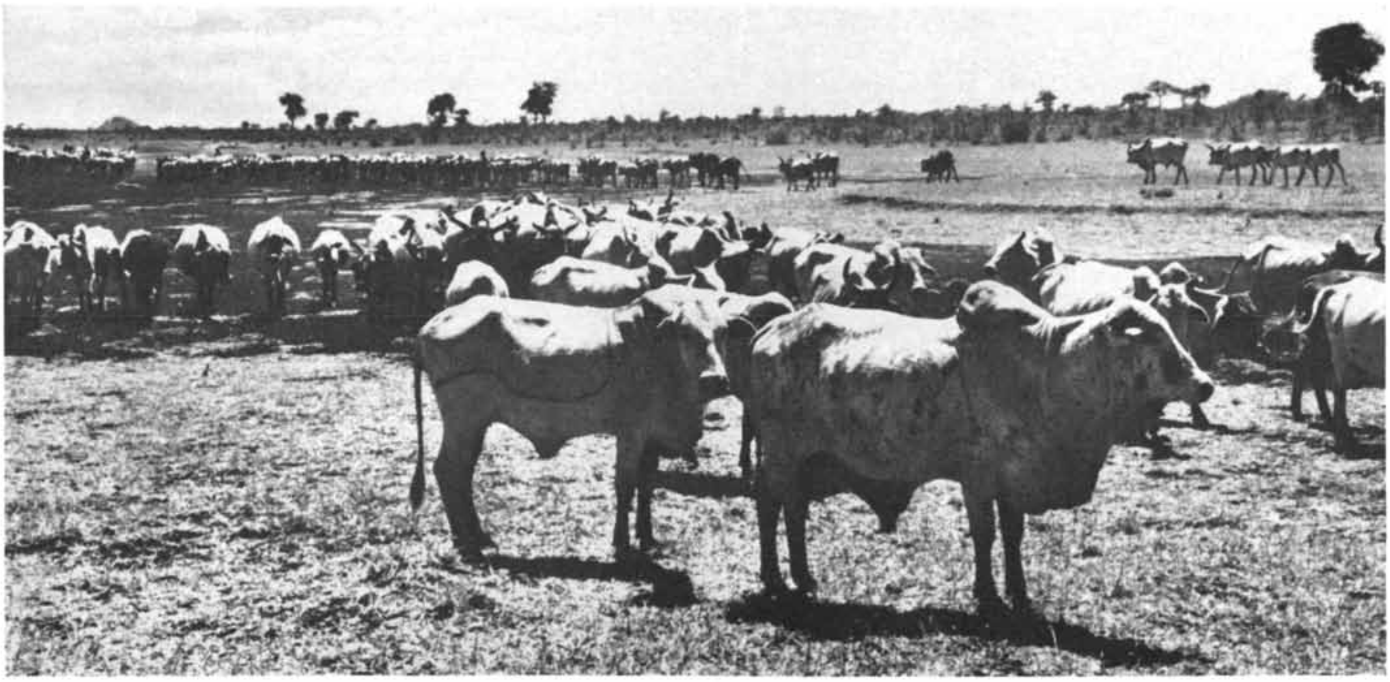
The relative importance of herd products, agricultural products and bush foods varies from year to year and from individual to individual. Married women and their daughters normally live in the permanent settlements and mainly eat cereal food, supplemented by milk when the cattle herds are nearby, but in years of crop failure all the people may move to the camps and subsist on milk and cattle blood until a new crop is harvested. Many young men and boys live almost exclusively on milk and cattle blood, but if a man is poor in cattle, the whole family may have to depend almost entirely on agricultural products and food gathered in the bush. Here we shall examine in detail only the husbandry practices of the Karimojong, to demonstrate how they are a response to the exigencies of both the biological and the social environment.

Karimojong husbandry involves total use of the environment: immediate utilization of resources, leaving none for a later time. Three reasons can be suggested for this basic principle of the Karimojong herdsman. First, in the past tropical cattle-keepers have migrated over large areas, simply moving from pasture to pasture as the forage was exhausted and driving out other people if they were in the way. The entire political history of East Africa is that of grazing areas changing hands from tribe to tribe, so that to maintain good grazing not only is dubious economically—who knows who will be taking advantage of it in the future?—but also invites outside competition into the area.

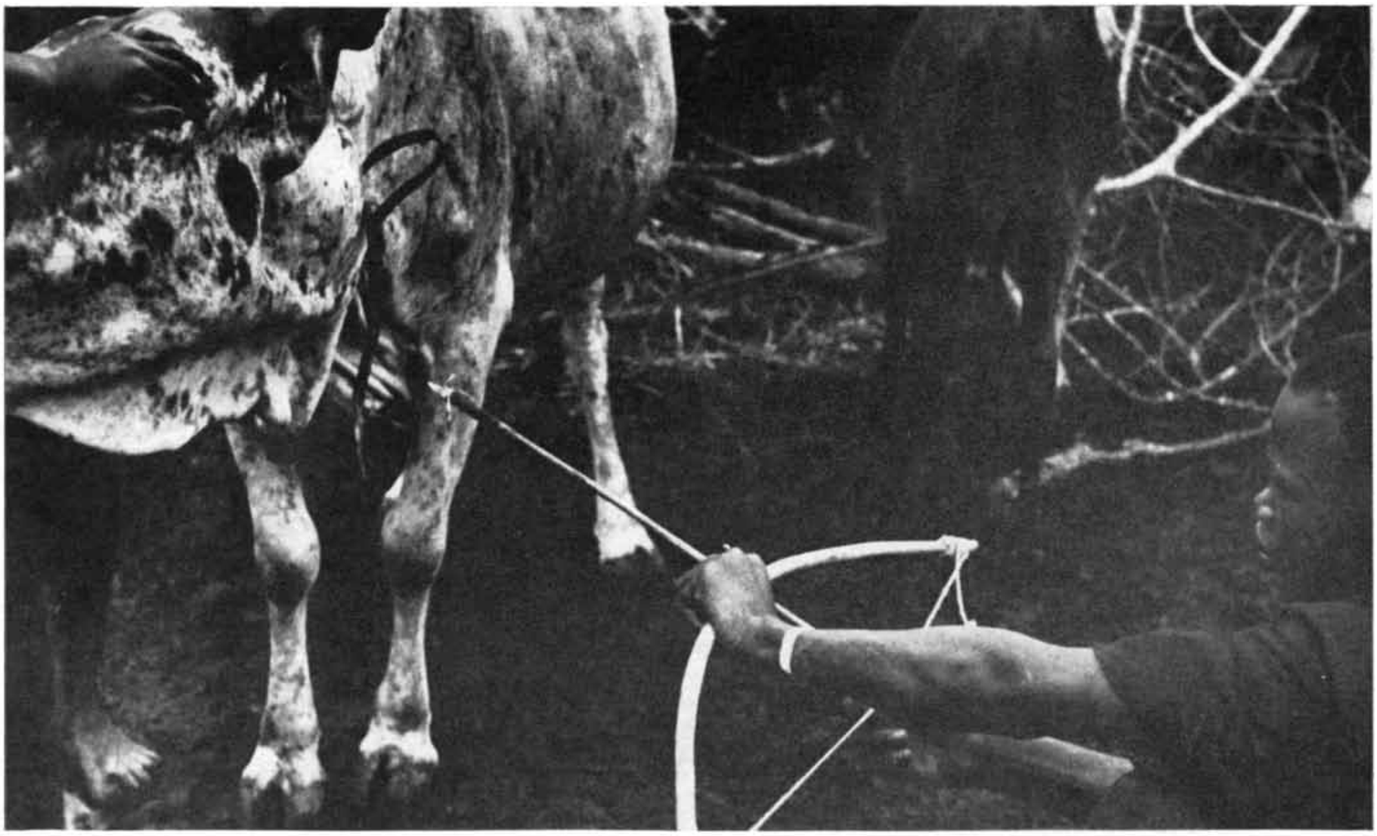
Second, in the past cattle and human epidemics have periodically led to a great reduction in the human and stock populations, giving the vegetation a chance to recover. The last population crash was late in the 19th century, and until very recently (certainly until the 1930's) Karimojong tribal land has almost certainly been underpopulated and undergrazed. Third, grazing in Karamoja is a tribal right, so that what one man saves only leaves something for another man to use.

For these reasons the Karimojong have no notion of the necessity—or even the desirability—to conserve grazing and to limit the number of cattle. The aim of the Karimojong herdsmen is to conserve their herds. They exploit their livestock largely by consuming the products of living animals: milk and blood.

All lactating cows are milked twice daily—morning and evening. First the calf is allowed to feed, in order to bring down the milk, then the cow is milked, and finally the calf is allowed to finish nursing. In addition, some four to eight pints of blood are taken at three- to five-month intervals from any animal except a bull or a cow that is pregnant or giving milk. The blood is tapped by tightening a thong around the neck of the animal enough to make the jugular vein stand out but not enough to choke the animal. Then an arrow with its tip wrapped in string (so that only about an inch can



KARIMOJONG HERDS stand at midday near a watering place in the western plains of the tribal area. The cattle show the humps and dewlaps characteristic of zebu stock. Here, at the end of the dry season, their humps are sagging (*note ox in right foreground*).



CATTLE BLOOD, a vital part of the Karimojong diet, is taken from an animal by piercing the jugular vein with an arrow wrapped in string. A thong is tied around the animal's neck, causing the vein to swell. Cattle are bled only once every three to five months.

penetrate) is shot into the vein. The blood flows freely, but when enough has been taken and the thong is released, the flow stops immediately.

The primary reason for exploiting the products of living cattle is the difficulty of storing herd produce in an area with an undeveloped technology located two degrees north of the Equator. The only animal product normally stored is ghee: butter that is churned from fresh milk curdled with cow's urine and then boiled and put in gourds. Otherwise the milk and blood products can be kept for only a few hours.

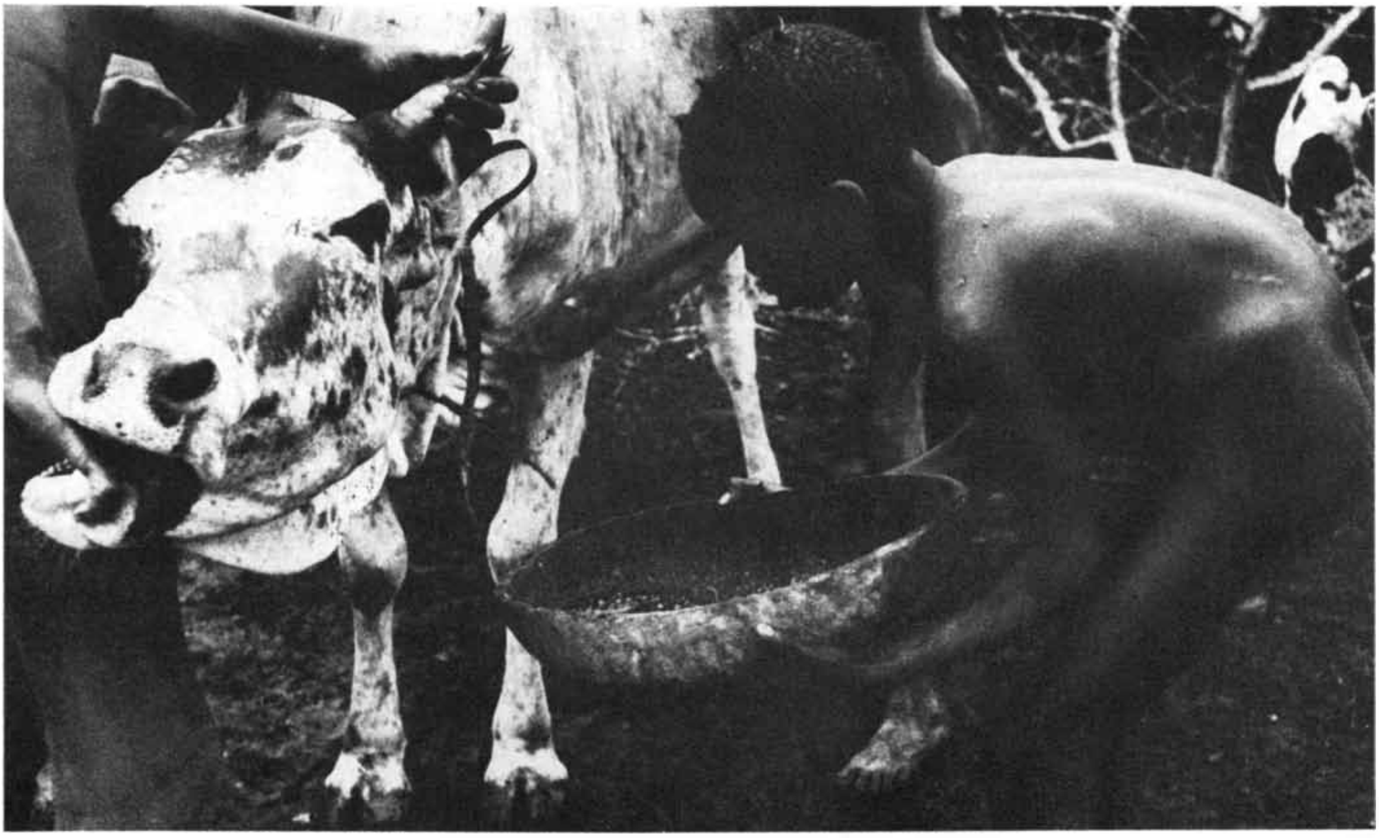
Meat can be dried and stored for long periods. If a Karimojong man has 400 pounds of meat from an ox slaughtered within his own settlement, however, his family will certainly receive less than a quarter of it; the rest must be shared with relatives, neighbors and friends. A man cannot refuse the begging of others, because reciprocal begging among the Karimojong is their method of social insurance. He never knows when his herd may be decimated, or when his wife's crops may fail. Thus a herd owner's family is better off taking milk and blood from an animal and keeping the animal until it dies. It is only the meat that the family need share with the neighbors.

The herding environment of the Karimojong is characterized by many uncertainties, the greatest of which is rainfall. It is impossible in the Karimojong tribal land to predict when the rain will fall, where it will fall and how much will fall. For example, in Moroto, the best-documented rainfall station, one can predict within 80 percent certainty that in the second week of March the rainfall will amount to anywhere from zero to 4.8 inches. Clearly the Karimojong cannot predict when the rain will fall. Neither can they predict where the rain will fall. In one year (1955) a station on the plains at Kangole recorded a rainfall of 20.01 inches, and a station only eight miles away at Lotome recorded 42.13 inches. Yet this is not a predictable pattern, since often Kangole has more rain than Lotome. Finally, the Karimojong cannot predict with any certainty how much rain will fall. The longest record of a rainfall station (Moroto) shows an annual rainfall of between 18 inches and 58 inches over a 34-year period.

Indeed, in the semiarid country of the Karimojong only two facts about rainfall seem beyond dispute. The first is that in general more rain will fall between September and March than between March and September (which enables the Karimojong to distinguish a wet season and a dry one). The second is that in general more rain will fall on the highlands than on the plains (which usually enables the Karimojong to find dry-season grazing for their cattle somewhere in the highlands). There is no month of the year without some probability of rainfall, and during the dry season anything from one inch to five inches may fall somewhere; it is also possible for areas to be without rain for four months of the dry season. Such extreme variability, affecting as it does the growth of herbage available to the livestock, has marked effects on Karimojong herding operations. The only two indubitable facts provide too narrow a base for anything but contingent strategies of livestock husbandry.

Topographically the setting for Karimojong herding is about 4,000 square miles of high plains (3,600 to 4,500 feet above sea level). The corners of the Karimojong tribal land are roughly marked by the mountain masses of four long extinct volcanoes, and the tribal land's eastern flank is a rocky ridge forming the watershed between the Nile and the Red Sea. Topographic and rainfall variability, together with variations in soil composition, water supply and vegetational cover, present the herdsman with a variety of habitats in which to operate.

The extreme eastern and western flanks of the country are both highland areas that we shall call Zone I. The shallow rocky or sandy soils are covered by



BLOOD IS CAUGHT in a bowl held by a herdboy. From four to eight pints will be taken and bleeding stops when the thong is loosened. A mixture of blood and milk is the standard food of the cattle camps, so that the herders literally live off their animals.

open deciduous woodland with a ground cover of perennial grasses. Rainfall is usually sufficient to keep water in at least some of the springs, rock pools and the stony upper courses of rivers.

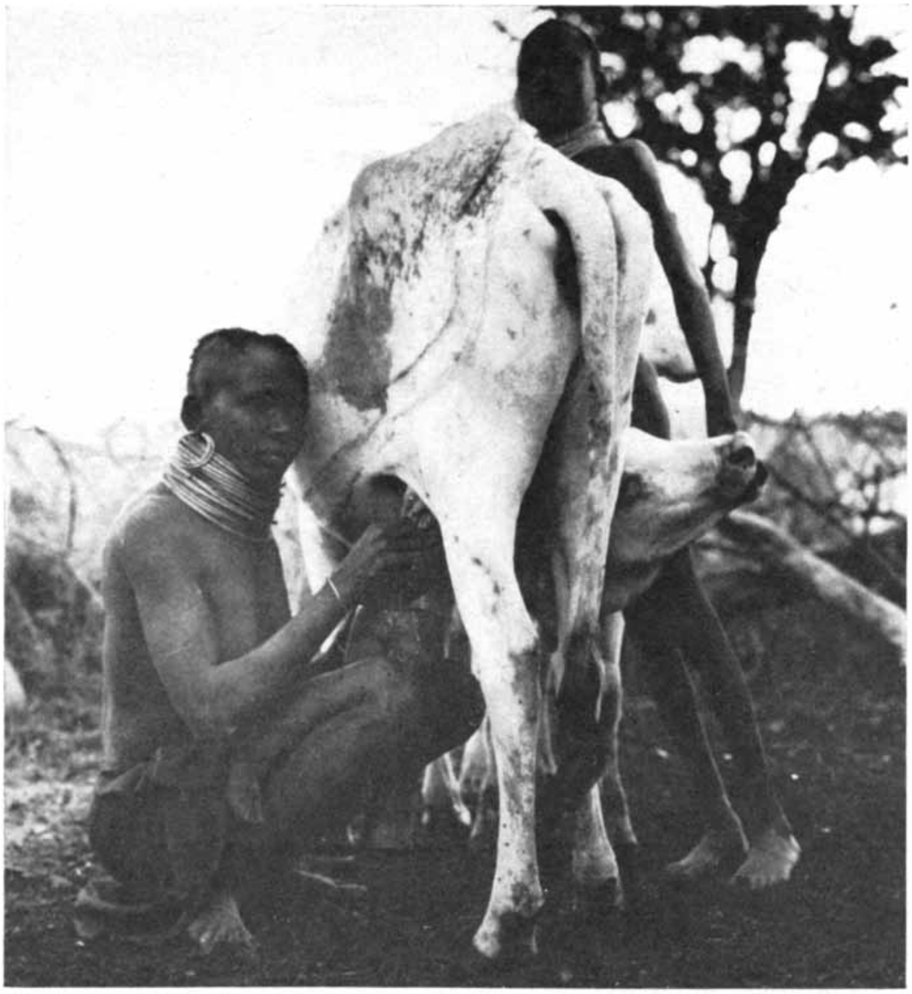
The central region (Zone II), which is crossed by several wide rivers, has sandy and clay loams and rich alluvial soil. Subsurface water is always available at known areas in the sandy riverbeds and can be tapped by digging wells. This is the region of most intensive land use. The Karimojong permanent settlements are located near the areas of alluvial soil, which are used for the cultivation of crops. Cattle are grazed near the settlements during the rainy season, and flocks of goats and sheep stay in the area all year. As a result the original vegetation has been destroyed and there is a secondary growth of scattered *Lannea* and acacia bushes or dense thickets of acacia and *Sansevieria*. The ground cover is mainly annual grasses and herbs. The rainfall varies markedly from year to year and from place to place.

The western plains (Zone III) are an area of red sandy loam ridges alternating with depressions of poorly drained heavy dark clay. It has a good growth of perennial grasses. The red ridges are treeless; the clay valleys are marked by a growth of scattered spindly *Acacia drepanolobium*. In this zone the rivers disappear underground, but their courses are marked by open woodlands of water-loving trees, particularly *Acacia seyal* and *Acacia gerrardii*. Sparse muddy ponds provide permanent or semipermanent water sources, and clay pans hold water for some three weeks after dry-season rainstorms.

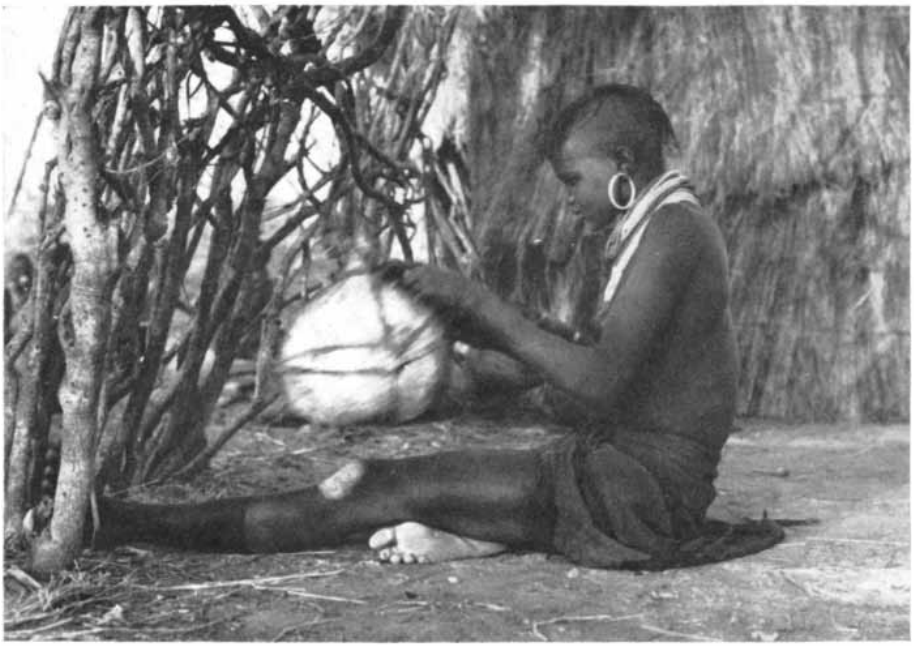
It is clear that the Karimojong herdsman must evaluate many variables in planning his herding program. Very few permanent sources of water are available on the western clay plains and in the eastern highlands (although the eastern highlands, with their higher rainfall, rarely lack water somewhere). The central area has relatively abundant permanent water, but its grazing, although nutritionally rich, is sparse during the rains and nonexistent during the dry season. The western plains and eastern highlands have abundant perennial grasses and extensive grazing areas, but their grasses, when dry, are nutritionally deficient. Dry-season rainstorms are needed to make the nutritionally rich green sprouts grow from the perennial roots, and particularly on the western plains such storms are infrequent. The waterlogged, sticky clay soils of the western plains are hazardous for cattle and herdsmen in the wet season, as are the tall grasses, which shelter predators dangerous to both livestock and herder. In the eastern highlands there is East Coast fever, a tick-borne disease usually fatal to cattle, and north on the watershed there are the Suk, who regularly raid Karimojong cattle and kill the herders.

The Karimojong respond to these stern conditions by manipulating the environment itself, by manipulating the internal structure of the herd and by manipulating the herd in relation to the environment. They are, however, far from being able to engage in each kind of manipulation to the same degree or with the same degree of success. The Karimojong manipulation of the environment to increase productivity is limited; its most important element is controlled burning. Karimojong herdsmen burn the dry grass on parts of the peripheral grazing area each year in the hope that the dry-season rains will come and the livestock can subsist on the remaining dry grass, supplemented by the fresh green shoots (*anomot*) that grow from the roots of the perennial grasses after burning. Even if the "grass rains" fail, the cattle can survive on the dry grass. The cattle, however, cannot maintain good condition without the nutritious *anomot*.

The Karimojong recognize and name various diseases, and they try to control the movement of men and animals to avoid the spread of disease. Moreover, they dig and maintain *atapars:* ponds to



MILKING at a home settlement is done by a mother-and-daughter team. The daughter stands, holding the cow's calf (*right*), which has been allowed to suckle briefly. The mother crouches with a vessel between her knees and draws milk while the cow grooms its calf. After some milk has been taken for settlement use the calf will be allowed to suckle again.



BUTTER FOR HOMESTEAD USE is made by a girl during a visit to an outlying cattle camp. She shakes a thong-wrapped gourd filled with curdled milk. When the butter forms, she will boil it to make ghee, which she will carry back to the homestead. Because the Karimojong have no means of refrigeration, ghee is the only milk product they can preserve.

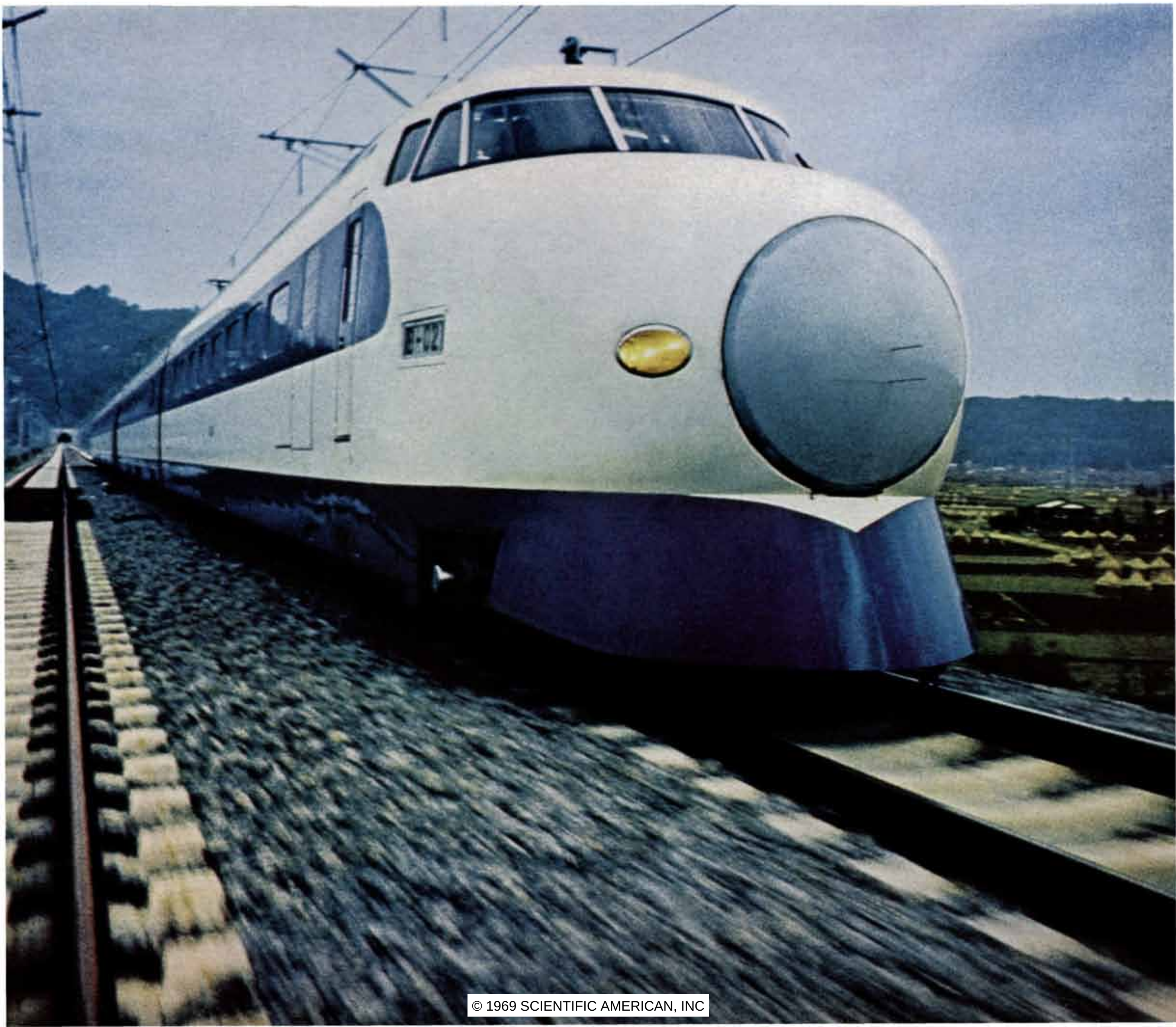
catch and hold water through at least part of the dry season. The custom is falling into disuse since the government started to dig wells and build dams. This is the extent to which the Karimojong manipulate their environment.

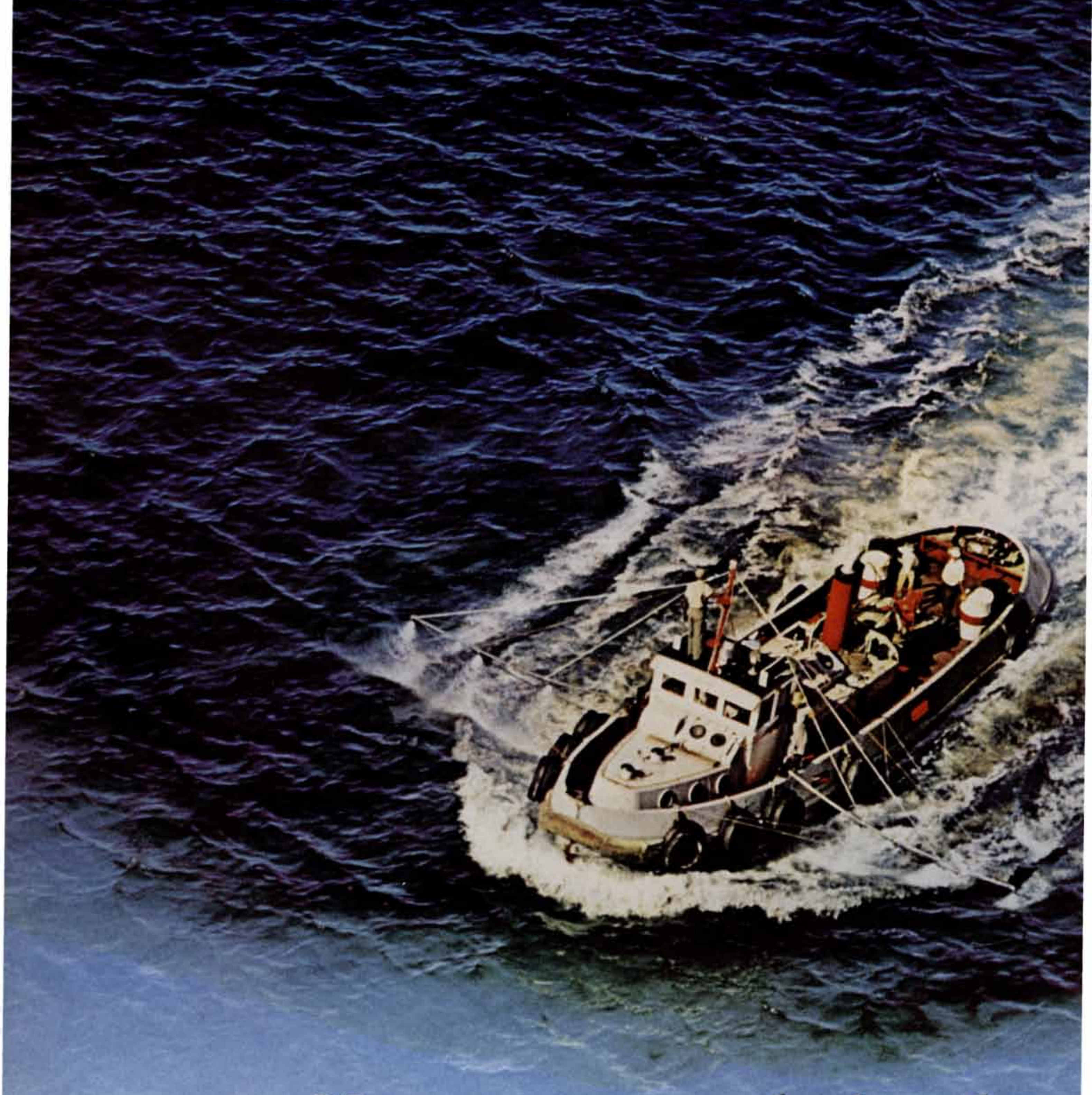
Manipulation within the Karimojong herd is also limited. The Karimojong select certain male animals to be herd bulls. Apparently bulls of light hide colors are preferred, and also bulls with a pendulous penis; the Karimojong believe this indicates an animal's female progeny will be good milkers. They do not castrate their bulls young, since calf mortality is high (up to 17 percent, even in a year without an epidemic) and they might end up with no bulls if they castrated the male stock before three months, as is common in the U.S. Castration is delayed until the male animal is more than a year old and the herd owner can be reasonably certain it will survive to maturity.

The Karimojong value their female animals highly and do not trade or kill them. Oxen (and an occasional barren cow) are slaughtered at religious ceremonies. The meat is then distributed to the people at the ceremony, with the largest quantity usually going to the old men. Since religious ceremonies are held most frequently in times of poor rainfall or after a crop failure, this is a way to reduce the herds slightly and to distribute meat to the human population when other foods are in short supply.

The Karimojong do not, however, employ slaughter or sale to systematically eliminate from their herds male stock, or female stock of low fertility or low milk yield. There is no obvious advantage to a herdsman's family in slaughtering culls from the herd. The government cattle buyer purchases only large oxen and cows, animals with which the Karimojong herdsmen do not readily part, and he pays little. With the money received for an 800-pound ox (which would yield some 400 pounds of dressed meat) a Karimojong could buy less than 300 pounds of cornmeal, the only food sold in relatively large quantities by the local shops. Furthermore, there are advantages for the Karimojong in keeping animals of low productivity. They are a source of blood, and they provide most of the livestock that is given away in bridewealth exchange and formal friendship contracts.

Bridewealth exchange and formal friendship are the means whereby a Karimojong herd owner can extend his circle of supporters. Administration and police





New way to save the beaches,

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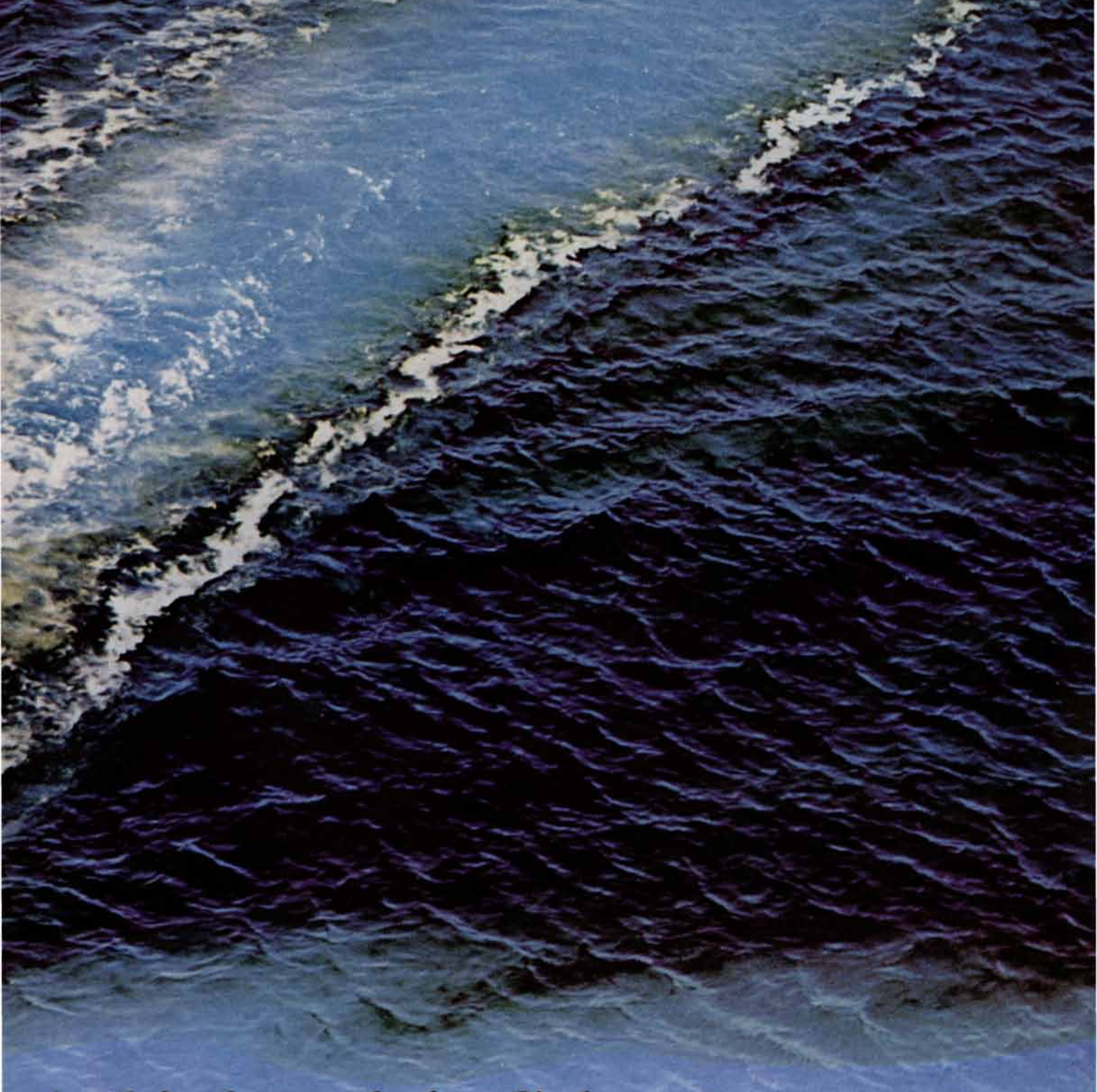
After the wreck of the supertanker *Torrey Canyon* two years ago, tons of detergents were used in an attempt to destroy a 700-square-mile oil slick before it reached the beaches of Cornwall and Brittany. It was a gallant effort. But the toxic detergents did far more damage to marine life than the oil itself did.

Scientists at Esso Research (a Jersey affiliate) were grappling with this problem long before the *Torrey Canyon* hit the rocks. And, little more than a year later, they found their answer. Corexit® 7664—an entirely new disper-



the birds and the fish.

sant that contains no toxic detergent.

Laboratory tests and practical application in subsequent tanker accidents have proved that Corexit disperses oil slicks far better than any detergent. And it doesn't even hurt a shrimp, one of the most sensitive sea creatures.

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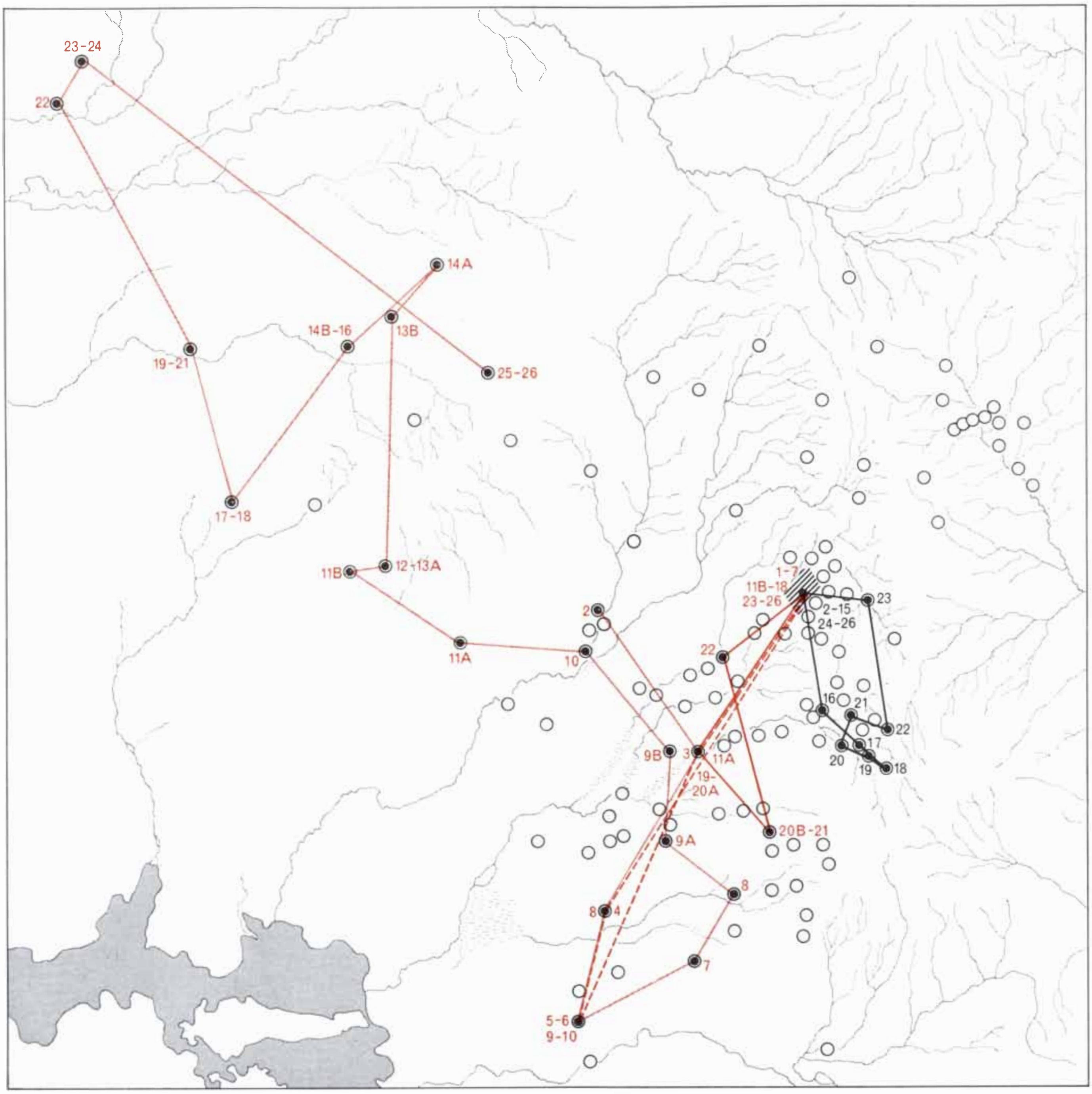
Corexit is not a cure-all for every type of oil spill. But it certainly does a great cleaning job on the open sea. Properly used and applied in time, most offshore oil spills need never reach a beach again.

A happy thought for the coming summer.

Standard Oil Company (New Jersey)

protection provided by the government are minimal at the local level. The main concern of the administration is to prevent intertribal raiding and cattle theft (which is considered by the Karimojong to be a valid means of enhancing their livelihood, not a crime). Murder would almost certainly be dealt with by the government, but the Karimojong have to depend on their friends and relatives, or on help from a magico-religious practitioner, to recover stolen property or prevent a man's rights from being denied by another Karimojong. The giving of livestock is the only way a man can extend his supporters beyond those relatives he was born with. He can marry a woman with many relatives and give each some livestock at the marriage ceremony. He can also contribute to the bridewealth of another man and thus ac-



SEARCH FOR GRAZING sends Karimojong herdsmen far afield. The open circles locate cattle camps used by one or another of seven homesteads in the Emoruangaberru area over a 25-month period. The agricultural activities of the homesteads were confined to a small nuclear area (*black hatching*). The effect of family size on herding practices is evident in the contrast between the movements of Pulukol's and Apalokosem's herds. With five senior herdsmen and four herdboys, Pulukol divided his cattle into two herds. One, a far-ranging camp herd, traveled up to 55 miles from home and never camped twice in the same place (*light colored line*). Numbers by each campsite indicate the months spent there; an accompanying letter indicates a stay of less than a month. Pulukol's second herd stayed at his homestead during the rainy seasons and made two circuits nearby during the two dry seasons (*colored solid and broken lines*). Apalokosem, an elderly man with only one grown son, could not divide his herd or move it far. For 15 months, a period of exceptionally good rainfall, his herd stayed at his homestead. Its maximum journey, some 12 miles, was made during the following dry season (*black line*). The authors could not determine the location of two of the herds during the first month of the period.

quire a formal friend who will support him as a relative would.

Thus manipulation within a Karimojong herd is limited to castrating bull calves at the age of about a year and using livestock of low productivity as a means of enhancing the owner's position in the community. The main effort of Karimojong husbandry is directed not so much to manipulation of the environment or of the animals within the herd as to manipulation of the herd within the environment. The Karimojong must take the animals to water and grazing; it is not technologically possible for them to bring water and fodder to the animals. Since any Karimojong herdsman has the right to graze his animals anywhere within the 4,000 square miles of the Karimojong tribal land, and since rainstorms in the dry season are often quite localized, cattle are moved frequently and often over great distances. The seven homesteads consisting of 250 people we studied used less than a square mile for agriculture and settlements but over a two-year period ranged across 500 square miles in grazing their herds [*see illustration on preceding page*]. Since there are many other Karimojong groups in the area, the groups overlap and intermingle. This is particularly true during the dry season; as the herdsmen say, "The sun mixes us up."

The movements of an individual's herd are influenced by many factors. Good grazing is available to a limited extent during the rainy season in the region of the permanent settlements but is always most abundant in the peripheral grazing areas, and during the dry season it is available only there. Water is more abundant in the area of the permanent settlements than it is in the peripheral grazing areas.

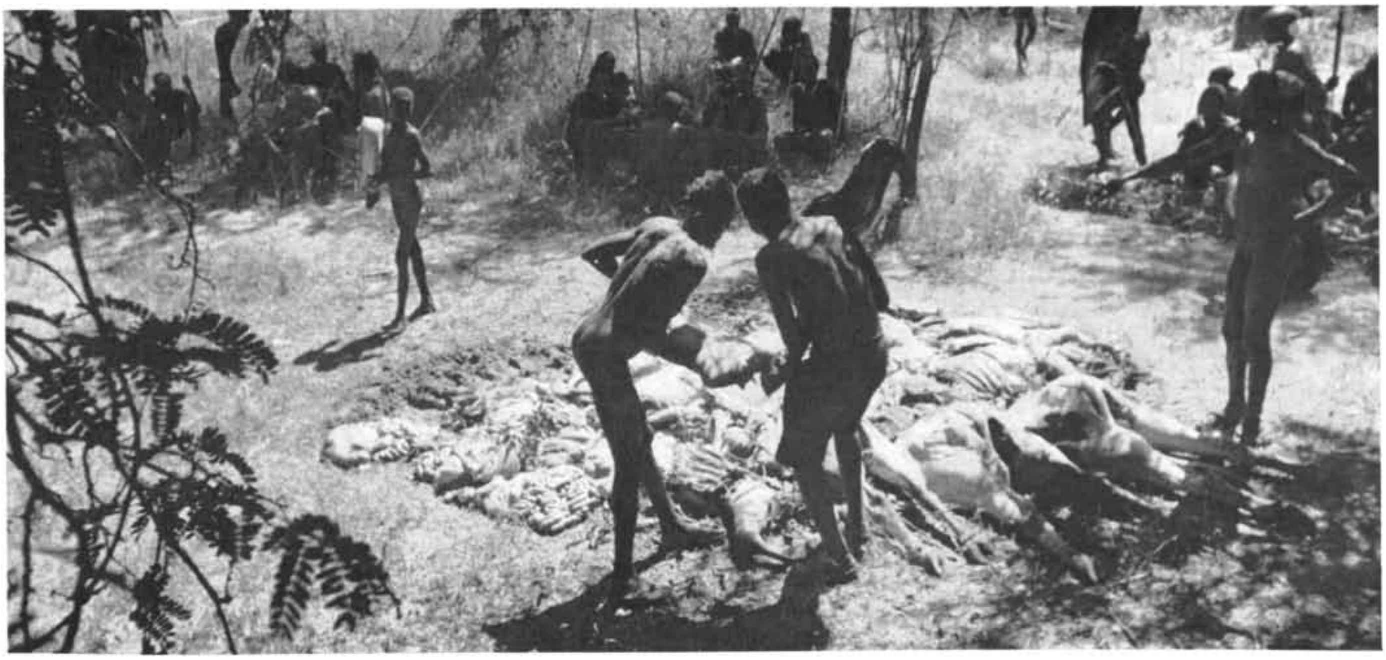
Another important consideration is the food needs of a herd owner's family. The young men and boys can travel with the herds wherever they go, and they live on milk and blood. From March to November, however, the married women and their daughters must spend most of their time near the permanent settlements in order to do the agricultural work.

Herd movements are also partly determined by the herding help available. A man with many sons, particularly if they are young unmarried men, can divide his herd and keep part of it in or near the settlement for as much of the year as possible. The rest of the cattle can be kept as a separate camp herd and graze the year round in the peripheral grazing regions, the areas of optimum grazing where the animals keep in excellent condition and provide abundant food for the herdsmen. A man with few sons must either herd with others and share the yields of his cattle or limit the movements of his livestock.

In addition to variables such as grazing, water and family size there are variations in disease patterns, danger from predators, danger from enemy tribes and the hazards of sticky clay soils. Each herdsman must try to gain what information he can about current grazing conditions, take into consideration the particular problems of the grazing area he is considering (as well as the needs of his family) and finally determine the particular place where his herd will graze. It is not surprising that there are such wide differences among the herd movements of different men, and even among the herd movements of the same man in different years.

In spite of the large numbers of cattle in Karamoja there is not sufficient livestock produce to feed the entire population all year. Only an estimated 12 percent of the cattle give milk for human consumption because of the high proportion of male stock in the herds (40 percent or more), the long maturation period for cows (3½ or four years), the long period between calves (more than 14 months), the short lactation period (less than eight months) and the fact that about half of the cows that are giving milk give only enough for the needs of the calf. Those cows with extra milk will during a harsh dry season give less than two pints a day beyond the needs of their calves. When grass is abundant, up to four pints a day of extra milk will be available. The theoretical amount of milk per person per day (based on the human and stock census) is of the order of a pint or less in the dry season and two pints or more during the rains. This, however, postulates a uniform distribution of milk among the people, which is not the case.

The division of the population between stock camp and permanent settle-



INITIATION CEREMONY is one of the rare occasions when the Karimojong slaughter cattle. As part of the ritual transition from boyhood to manhood, each candidate must spear an ox. The animal is then dismembered and its parts are added to a common pile (*center*) before roasting. The donor of an animal receives head and neck for his own use and shares this portion with his whole family.

ment, which is an important aspect of the manipulation of the herds within the environment, is also important in the distribution of cattle products among the population. The Karimojong herdsmen in the stock camp occasionally get sorghum beer, if their wives or girl friends come to visit and bring it, and in Zone I they can gather wild fruits while herding. Otherwise they live exclusively on the produce of their herds: the daily supply of milk and blood, and occasional meat if an animal dies or is slaughtered.

We tabulated the allocation of milk at a stock camp on one day of each month from March through June. The men and herdboys received 2½ pints of milk or more, in addition to receiving a portion of blood. The women and girls were allocated about a pint of milk each. Their only other food resource was their own grain, brought on donkeyback from the permanent settlements.

The men and boys drink the whole milk, often mixed with blood. The women and girls churn out the butter (which is stored as ghee and taken to the people remaining in the permanent settlements) and drink the buttermilk or add it to the porridge they prepare.

In the permanent settlements, on the other hand, the food is porridge—usually sorghum but occasionally corn or millet—with milk as a garnish when the cattle are nearby. When no milk is available, other garnishes are used: mushrooms, the fruit of the tamarind and other trees, wild honey and boiled herbs.

To summarize, the Karimojong herding system is a response to the complex problems faced by the Karimojong. These problems are (1) the lack of technological means for storing food obtained from livestock and the inability to sell livestock at a price commensurate with their value to buy other foodstuff at a price commensurate with its value; (2) the environmental and technological conditions that make it necessary to take livestock to forage and water instead of bringing water and forage to the livestock; (3) rainfall that is highly unpredictable in both time and space; (4) a large variety of habitats for grazing, each with its own peculiar hazards and advantages; (5) a conflict between the needs of the cattle for good grazing and the needs of those people tied down to the permanent settlements, particularly the women and girls, for cattle produce; (6) the periodic tribewide shortages of grazing and water that can cause high mortality even among the hardy Karimojong livestock; (7) the need for protecting a man's social and political rights, and for insurance against catastrophic losses of livestock by enemy raids, epidemics, thirst or starvation.

The Karimojong response to these problems is (1) to keep large numbers of male animals as well as female ones, and to use the produce (milk and blood) rather than slaughter the animals for meat; (2) to move livestock freely throughout the tribal land; (3) to split herds into independent units that move in response to the often conflicting needs of the settlements for milk and the needs of the livestock for grass and water; (4) to run large numbers of animals of low productivity but great hardiness to convert the sparse, rough herbage into food for the human population; (5) to exchange cattle with friends or in-laws, who will then provide support in time of social or political need or lend livestock or give milk if herds are decimated.

Karimojong herding operations do not conform to notions of rationality expressed in the dairy and ranching enterprises familiar to Western economies, but they nonetheless exhibit a rational solution to the problem of supporting a substantial population in a variable environment. When other approaches are recommended by outsiders as being "more rational," it is usually with the implicit assumption that two of the major constraints in the ecological situation can be changed: the total energy level in the system can be increased by inputs of various kinds (building dams, drilling for water, importing seed and so on) and the ratio of available resources to dependent humans can be increased by resettling some of the people elsewhere. The first of these changes represents a considerable financial burden for a developing economy; the second, a grave political problem for a new nation. In the ecological system actually presented by the subsistence herding of the Karimojong it is hard to see how their rationality can be improved on. The same conclusions probably hold for the other traditional herding systems found throughout Africa.

BOWL OF BLOOD AND MILK is offered by the bride's family to the men escorting the groom at a Karimojong wedding. Prone man at left drinks while a host, seated at right, stirs the mixture with a stick. The offer of cattle produce by the bride's side echoes the groom's present of cattle to her family. Surplus cattle among the Karimojong are mainly used to acquire additional wives.

ROTARY ENGINES

Several ingenious engines work with a rotary motion instead of the traditional reciprocating one. The aim is to combine the virtues of the reciprocating engine and the gas turbine

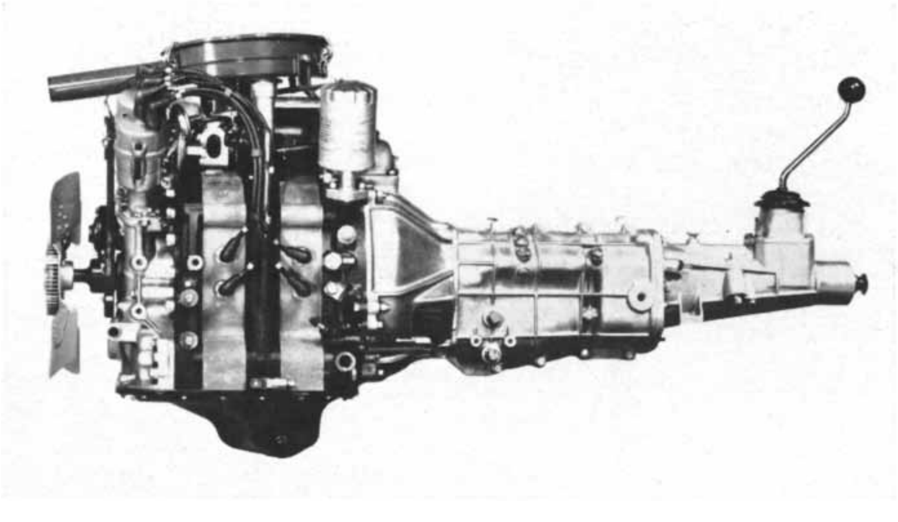
by Wallace Chinitz

Each year in the U.S. alone more than 10 million reciprocating-piston internal-combustion engines are built to provide power for automobiles, trucks, boats, locomotives and small to medium-sized airplanes. These engines are all based on a principle first demonstrated in 1876 by Nicolaus August Otto, who found a way to burn a compressed mixture of illuminating gas and air in the cylinder of an engine without producing destructive explosions. The "Otto cycle" of most modern reciprocating internal-combustion engines is usually an operating sequence in which the piston makes either two or four strokes, most commonly four. The first stroke draws a mixture of fuel and air into the combustion chamber, the second compresses the mixture, the third (the power stroke) follows ignition of the mixture, the fourth expels the waste gases. The reciprocating engine has been so successful that one is seldom aware that a small army of inventors is determined to see it replaced by some kind of "rotary" engine.

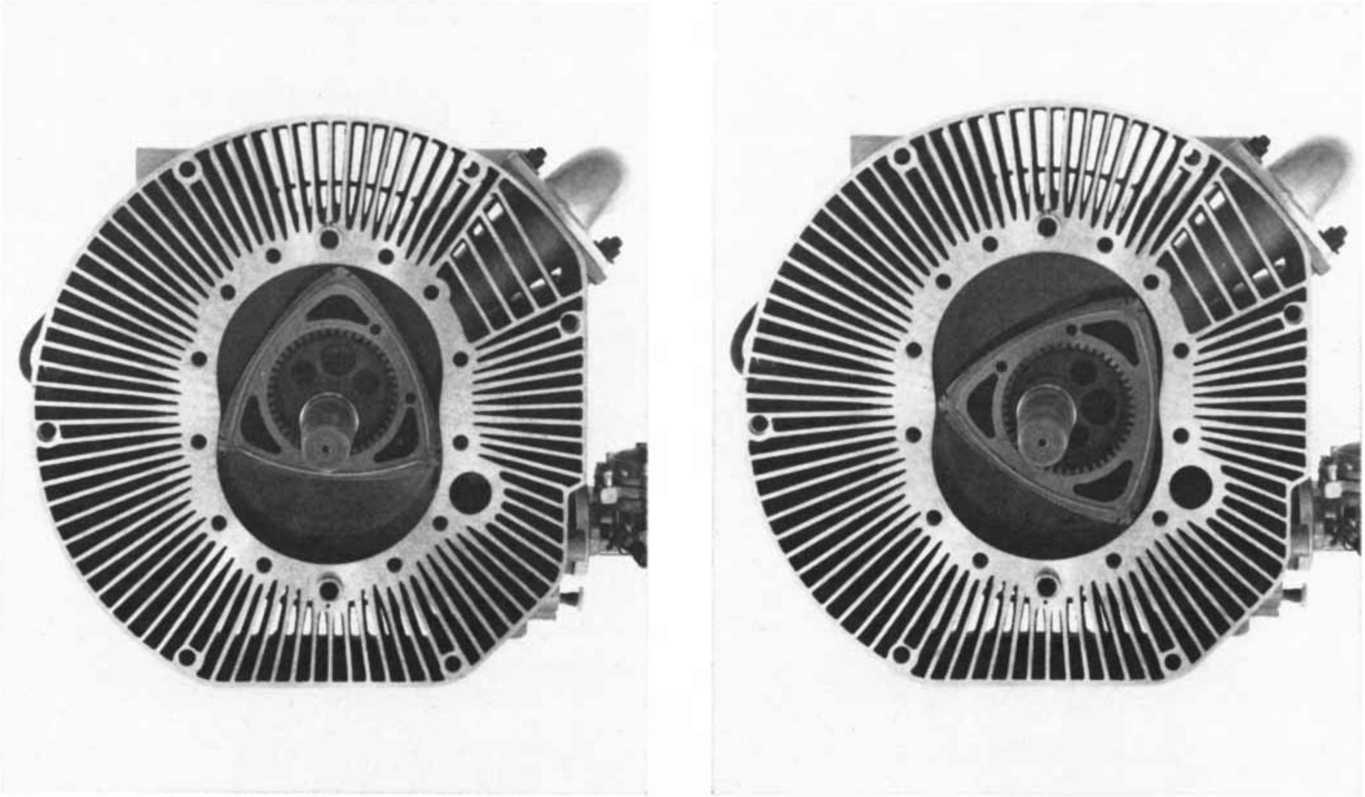
For the task of powering high-speed aircraft the reciprocating-piston engine has already been replaced by a nonreciprocating internal-combustion engine: the gas turbine jet engine, or turbojet. The turbojet was initially able to supplant the reciprocating engine for aircraft because it overcame the speed limitations formerly imposed by the propeller and because it could liberate a large amount of energy in a short time. In due course turbojets were found to be more reliable than piston engines, but it was primarily the military need for high-speed aircraft that induced the major powers to invest billions of dollars in the development of these engines. As a consequence of this massive military investment powerful turbojets became available for commercial aircraft.

The failure of the gas turbine to emerge as a significant competitor of the reciprocating engine for land and water vehicles testifies to the reliability, low cost, efficiency and high performance that have been engineered into the Otto cycle by some 90 years of development. The gas turbine may eventually power the family car, but automobile manufacturers seem to be less optimistic about the possibility than they were in the early 1960's. Meanwhile the inventors who hope that the Otto engine will be replaced by a rotary engine other than a gas turbine have found periodic encouragement in the industry. One rotary engine, conceived in 1956 by Felix Wankel, is available in two automobiles built by the German manufacturer NSU Motorenwerke AG: the Spider, which has a 64-horsepower Wankel, and the larger Ro 80, which has a two-rotor Wankel of 125 horsepower. A Japanese automobile, the Mazda 110 S, is powered by a similar two-rotor Wankel, built under an NSU license, that delivers 128 horsepower at 7,000 revolutions per minute. In the U.S. the Curtiss-Wright Corporation has had engines of the Wankel type under development for more than eight years. In cooperation with Fichtel & Sachs AG of West Germany, Curtiss-Wright has developed an air-cooled 20-horsepower Wankel engine that has recently been adopted by several manufacturers as a power plant for snowmobiles. The single-rotor unit is built by Fichtel & Sachs and distributed in the U.S. by Curtiss-Wright.

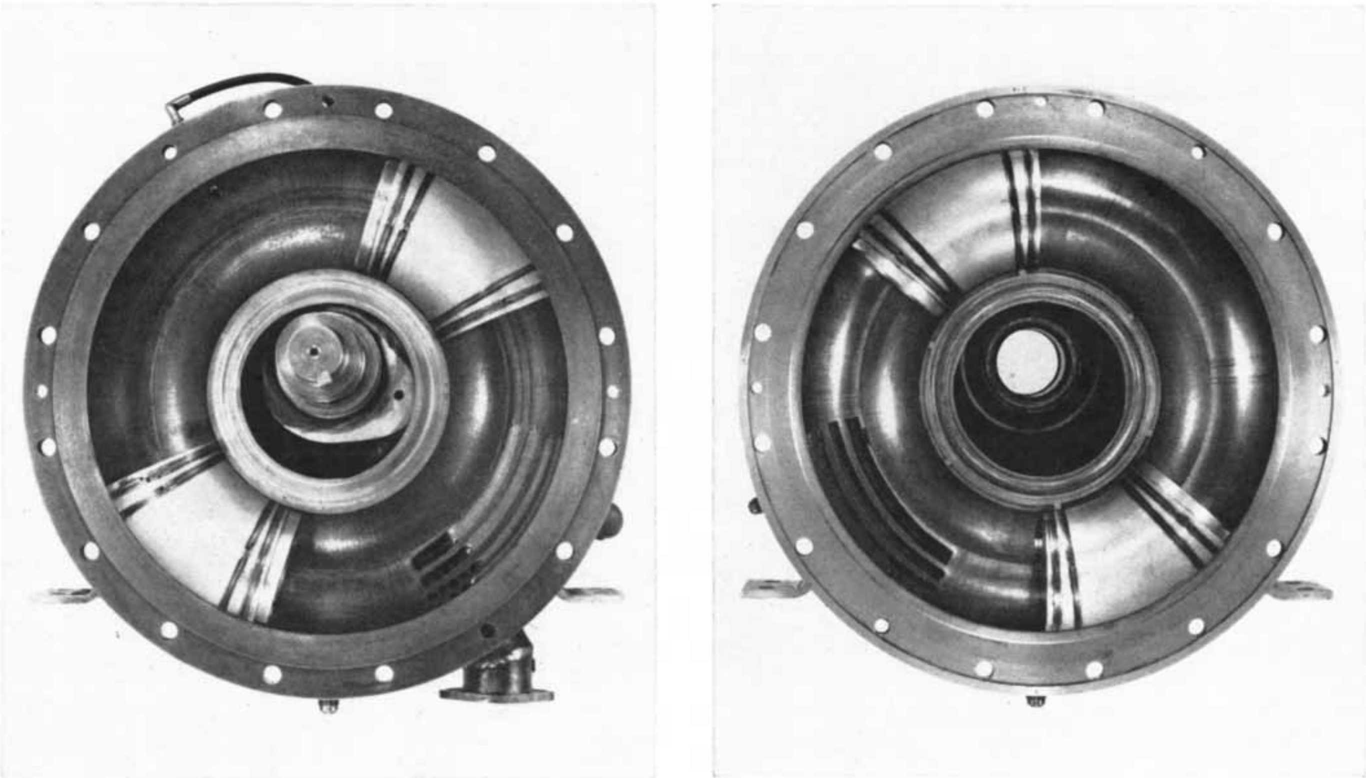
The relative virtues and drawbacks



JAPANESE ROTARY ENGINE powers a new sports sedan not yet available in the U.S., the Mazda 110 S, manufactured by Toyo Kogyo Company Ltd. of Hiroshima. This engine of the Wankel type delivers 128 horsepower at 7,000 revolutions per minute; with it the Mazda reportedly can cover a quarter of a mile from a standing start in the remarkable time of 15.8 seconds. The engine contains two three-lobed rotors, which are housed in the two light-colored chambers seen here from the side. Each chamber is equipped with two spark plugs, presumably to increase combustion efficiency. The engine has a total displacement of 60 cubic inches (30 cubic inches in each chamber) and a compression ratio of 9.4 to one.



CURTISS-WRIGHT ROTARY ENGINE, also of the Wankel type, has recently been adopted as a power plant by several builders of snowmobiles. The two photographs show how the rotor moves into the two lobes of the chamber as it rotates eccentrically. The intake is at the lower right, the exhaust at the upper right. The engine was developed in collaboration with Fichtel & Sachs AG of West Germany, which builds the units for distribution in the U.S. The engine is air-cooled and develops 20 horsepower at 5,000 r.p.m. It has a displacement of 18.5 cubic inches and a compression ratio of eight to one. It weighs only 2.8 pounds per horsepower.



TSCHUDI ROTARY ENGINE, conceived by the Swiss-born engineer Traugott Tschudi, has been under development for more than 40 years. The engine contains two pairs of pistons that travel in a doughnut-shaped chamber. These photographs of a working prototype of the engine were taken in the shops of the Blair Tool and Machine Corporation. The engine has been opened to show how the two pairs of pistons are attached to separate halves of the toroidal chamber (*see top illustration on pages 94 and 95*). The engine delivers 88 horsepower at 1,600 revolutions per minute. The displacement is 77 cubic inches, the compression ratio eight to one.

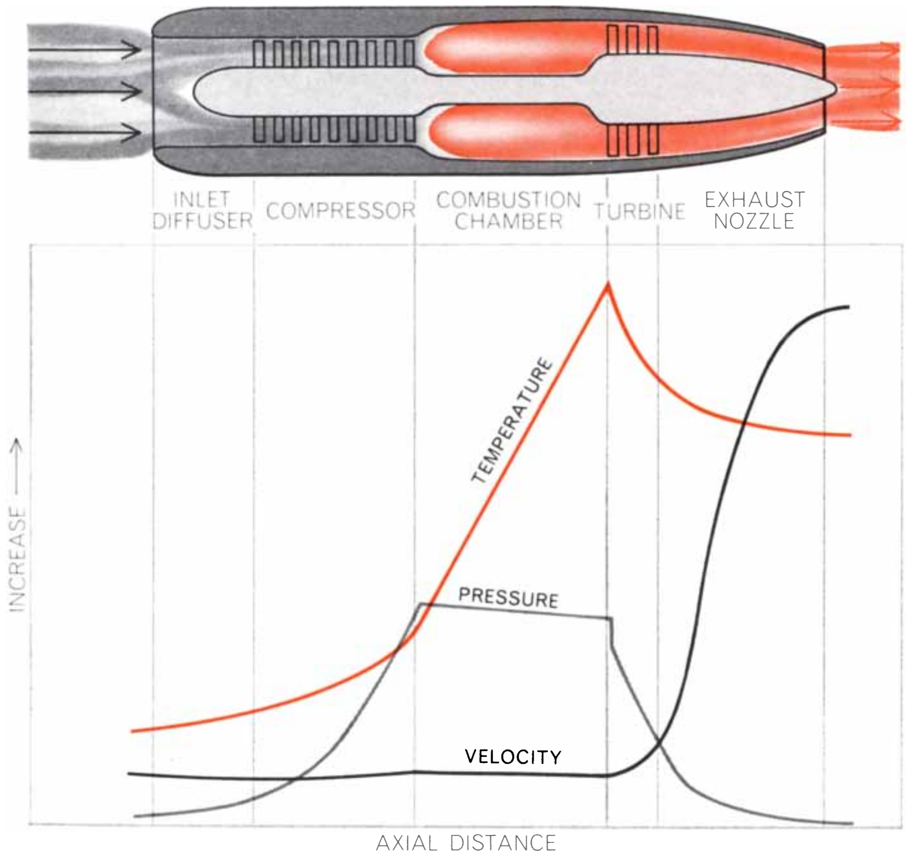
of rotary and reciprocating engines become clear if one contrasts the operation of a gas turbine with that of the familiar spark-ignition reciprocating-piston engine. The reciprocating engine [*see illustration on opposite page*] consists of a cylinder (at least one) within which a piston moves in and out. The piston is attached to a piston rod that is connected to a crank and a crankshaft. The head of the cylinder contains a spark plug and is fitted with two valves: an intake valve to admit the mixture of fuel and air, and an exhaust valve. At the beginning of the cycle the intake valve opens and the piston travels outward, drawing a charge of fuel and air into the cylinder. Next, with both intake and exhaust valves closed, the piston travels inward, compressing the mixture. When the piston is all the way in, or close to it, the spark plug fires and ignites the mixture. The combustion of the gas increases its pressure (and temperature), which drives the piston outward, imparting energy to the crank by way of the connecting rod. When the piston is almost all the way out, the exhaust valve opens, and as the piston travels inward again the combustion products are forced out of the cylinder. The four-stroke cycle then repeats. Engines with two-stroke cycles also exist and are widely used. In the diesel engine no spark is required for ignition; the air-fuel mixture is so highly compressed that it ignites spontaneously at the end of the compression stroke. All reciprocating engines, however, fire discontinuously.

The gas turbine engine, on the other hand, fires continuously [*see illustration below*]. It draws air through a diffuser and into a compressor that raises its pressure. The high-pressure air passes into a combustion chamber, where it is mixed with fuel and produces an intense flame. The combustion gas is directed through a turbine, where its pressure decreases and its velocity increases. The function of the turbine is to drive the compressor. The gas velocity is further increased as it passes through an exhaust nozzle before it is finally expelled into the atmosphere. A net force (thrust) results from the change in momentum of the gases between the inlet and the exhaust. If the gas turbine is intended to drive an automobile, it must be designed so that as much energy as possible is absorbed by the turbine; the turbine power is then divided between the compressor and the load on the drive shaft.

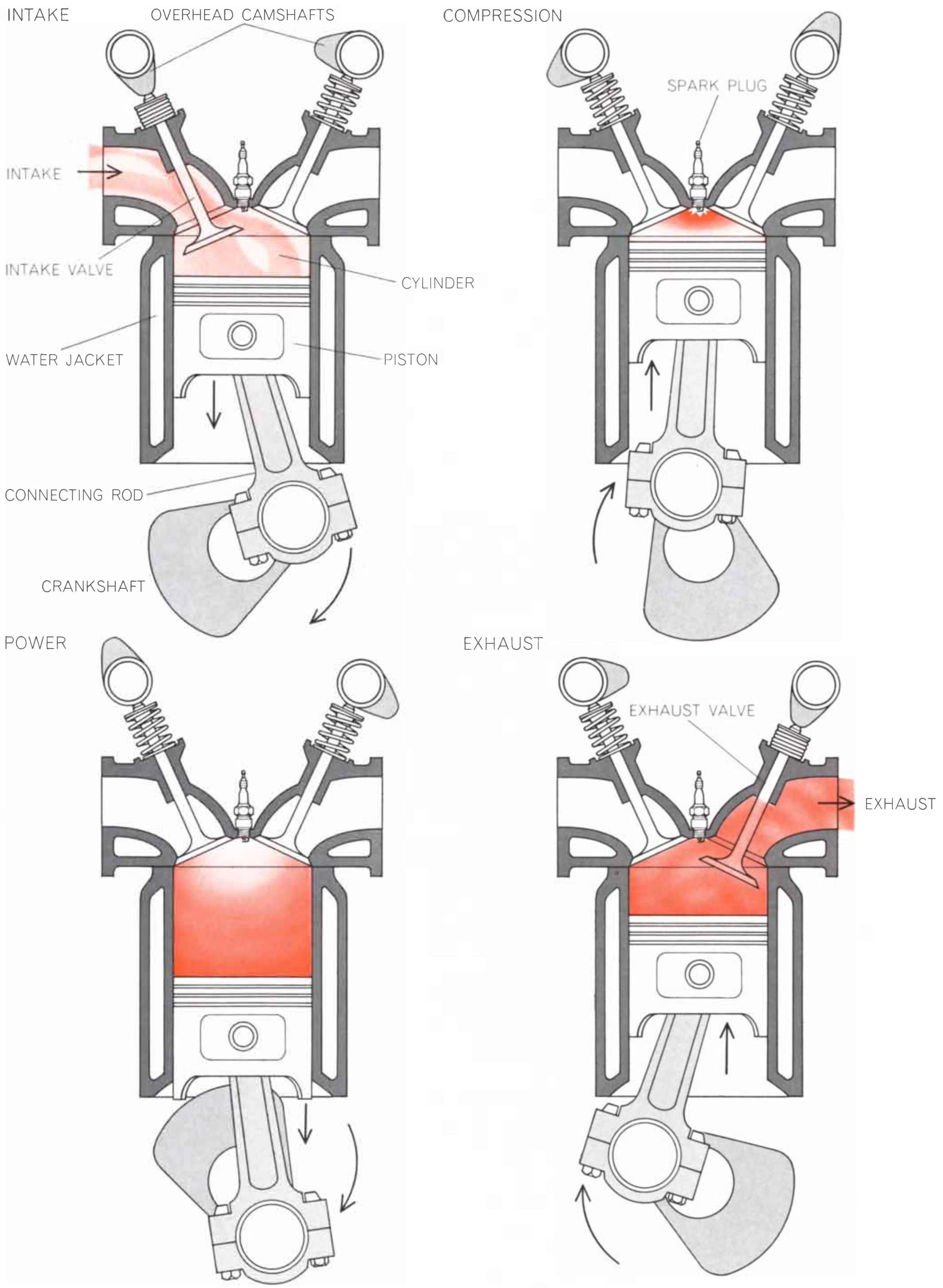
Because the gas turbine operates continuously and because power is directly related to the quantity of fuel that can be burned in a given unit of time, one can obtain a high output of power from a small engine. Moreover, the absence of reciprocating parts permits higher operational speeds in a gas turbine than in an ordinary piston engine, and this too leads to higher power output. In the piston engine the conversion of linear reciprocating motion to rotary motion, by means of the connecting rod-crankshaft arrangement, is inherently wasteful of the energy supplied by the combustion process. During the power stroke, as the piston pushes on the piston rod, the crank (and crankshaft) moves through approximately half a circle. At the start of the piston's travel, when the crank is near its inward dead center, virtually none of the force of the piston is transmitted to the crank. The transmitted force reaches a maximum when the crank is at right angles to the piston axis, that is, when the piston is about halfway down the cylinder; then it decreases again. As a result the energy transmitted to the crankshaft is only a fraction of the energy arising from the combustion process.

The gas turbine, however, has an efficiency limitation of another kind. The temperature of the combustion gas must be kept low enough to prevent destruction of the turbine blades: usually below 2,000 degrees Fahrenheit. Because the combustion chamber of a piston engine is exposed to its peak combustion temperature only for brief periods, the maximum temperature can be much above the temperature at which the structural materials would fail. Instantaneous maximum temperatures in a typical automobile engine reach 5,000 degrees F. Engine efficiency is directly related to the peak temperature that can be achieved in the thermodynamic cycle. The efficiency of a modern aircraft gas turbine is about 20 percent. The efficiency of a high-performance automotive reciprocating engine is about 40 percent. This relatively high efficiency helps to account for the continuing popularity of the reciprocating-piston engine.

What many inventors have been seeking is some way to eliminate the piston engine's low-efficiency crankshaft while retaining its advantage of high intermittent temperatures. If this could be accomplished, some kind of ideal engine



TURBOJET ENGINE performs the basic functions of intake, compression, combustion and exhaust simultaneously in different parts of the engine. The curves show how the air drawn in through the inlet diffuser changes in velocity, pressure and temperature as it travels through the compressor, reacts with fuel in the combustion chamber, performs work in passing through the turbine and leaves through the exhaust nozzle. The function of the turbine is to turn the compressor. Thrust results from the change in momentum of the gases between inlet and exhaust. The largest turbojet engine used in aircraft develops 43,500 pounds of thrust. At 375 miles per hour one pound of thrust equals one horsepower.



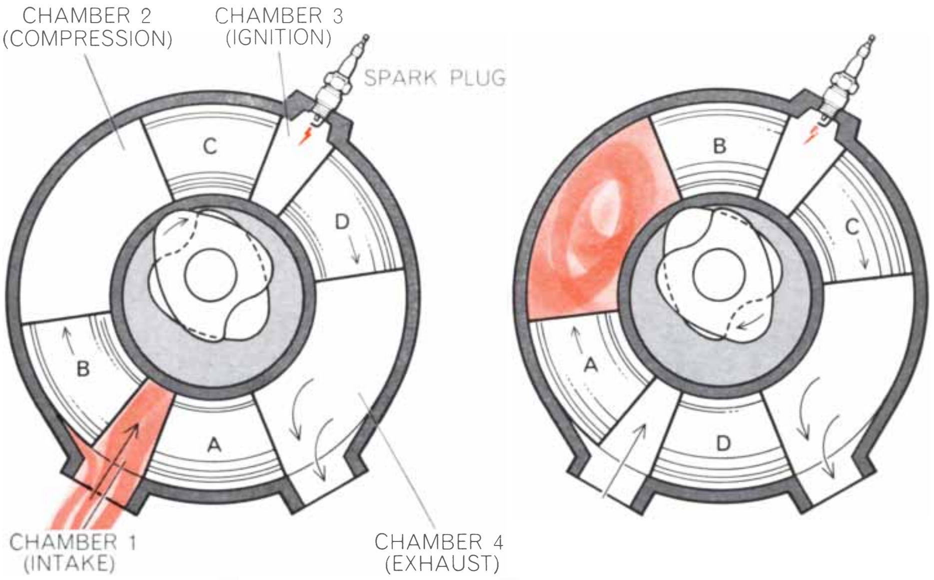
CONVENTIONAL PISTON ENGINE employs the four strokes of the "Otto cycle" first demonstrated in an engine in 1876 by Nicolaus August Otto. During the intake stroke air mixed with fuel is drawn into the cylinder. During the compression stroke the fuel-air mixture is reduced to about 10 percent of its original volume in modern engines. Firing of the spark plug initiates combustion; the expanding gases produce the power stroke. When the piston again travels upward, the exhaust gases are driven out through the exhaust port.

should emerge. In actuality there are 30 to 40 such engines, all "ideal" to a greater or lesser extent. They can be grouped into four general categories: (1) "cat and mouse" (or scissor) engines, which are analogues of the reciprocating-piston engine except that the pistons travel in a circular path; (2) eccentric-rotor engines, in which motion is imparted to a shaft by a rotor that is eccentric to the shaft; (3) multiple-rotor engines, which are based on simple rotary motion of two or more rotors, and (4) revolving-block engines, which retain reciprocating pistons but extract rotary motion by means of cams and gears rather than through a crank and crankshaft.

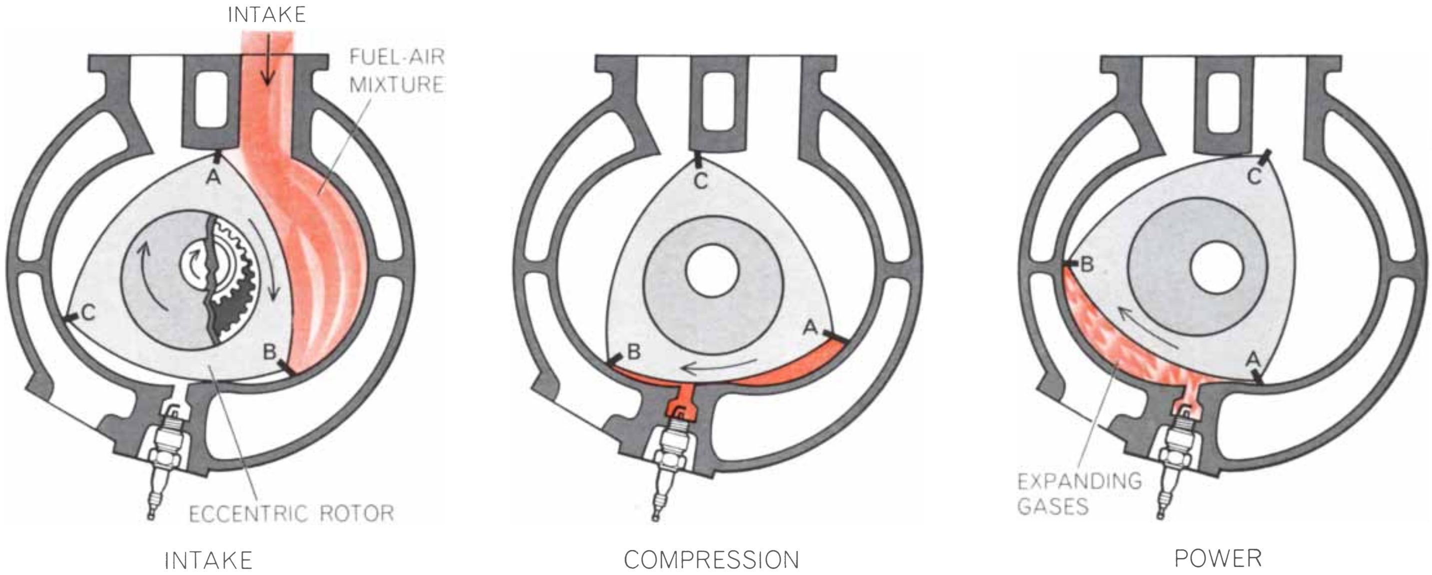
I shall describe some of the more interesting engines of each type. Typical of the cat-and-mouse category is the engine developed by the Swiss inventor Traugott Tschudi, who had the original idea in 1927. In the Tschudi engine [*see illustration at right*] the pistons are sections of a torus and travel around a toroidal cylinder. The cylinder contains four pistons, which operate in pairs. The members of each pair are always separated by 180 degrees, but the separation between pistons in different pairs is variable. This variation is employed to produce the analogue of the four strokes of the standard Otto cycle. If one follows the motion of piston *A* of the pair *AC* and piston *B* of the pair *BD*, one can see why the Tschudi is called a cat-and-mouse engine.

The intake stroke begins with *A* and *B* close together; as *A* remains stationary *B* begins moving away, drawing in a fresh mixture of fuel and air. Piston *B* then stops and piston *A* accelerates to overtake it; this is the compression stroke. (The energy for the compression stroke comes from the simultaneous power stroke that follows ignition of the charge between pistons *C* and *D*.) The charge compressed between *A* and *B* has now been rotated to a position where it can be ignited. The rotor attached to piston *A* locks, allowing the explosion to drive piston *B* away from *A*. At the end of the power stroke the rotor attached to piston *B* locks and *A* again catches up, driving the combustion gases out through an exhaust port. At the end of this four-stroke sequence the two pistons have traveled once around the toroidal chamber and are back where they started. It should be noted that within the torus the four pistons form four chambers at all times; thus at each instant all the processes comprising the four-stroke Otto cycle are taking place.

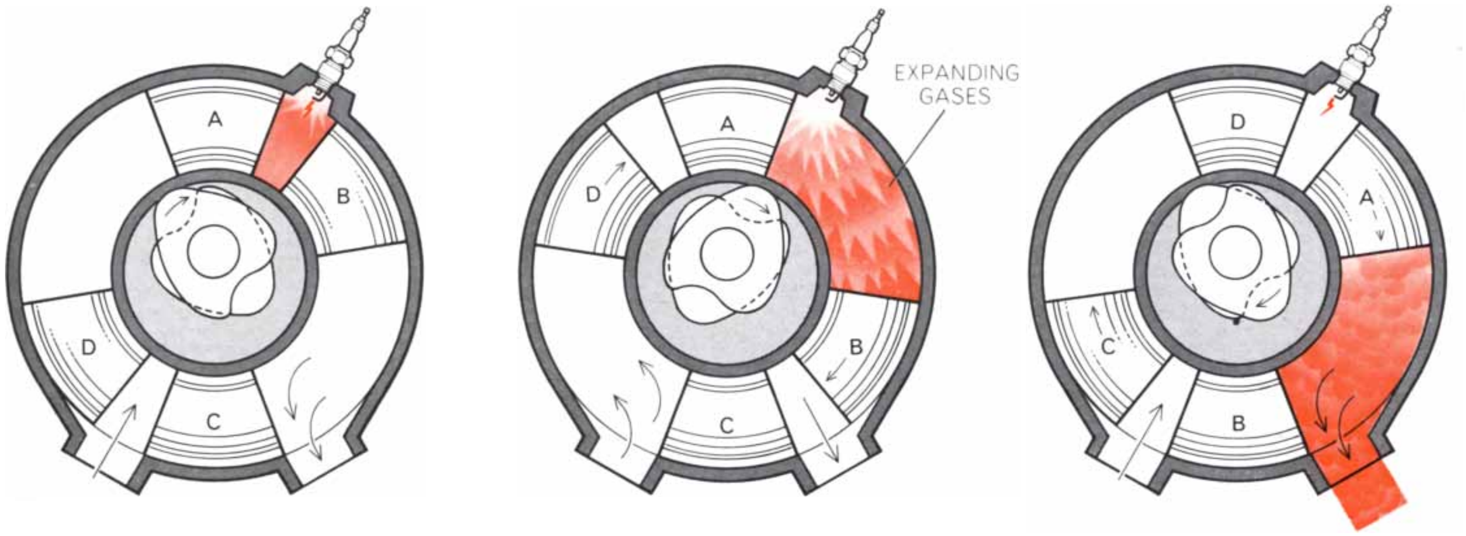
The motion of the rotors, and hence of the pistons, is controlled by two cams that bear against rollers attached to the rotors. The cam and rollers associated with one of the rotors will disengage when one wants to stop the motion of that rotor. The shock loads associated with starting and stopping the rotors at high speeds may be a problem with



TSCHUDI ENGINE is one of several "cat and mouse" rotary engines, so named because the pistons alternately run away from and catch up with each other. In the Tschudi engine intake, compression, combustion and exhaust occur simultaneously in different parts of a



WANKEL ENGINE employs a three-cornered rotor that turns on an eccentric gear. The shape of the rotor dictates the shape of the trochoidal chamber. As in the Tschudi engine, the intake and exhaust ports are always open. The rotor divides the main chamber into three small chambers; at any instant three of the four stages of the Otto cycle (intake, compression, power and exhaust) are



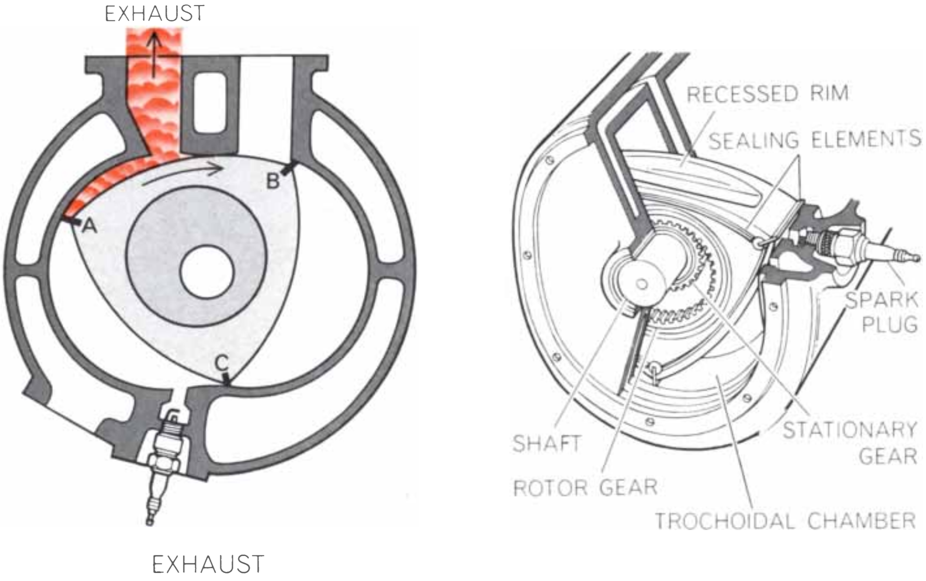
toroidal chamber. Pistons *A* and *C* are affixed to one rotor and travel together 180 degrees apart; pistons *B* and *D* are similarly affixed to a second rotor. The sequence of events (*color*) that takes place between pistons *A* and *B* is repeated between *B* and *C*, *C* and *D* and *D* and *A*. To simplify the diagrams the arrangement of rollers that engage the cams attached to the drive shaft is omitted.

this engine, although Tschudi appears to have circumvented this somewhat in a prototype engine he has tested. The problem of fabricating toroidal pistons does not appear to be as formidable as was once thought. There still appear to be problems, however, of providing adequate sealing and lubrication; such problems are characteristic of virtually all the rotary engines I shall discuss.

An engine similar in operation to the Tschudi is one developed by E. Kauertz. In the Kauertz engine the pistons are vanes that are sections of a right circular cylinder. Another difference is that whereas one set of pistons is attached to a rotor that travels with a constant angular velocity, the motion of the second set of pistons is controlled by a complex gear-and-crank arrangement that enables the pistons to accelerate and decelerate. In this way the chambers between the pistons can be made to vary in volume in a prescribed manner. Hence the standard piston-engine cycle can be duplicated. Kauertz has tested a prototype that was found to run smoothly and to deliver 213 horsepower at 4,000 revolutions per minute. Here again, however, the varying angular velocity of the second set of pistons gives rise to inertial effects that must be absorbed by the gear-and-crank system. Over extended periods this is likely to create problems.

The cat-and-mouse and scissors characterizations of these engines should be clear once the picture of pistons alternately running away from and catching up with each other is firmly in mind. Other engines of this type include designs by Hans Maier, J. C. Rayment and Melvin Rolfsmeyer. (Rolfsmeyer has named his engine the Virmel, after his wife Virginia and himself.) The designs differ principally in the system used to achieve the cat-and-mouse effect. Given sufficient development funds to attack the problems mentioned, there does not appear to be any reason why one or more of these engines could not be made competitive with the standard reciprocating engine. One incentive for pursuing the development of these engines is their potential for achieving good combustion efficiency, which means that their exhaust should be low in atmospheric pollutants. Whether they can be made superior to conventional engines in this regard remains to be demonstrated.

The leading example of the eccentric-rotor engine is the Wankel, which has also received far more development to date than any other rotary engine. The basic engine has only two primary moving parts: the rotor and the drive shaft [*see illustration at left*]. The rotor, which is three-cornered, moves in one direction inside a trochoidal chamber (a chamber whose shape conforms to the shape of the eccentric rotor). The chamber has peripheral intake and exhaust ports. (In one version of the engine the intake port has been moved to the side



simultaneously taking place. The sequence of events in one subchamber is shown here in color. The detail at far right shows the arrangement of gears that transmits power to the drive shaft. A second rotor and trochoidal chamber can readily be added to the same shaft.

wall of the engine so that the intake flow is parallel to the rotor axis. This tends to reduce the overlap between the intake phase and the exhaust phase of the operating cycle, thus permitting a shorter intake phase and lower fuel consumption.)

The rotor divides the trochoidal chamber into three smaller chambers, each of which is an analogue of the cylinder in the standard piston engine. The events in one chamber are repeated sequentially in the other chambers as the rotor makes one complete revolution. If we examine the rotor position when Chamber 1 is ending the intake phase, we find that Chamber 2 is simultaneously entering the combustion phase and Chamber 3 is beginning the exhaust phase.

To increase the volume of each chamber each segment of the rotor rim is recessed. During the combustion-expansion phase unburned gas tends to flow at high velocity away from the combustion zone toward the opposite corner. As a result this kind of engine, like the ordinary piston engine, tends to leave part of the charge unburned. In addition to limiting the performance of the engine the unburned gas is a source of air pollution. Ways are now being sought to increase the turbulence in each chamber, in an effort to enhance the mixing between the burned and the unburned gases and improve combustion efficiency. In the latest NSU designs combustion efficiency has evidently been improved by placing two spark plugs in the combustion chamber.

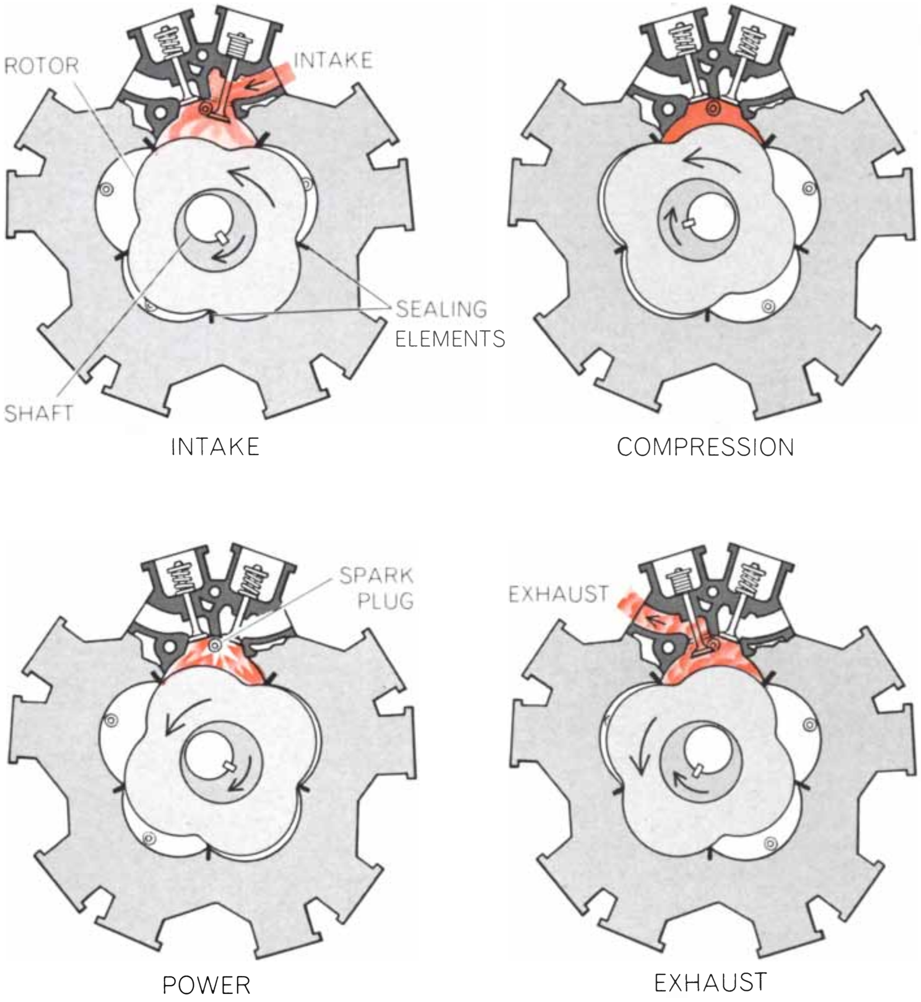
Wankel engines have demonstrated a number of impressive features. For example, even in their present state of development Wankel engines generally match, and in some cases have exceeded, comparable piston engines in horsepower output per pound of engine weight. To increase power output one can readily increase the number of rotor-and-chamber units attached to the same drive shaft, with the result that engine performance increases faster than engine volume and weight. To increase the power output of piston engines (without increasing the number of pistons) one must increase the volume of each cylinder, which leads to a substantial increase in engine size and weight.

The rotor and drive-shaft assembly of a Wankel engine can be completely balanced. Because the rotor normally turns at a constant velocity in one direction, vibration is virtually absent and noise levels are low. As with the cat-and-mouse engines, the intake and exhaust ports of a Wankel engine always remain open; the flow of gas into and out of the engine is never interrupted. This eliminates surging and the problems associated with valves that must be activated many times a second. To pay for this simplicity designers have had to find ways of keeping gas from leaking between the chambers. Reasonably effective seals have now been devised with springs that maintain a light pressure against the trochoidal surface.

Tests indicate that Wankel engines can run on a wide variety of fuels without "knock." These fuels include ordinary gasoline as well as cheaper grades. The Wankel has so few parts that it should be less costly to manufacture than a conventional piston engine.

Currently the Wankel, in addition to powering automobiles made by NSU in Germany and Toyo Kogyo (builder of the Mazda) in Japan, is being tested in the U.S. as a marine and truck engine. As the power unit for an electric-generator installation a 185-horsepower Wankel engine weighed less and consumed less fuel than either a diesel engine or a gas turbine with which it was placed in competition. It is expected that small Wankel engines will be useful for lawn mowers and chain saws. This wide range of applications is made possible because Wankel engines can be designed in an uncommonly wide range of sizes. NSU has been developing engines that range from three to 800 horsepower.

Another eccentric-rotor engine, conceptually equivalent to the Wankel, is one being developed jointly by Renault Incorporated and the American Motors Corporation. It is sometimes called the Renault-Rambler engine. The rotor has four lobes and revolves inside a five-lobe chamber [*see illustration at left*]. When a lobe moves into a cavity, it compresses the fuel-air mixture. Each cavity is equipped with a spark plug and two valves, one for intake and one for exhaust. The valves make this engine more complicated than the Wankel. On



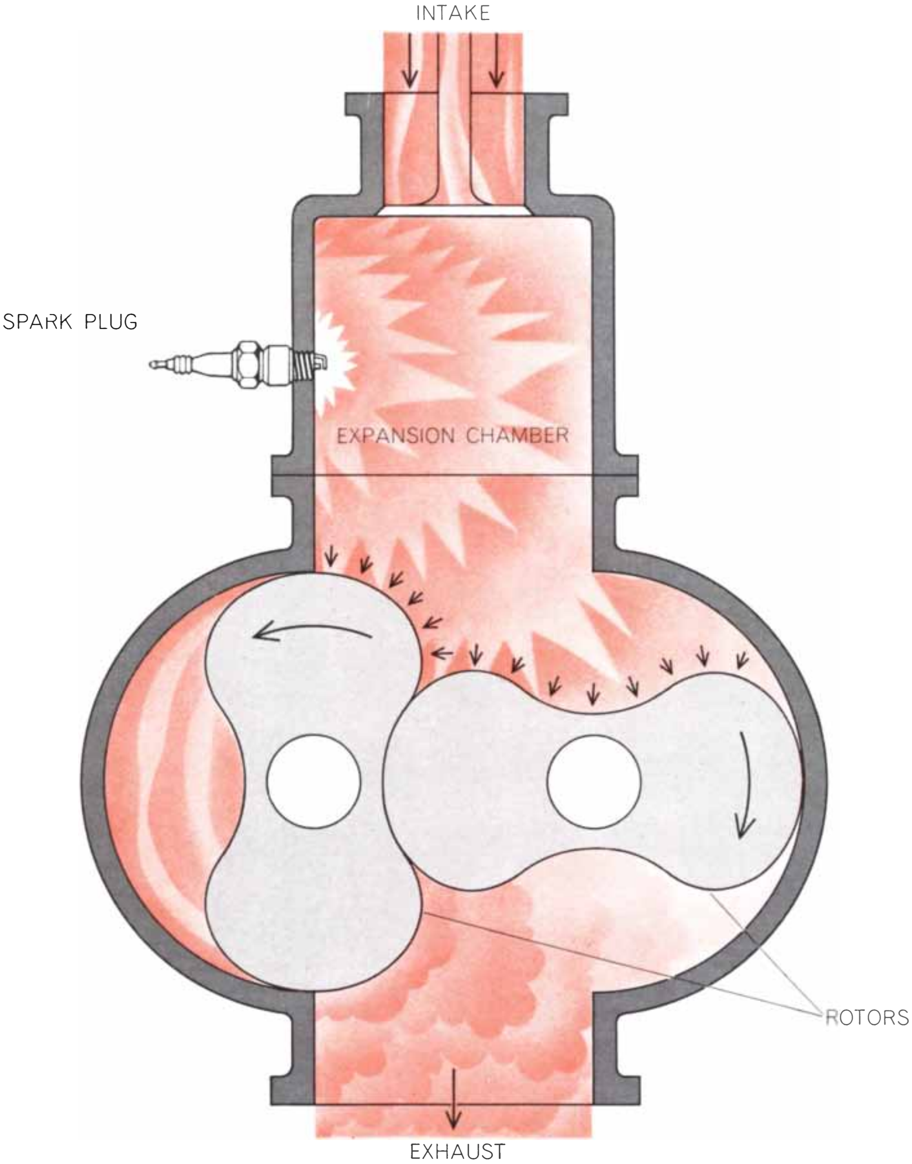
RENAULT-RAMBLER ENGINE is another eccentric-rotor design. It differs from the Wankel engine in having separate intake and exhaust valves and a spark plug in each cavity of the multicavity chamber. Thus the full cycle of intake, compression, power and exhaust occurs in each cavity. The first three steps take place during the entry and exit of one lobe of the rotor; the fourth step, exhaust, is accomplished by the next lobe of the rotor. Heat is better distributed around the housing than it is in the Wankel.

the other hand, sealing between chambers may be simpler than it is in the Wankel, and since each cavity acts as a combustion chamber, heat is more evenly distributed than it is in the Wankel, where combustion always takes place in the same region of the chamber.

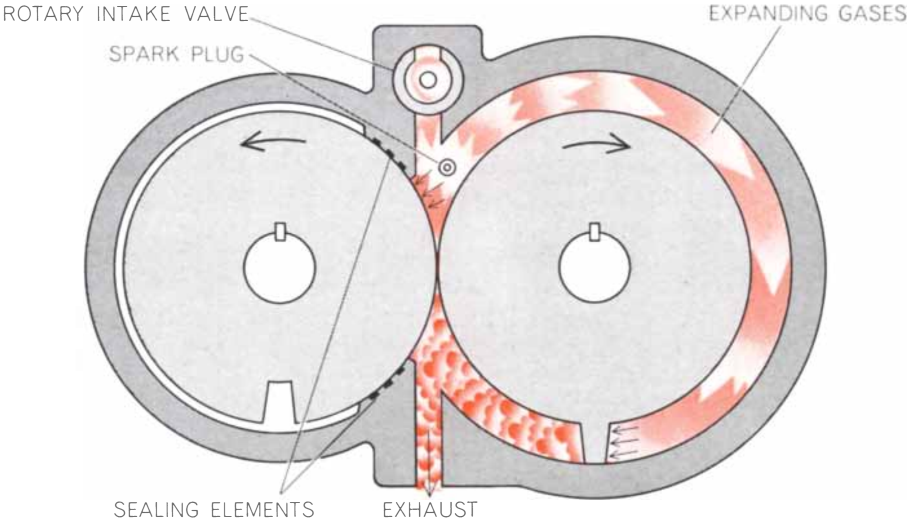
The Wankel engine has stimulated the invention of several similar engines. The Jernaes engine, for example, resembles the Wankel except that it has no internal gearing. Instead the rotor has affixed to it three planetary gears that mesh with a gear attached to the output shaft. The Ferro engine closely follows the Wankel except that a complicated internal rotor arrangement replaces the Wankel's eccentric shaft. The Geiger engine has a rotor consisting of three shoes that operate on an oval (rather than a trochoidal) track. Isuzu, a Japanese firm, has tested a design similar to the Renault-Rambler engine except that the rotor has only two lobes (instead of four) and operates in a housing with three lobes (instead of five). Other designers have tried a three-lobe rotor in a four-lobe housing. It can be fairly concluded that engines of the eccentric-rotor type are well beyond the experimental stage. Their inherent simplicity should make them attractive competitors of the piston engine for a wide variety of applications.

The third of the four categories of unconventional engines I shall describe are those with multiple rotors. These engines employ simple rotary motions without eccentric linkages or oddly shaped chambers [*see illustrations at right*]. In a typical engine of this kind the fuel-air mixture enters the combustion chamber through some type of valve. There is no compression; the mixture is simply ignited and burns in the combustion chamber. The hot gas expands and pushes against two intermeshing rotors. Trapped between the rotors and the walls of the chamber, the combustion gases eventually travel to an open exhaust port.

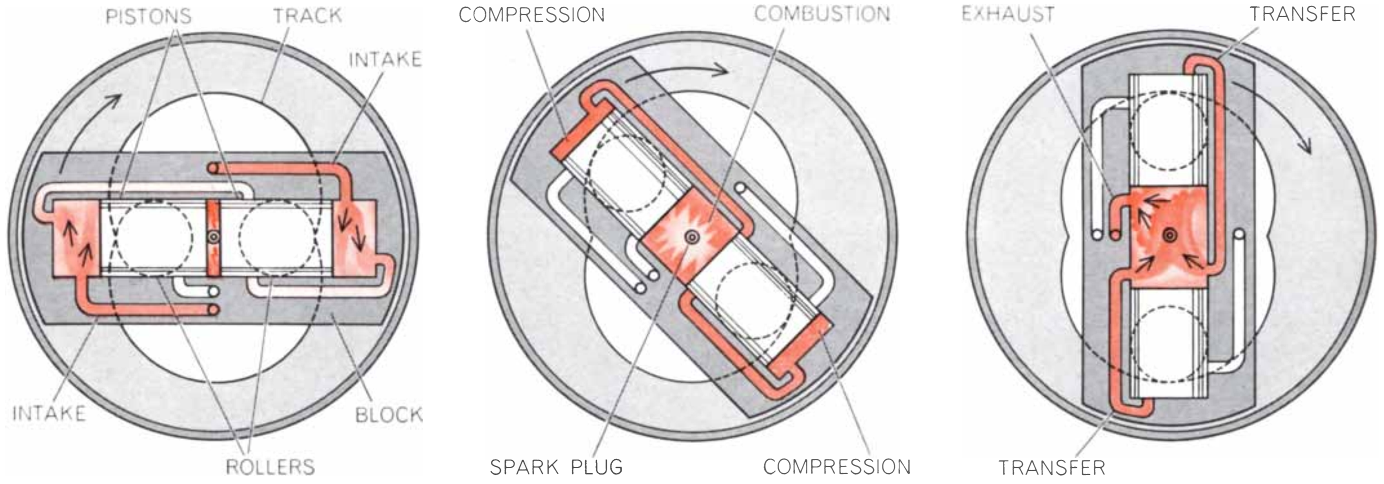
The principal problems associated with all engines of this type are twofold: the absence of a compression phase leads to low efficiency, and sealing between the rotors is enormously difficult. One theoretical estimate of the thermal efficiency of the two-rotor engine just described is only 4 percent. Nevertheless, engines of this type abound. One, the Unsin engine, replaces the trochoidal rotors with two circular rotors, one of which has a single gear tooth on which the gas pressure acts. The second rotor has a slot that accepts the gear tooth. The two rotors are in constant frictional



SIMPLE MULTIROTOR ENGINE consists of two rotors that nest into each other and rotate in opposite directions. The air-fuel mixture is not compressed after entering the chamber, hence the efficiency of the engine is low. The expanding gases force the rotors to turn as shown. The exhaust gases leave through a port that always remains open.



UNSIN ENGINE employs two circular rotors, one of which has a single tooth on which the expanding gases act. The second rotor, in frictional contact with the first, contains a slot for the tooth. To improve efficiency the Unsin engine, as well as the engine shown at the top of the page, could be provided with a mechanism for compressing the intake charge.



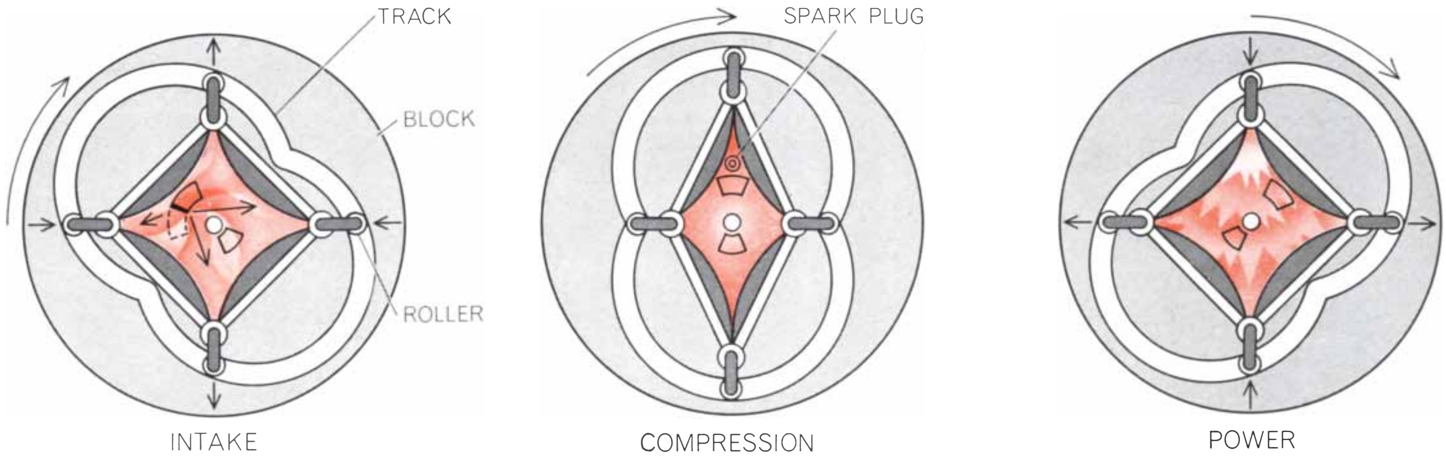
MERCER ENGINE is one of several unusual designs in which the entire engine block revolves. Two pistons operate in a single cylinder. Attached to the pistons are rollers that run in a stationary track consisting of two circular arcs. As the pistons are driven outward by the explosion of the air-fuel mixture the rollers press against the track and force the block to rotate. The outward motion of the pistons also compresses a fresh charge that has been introduced behind the pistons. When the pistons are farthest apart, the exhaust ports are uncovered and vent the spent gas. The purging is facilitated by the transfer of fresh charge from the region behind the pistons where it has been compressed. The pistons then move together to recompress the air-fuel mixture prior to combustion.

contact, and in a small prototype engine sealing was apparently adequate. The inventor recommends that some compression of the intake charge be provided externally for larger engines.

The last of the four categories of rotary engines includes some rather curious hybrids: reciprocating piston motion is retained but is combined with rotational motion of the entire engine block. One engine of this type is the Mercer [*see illustration above*], in which two opposing pistons operate in a single cylinder. Attached to each piston are two rollers that run on a track that consists of two circular arcs. When the pistons are closest together, the intake ports to the chambers behind the pistons are uncovered, admitting a fresh charge. At this moment a charge contained between the pistons has achieved maximum compression and the spark plug fires. The pistons separate as combustion takes place between them, which results in a compression of the gases behind the pistons. The pistons' moving apart, however, forces the rollers to move outward as well. This latter motion can occur only if the rollers run on their circular track, which forces the entire engine block to rotate. When the pistons are farthest apart, the exhaust ports are uncovered and the combustion gases are purged. At the same time the compressed fresh charge behind the pistons is transferred to the region between the pistons to prepare for its recompression and combustion—events brought about by the continuing rotation of the block.

No doubt some of the fresh charge is lost to the exhaust during the transfer process. In addition, stresses on the roller assembly and cylinder walls are likely to be quite high, which presents design problems. Cooling is a further problem, since cooling of the pistons is difficult to achieve in this arrangement. On the other hand, the reciprocating piston motion is converted directly to rotary motion, in contrast to the connecting-rod-and-crank arrangement in the conventional piston engine. Moreover, no flywheel should be necessary, since the entire rotating block acts to sustain the rotary inertia.

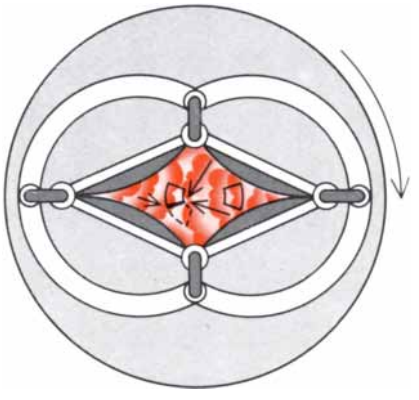
The Selwood engine is similar, except that two curved pistons opposed 180 degrees run on toroidal tracks. The design somewhat resembles the Tschudi cat-and-mouse engine, except that in the Selwood design the pistons travel through only 30 degrees of the toroidal track. This motion forces the entire block to rotate. The Leath engine has a square rotor with four pistons 90 degrees



RAJAKARUNA ENGINE uses a combustion chamber whose four sides are hinged so that the cross section changes from a square to a diamond and back again at different stages of the operational cycle. The changes in shape force the surrounding engine block to rotate.

apart, with a roller connected to each. As in the Mercer engine, the reciprocating motion of the pistons forces the rollers to run around a trochoidal track, which causes the entire block to rotate. The Porsche engine uses a four-cylinder cross-shaped block. Again, rollers are attached to each of the four pistons. In this arrangement power is generated on the inward strokes of the piston. The Rajakaruna engine has a combustion chamber whose sides are pin-jointed together at their ends [*see illustration at bottom of these two pages*]. Volume changes result from distortion of the four-sided chamber as the surrounding housing, which encloses a trochoidal track, rotates. The hinge pins are forced against the track. Cooling and lubrication problems will be encountered with this engine, as will excessive wear of the hinge pins and track.

Although the four general types of rotary engine I have described are by no means the only ones, the vast majority of such engines fall into one of these categories. Many of the engines involve relatively minor modifications of earlier designs. In others the departures are radical, although not necessarily improvements on what already exists. One nonetheless has the feeling that, given sufficient development, some of these engines should prove to be advances on the contemporary reciprocating-piston engine. To a large extent the Wankel engine has already demonstrated this to be true. The key phrase, however, is "given sufficient development." Since few inventors have private resources adequate for the task, they are obliged to become salesmen in the hope of convincing others to pay the high costs required to demonstrate their engines' feasibility and superiority.



EXHAUST

The four "strokes" of the standard Otto cycle are illustrated here from left to right.

THE GOLGI APPARATUS

For years the function of this cell component was a mystery. Now radioautography has clarified its role as the primary site for the packaging of secretions and the synthesis of large carbohydrates

by Marian Neutra and C. P. Leblond

In 1898 the Italian microscopist Camillo Golgi, using a special silver stain he had developed, discovered certain previously unknown bodies in the cytoplasm of nerve cells. They were extremely small structures that appeared to be composed of minute plates and threads. The eminent Spanish histologist Santiago Ramón y Cajal had seen the same curious bodies in silver-stained cells several years earlier, but he had not reported the observation at the time because, as he wrote later in his memoirs, "the confounded reaction never appeared again!" The mysterious structure was christened the Golgi apparatus.

For their studies of nerve cells (which were conducted independently) Golgi and Ramón y Cajal were jointly awarded the Nobel prize for physiology and medicine in 1906. Although the Golgi apparatus was given much attention, for many years there were doubts about its existence, some investigators dismissing the reported observation as a mere artifact. Eventually, in the 1950's, the electron microscope removed all doubts. It showed that a Golgi apparatus was present in all cells and that it consisted of one or more stacks of tiny flattened sacs—"saccules."

The clear new look at this component of cells raised it to the level of a first-class enigma. What is the activity of the Golgi apparatus? What purpose does it serve in the processes of the cell? These questions have been heatedly debated and vigorously explored. A number of diverse bits of information bearing on the subject have recently come to light, and the pieces of the puzzle are now beginning to fit together. They indicate that the Golgi apparatus is one of the main chemical factories of the cell, producing substances that are of prime importance in all living organisms.

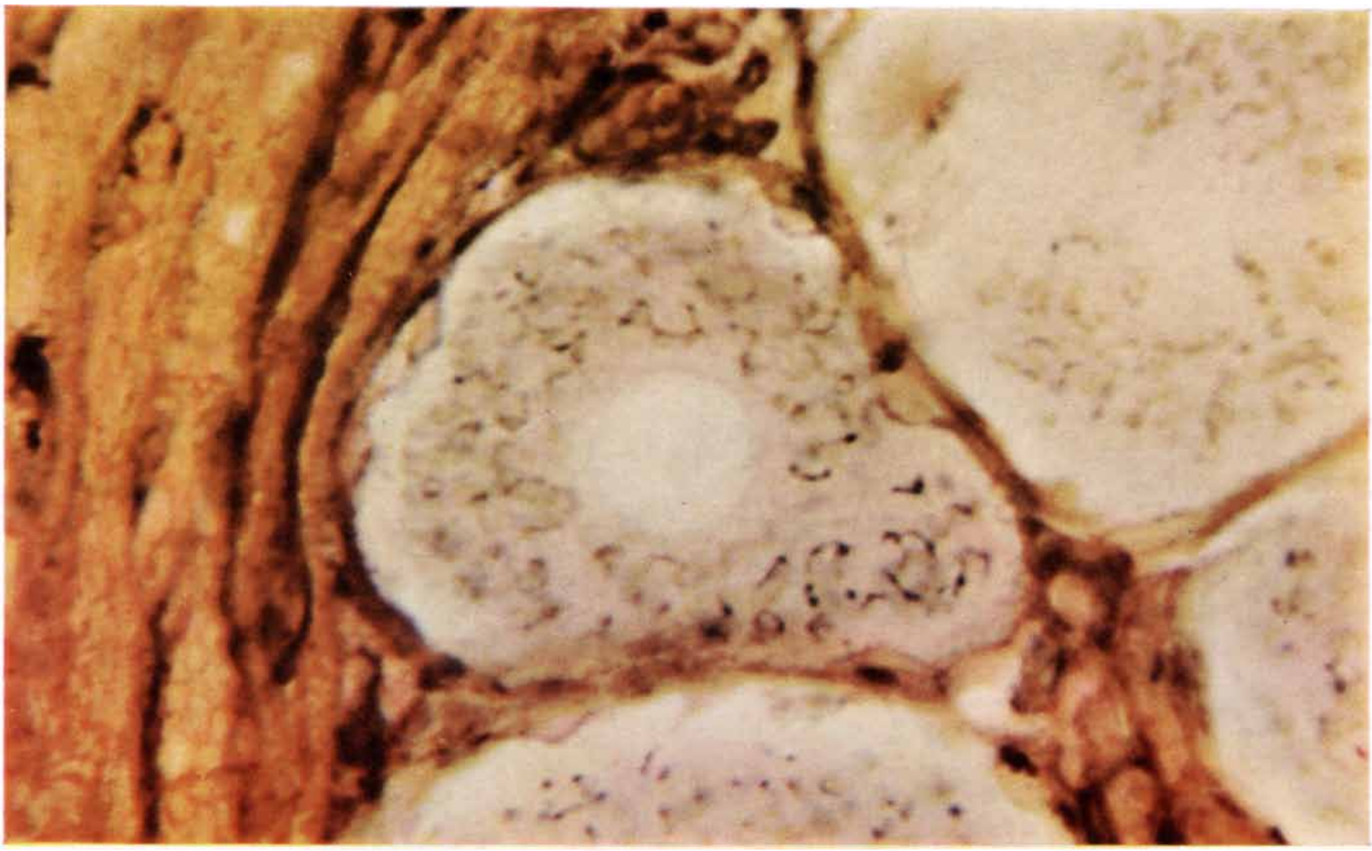
The story of this research begins with an observation made by Ramón y Cajal in 1914. Examining the intestinal cells called goblet cells, he noticed that there were tiny droplets of mucus in the region of the Golgi apparatus. These cells are known to secrete a mucus that spreads over all the cells lining the intestine and forms a protective coat against invasion by bacteria and foreign substances. Ramón y Cajal suggested that the Golgi apparatus might be the intracellular factory where the mucus is synthesized.

At the time the presence of the mucus droplets in the Golgi apparatus could only be taken as a suggestive circumstance; there was no way to determine if the material was actually manufactured there. With the electron microscope we can now observe that globules of mucus do in fact arise from the Golgi apparatus. In our laboratory at McGill University we have examined in detail the Golgi apparatus of goblet cells in the intestine of the rat.

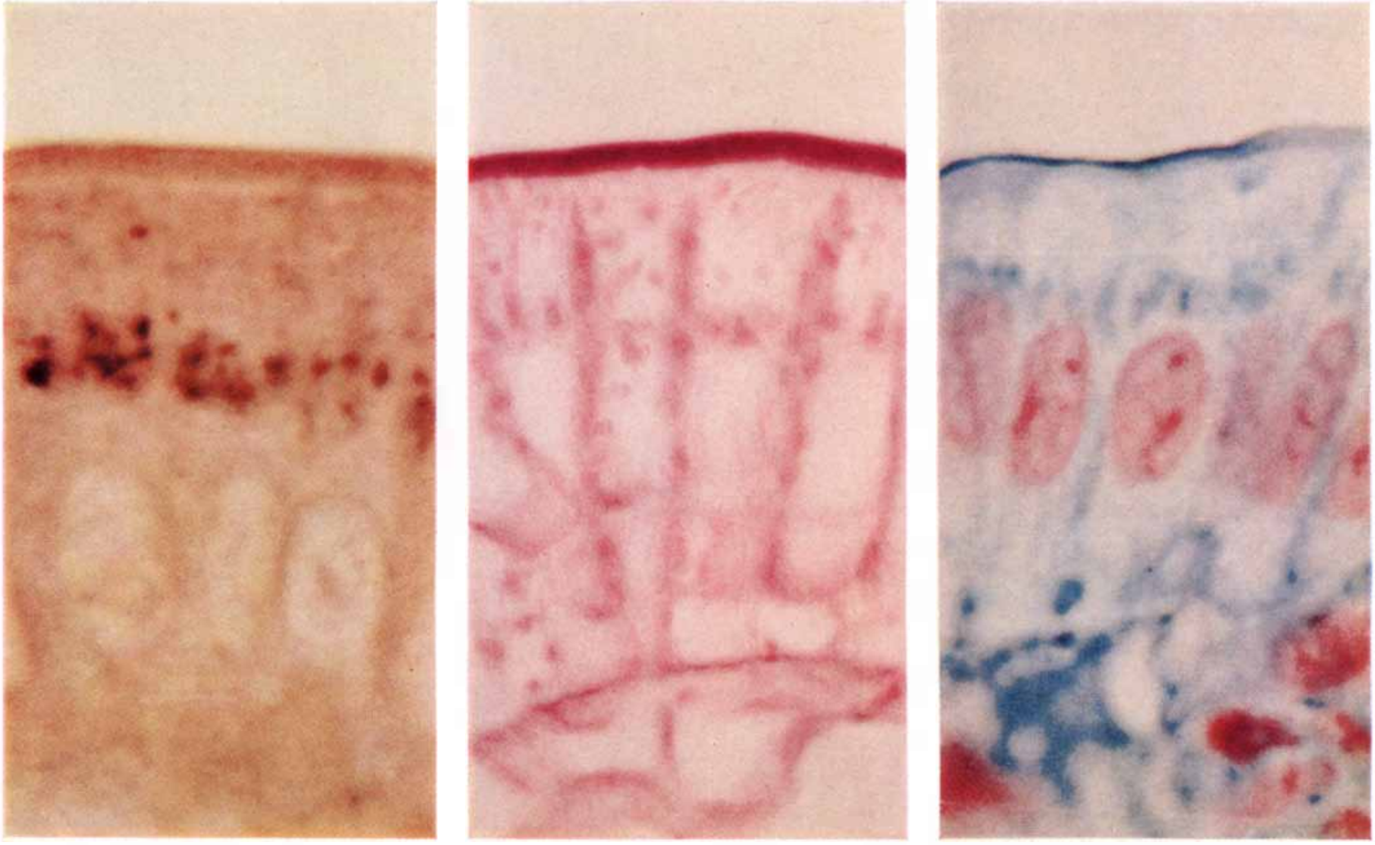
The goblet cell is a long, narrow structure, so shaped because it is squeezed between other cells of the intestinal lining. Within this cell the Golgi apparatus forms a cuplike structure that is made up of several elements, each consisting of a stack of eight or 10 saccules [*see illustration on page 102*]. The saccules at the bottom of the stack are flattened and apparently empty; those at the top of the stack, however, are swollen with material, and they develop into spherical, mucus-filled globules that detach themselves from the stack and float up to the cell membrane, where they are discharged from the cell.

The secretion of mucus from the goblet cell is of the familiar type called external secretions; other secretions of the same kind are the sweat and tears released to the outside surface of the body and the saliva, enzymes and mucus delivered into the digestive and respiratory tracts. We now know that there are also many internal secretions within the body, produced by specialized cells. For example, the cells of glands such as the thyroid and pituitary secrete hormones; liver cells secrete blood proteins; plasma cells secrete antibodies; other specialized cells secrete material that forms bone, cartilage or fibers, and many cells secrete onto their own surface a thin coat of material that holds cells of the same kind together [see "How Cells Associate," by A. A. Moscona; SCIENTIFIC AMERICAN, September, 1961].

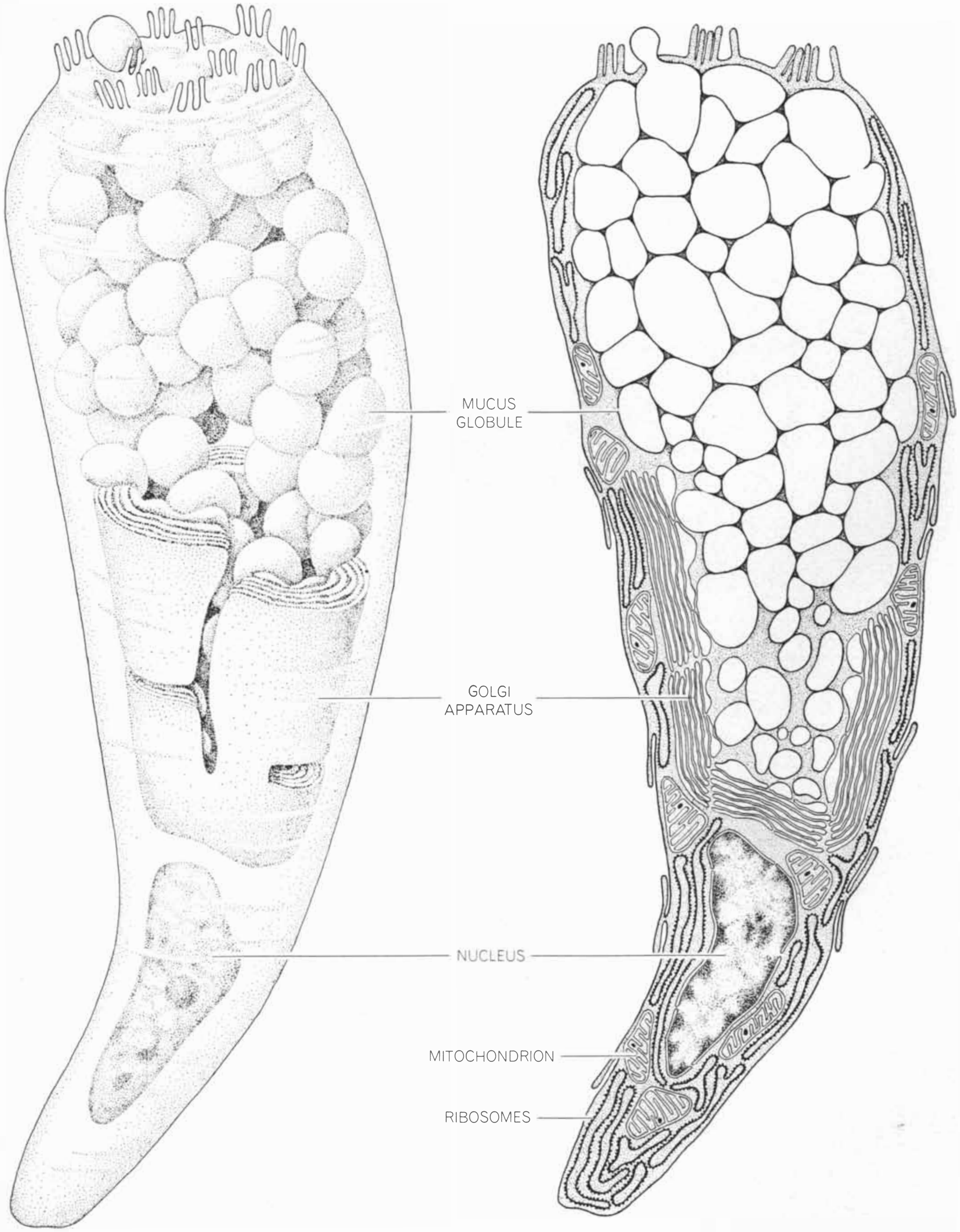
Is the Golgi apparatus, then, involved in internal as well as external secretions and, if so, just what is its role? These questions have been investigated with the technique of radioautography. The substance first chosen for investigation was protein, and the experiments were designed to show not only where the protein is synthesized but also where it migrates in the cell after its synthesis. In protein synthesis cells utilize amino acids as building blocks. If an experimental animal is injected with amino acids labeled with radioactive atoms, the animal's cells build up radioactive protein from them. After a measured time interval the tissue under study is taken from the animal and then hardened by the process known as fixation. Next a thin section of the tissue is sliced off, coated with a photographic emulsion and left in a darkroom. Radioactive atoms in the tissue activate nearby silver grains in the emulsion so that, on photographic development, these grains show up as darkened spots, indicating just where the newly synthesized, radioactive protein is located in the cells. (Whatever free labeled amino acid has not been taken up into protein will have been extracted in the course of fixation and other treatments to prepare the cells for the micro-



NEW STRUCTURE in cells, first seen by Camillo Golgi when he stained nerve tissue with silver salts, was said to be composed of a network of plates, threads and dots. It came to be called the Golgi apparatus. The structures are seen here (most clearly at right in central cell) in rat nerve cells stained by the Maillet technique, the results of which are similar to those obtained by Golgi's method.



STAINING METHODS indicate that glycoproteins are present in the Golgi apparatus. The Maillet technique locates several Golgi apparatuses as groups of dark brown bodies in three columnar cells from rat intestine (*left*). A technique that colors glycoproteins a pinkish magenta shows that some of the cell glycoprotein is found in the same region of other columnar cells (*center*). A technique that colors acidic groups blue shows that acidic carbohydrates, components of glycoproteins, are also in the Golgi region (*right*).



GOBLET CELL, which secretes mucus into the intestine, is seen in three dimensions with the cell membrane rendered transparent (*left*) and in section, as it appears in an electron micrograph (*right*). The Golgi apparatus looks like a cracked cup (*left*), with mucus globules budding off from the cup and moving upward to be released at the top surface of the cell. The section (*right*) shows cell components. The mitochondria supply energy. Ribosomes, which line the membranous endoplasmic reticulum, are the sites at which proteins are synthesized. The cuplike Golgi apparatus appears as a U-shaped structure just above the nucleus of the cell.

scope.) If the slice of tissue is taken from one to five minutes after the animals are given the radioactive amino acid, one can expect to find the new radioactive protein close to its site of synthesis; samples taken later enable one to trace subsequent migrations of the protein.

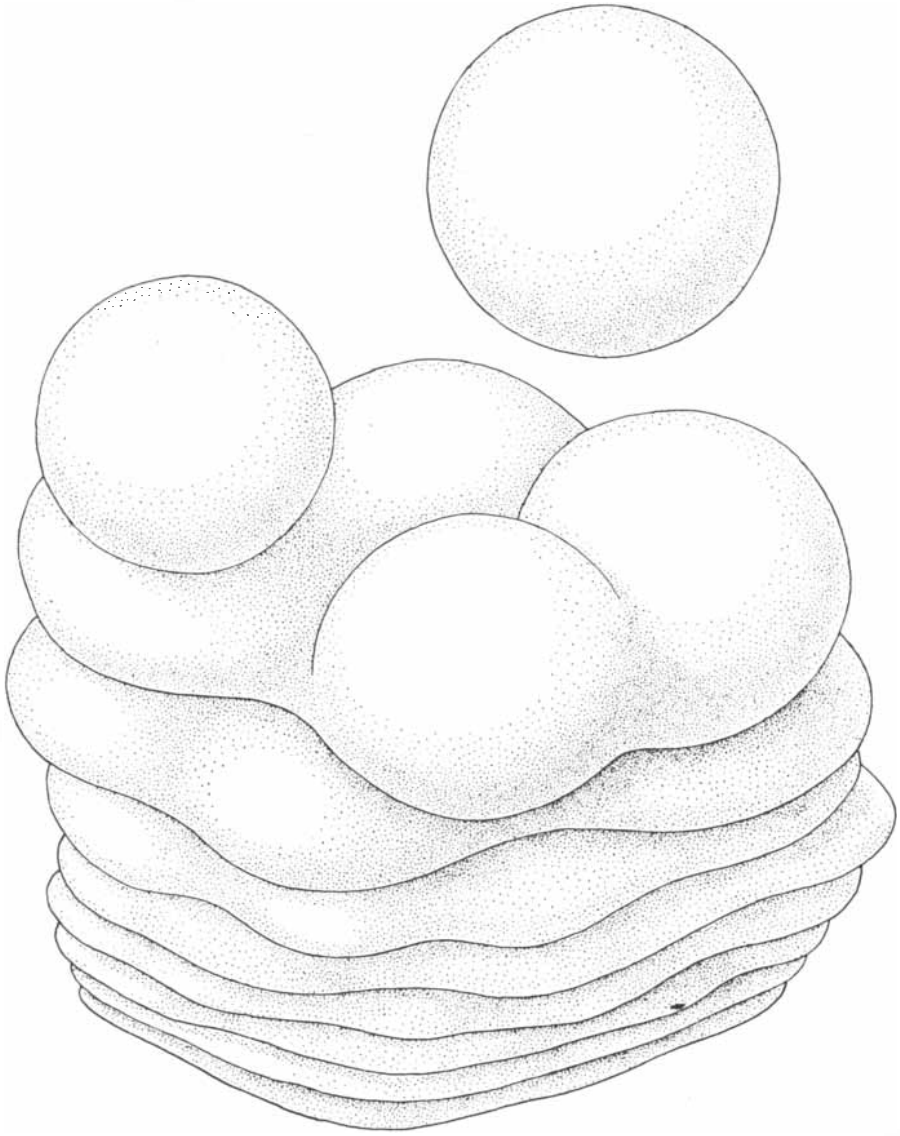
In 1961, with Hershey Warshawsky and Bernard Droz, one of us (Leblond) performed such experiments with cells of the pancreas. As was to be expected, we found that newly synthesized proteins were located in a region of the cell rich in ribosomes, the bodies biochemists had shown to be the site of protein synthesis. Within minutes after their synthesis, however, the proteins migrated to the location of the Golgi apparatus in the cell. Soon afterward they turned up in granules of secretion that still later were released by the cells as a pancreatic secretion. Lucien G. Caro, working in the laboratory of George E. Palade at the Rockefeller Institute in New York, conducted a similar experiment at about the same time with the aid of the electron microscope. He showed with added precision that soon after their synthesis on ribosomes in pancreatic cells the secretory proteins were funneled through the Golgi apparatus. Since then investigators in other laboratories have observed that secretory proteins follow the same course in several other types of cell: thyroid cells, plasma cells, cartilage cells and even the enamel-forming cells of teeth.

Why do these proteins pass through the Golgi apparatus? Do they undergo some essential processing operation there? One can see with the electron microscope that proteins come out of the apparatus neatly packaged in globules whose membranes have been donated by the Golgi saccules. It seems hardly likely, however, that this elaborate system exists simply for the purpose of putting the proteins in bags; nature has a way of avoiding complex solutions for simple problems. We therefore decided that a closer look had to be taken at the protein products themselves, to determine if their sojourn in the Golgi apparatus was responsible for some important change in their chemical form.

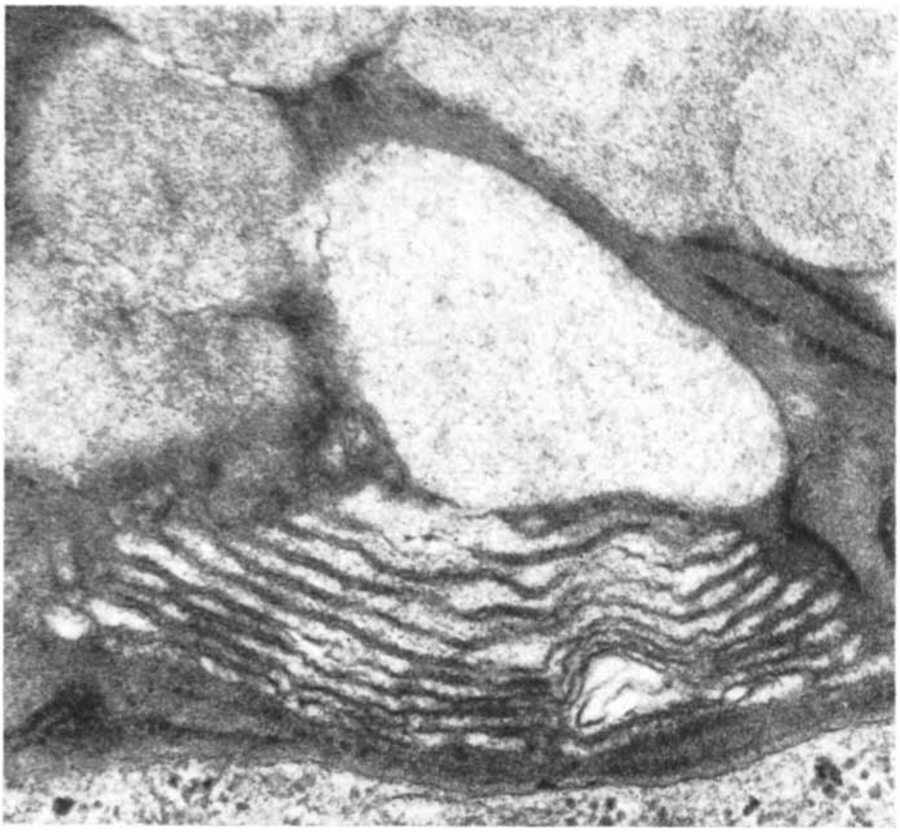
It is a striking fact, recently pointed out by Edwin H. Eylar of the University of Southern California School of Medicine, that almost all proteins secreted by cells, in contrast to those that are not secreted, are glycoproteins, that is, proteins combined with sugar. The mucus secreted by the intestinal goblet cells, for example, consists mainly of a glycoprotein that contains a large amount of carbohydrate (which may account for the fact that mucus is highly viscous). Similarly, secretory enzymes, hormones, plasma proteins, antibodies and cell-coating secretions generally contain some carbohydrate, although sometimes only a small amount of it. The carbohydrate part of the glycoprotein consists of chains of linked sugars that are firmly attached to the protein molecule by covalent bonds at specific sites along its length. These side chains may be short and simple [*see illustration on page 105*] or they may be long and branched.

It is not entirely clear what role the carbohydrate plays in secretory proteins; Eylar suggests that it may facilitate the exit of the proteins from the cell. In any case, the distinctive association of carbohydrate with secretory proteins excited our interest. Was the Golgi apparatus somehow involved in the formation of this association?

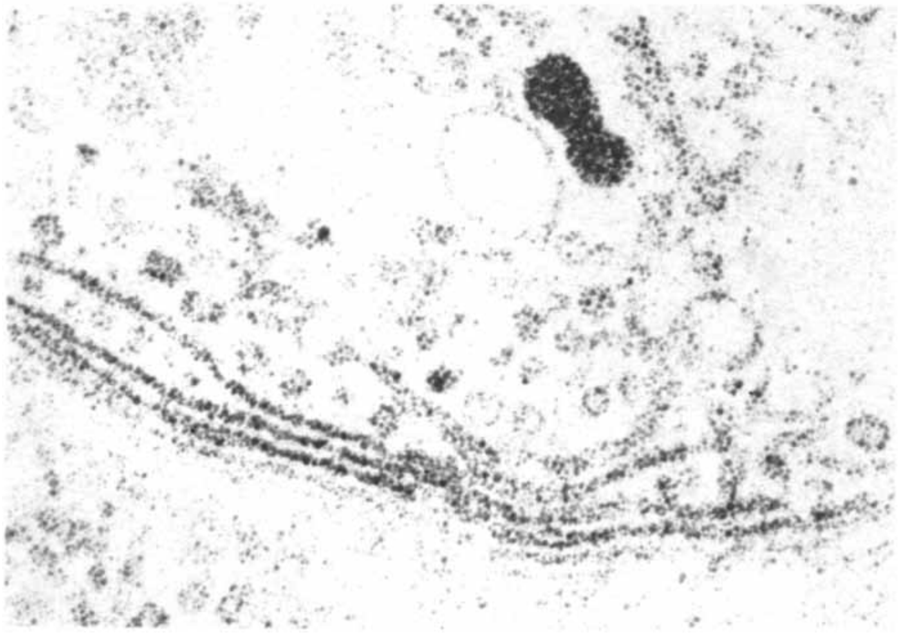
The glycoprotein in cells can be stained selectively to a magenta color by a technique employing a strongly oxidizing acid (periodic acid) and the Schiff reagent. We applied this technique to various tissues, including goblet cells, and found that it not only stained glycoprotein secretions a bright magenta but also specifically stained the region of the Golgi apparatus in the cells. When certain compounds of silver were used instead of the Schiff reagent, the glycoproteins were stained black instead of magenta. The black was caused by silver deposits that proved to be dense enough to be seen in the electron microscope. Recently Alain Rambourg, William Her-



GOLGI STACK (like the one just above the nucleus in the drawing at the right on the opposite page) is seen here in three dimensions. It is a pile of saccules, successively more distended from bottom to top by accumulations of the cell's secretion product, mucus. Each filled saccule becomes one or more spheroidal mucus globules, two of which are seen (*top*).



SACCULES from the Golgi apparatus of a goblet cell, comparable to those in the drawing on the preceding page, are seen in section, enlarged 80,000 diameters in an electron micrograph. Each of the dark lines constituting the stack is composed of the walls of two adjacent saccules. At the base of the stack the saccules are nearly empty. More and more light material accumulates in them until they turn into mucus globules, several of which are visible here. The light material is the secreted mucus, which is mainly composed of glycoprotein.



GLYCOPROTEIN is visualized in saccules of a columnar cell stained by the periodic acid-silver technique and enlarged 70,000 diameters in an electron micrograph. Here the three dark lines are not saccule membranes but the glycoprotein content of three saccules. These are at the top of a Golgi stack. The lighter line below them is the next saccule, containing less glycoprotein; the saccules below it are hardly stained. The gradient in staining indicates that glycoprotein accumulates as saccules migrate toward the top of the stack. The stained vesicles above the stack arise from the top saccule and also contain glycoprotein. The dark body (*top*) is probably a lysosome, a baglike container of glycoprotein enzymes.

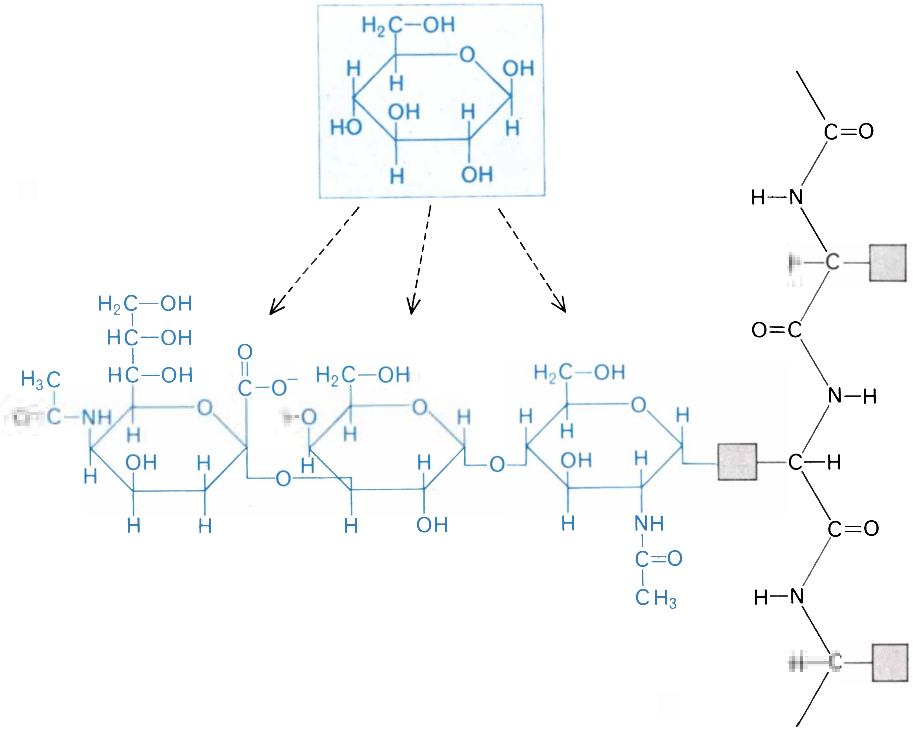
nandez and one of us (Leblond) found that this technique stains the Golgi apparatus in all cells examined because silver-staining glycoprotein is present within the Golgi saccules, particularly those at the top of the stacks [*see bottom illustration at left*]. Finally a group of investigators in Chile headed by Gabriel J. Gasic (who is now at the University of Pennsylvania) also established that carbohydrate was present in the Golgi apparatus by means of a staining technique that colors the acidic groups of carbohydrates blue.

It began to look as if the Golgi apparatus might actually be the site where carbohydrate was added to proteins to form glycoproteins. Indeed, certain biochemical studies pointed in that direction. There was evidence that the carbohydrate is not added until after the protein molecule has been built on the ribosomes. Biochemists, using tracer techniques like those that had shown that ribosomes are the site of protein synthesis, were seeking to hunt down the location in the cell where carbohydrate is tacked on to the protein. They found that radioactively labeled carbohydrate introduced into liver cells was mainly incorporated into glycoprotein in a portion of the cell that was rich in membrane material (but not in ribosomes). It appeared to us that this "membrane site" might well be the Golgi apparatus, and we set out to investigate the question by experiment.

We injected glucose labeled with tritium (the radioactive isotope of hydrogen) into young rats and followed the fate of the sugar by radioautography of the goblet cells of the large intestine. The British biochemists P. Draper and Paul Kent had shown that the large intestine makes use of glucose to build up the carbohydrate part of the glycoprotein of mucus. (The glucose is first transformed into the simple sugars from which the carbohydrate chains in glycoprotein are formed, such as galactose, acetylglucosamine and sialic acid.) We could therefore expect that glycoprotein produced by the rats' goblet cells after the injection of labeled glucose should itself be labeled with radioactivity, so that in radioautographs made soon after the injection the labeled glycoprotein should be detected at the site of its formation.

We followed the course of events by studying specimens of the rats' tissues taken at various intervals after the injection. The rat's large intestine was removed and embedded in hard plastic, which was cut into extremely thin sections; each section was covered with a layer of fine-grained photographic emulsion, and the specimen was then stored in the dark for several months to allow sufficient exposure of the emulsion to the sources of radioactivity in the tissue. After development the emulsion was examined in the electron microscope to locate the radioactive spots in the cells.

In specimens taken within 15 minutes after the glucose injection all the radioactivity we could detect (which was likely to be from freshly synthesized glycoprotein) was found to be at the site of the Golgi saccules. We interpreted this as rather clear evidence that the Golgi saccule is indeed the membrane site where carbohydrate is added to protein to form glycoprotein. Later specimens showed that by 20 minutes after the injection globules of mucus containing radioactive glycoprotein were beginning to appear, and by 40 minutes all or almost all the radioactivity had passed out of the Golgi apparatus and was being carried off by mucus globules.



HYPOTHETICAL GLYCOPROTEIN consists of a protein backbone (*black*) with amino acid side chains (*gray*) to which carbohydrate chains, one of which is shown here (*color*), are attached. The composition of the sugar chains varies; here the units are N-acetylglucosamine (*attached to protein*), galactose (*middle*) and sialic acid (*left*). These simple sugars can be obtained by modification of glucose (*top*) supplied to the cell from the blood.

What was the origin of these globules? It is unlikely that the large molecules of glycoprotein can pass through membranes such as those that comprise the walls of the Golgi saccules. We assume, therefore, that the saccules successively swell with an accumulation of mucus and bud off, one after the other, as mucus-filled globules. Apparently within 40 minutes the eight or 10 saccules that originally composed a stack have been transformed into globules and have left in this way; as fast as they bubble off the top of the stack, however, they are replaced at the bottom, so that the stack always remains the same size.

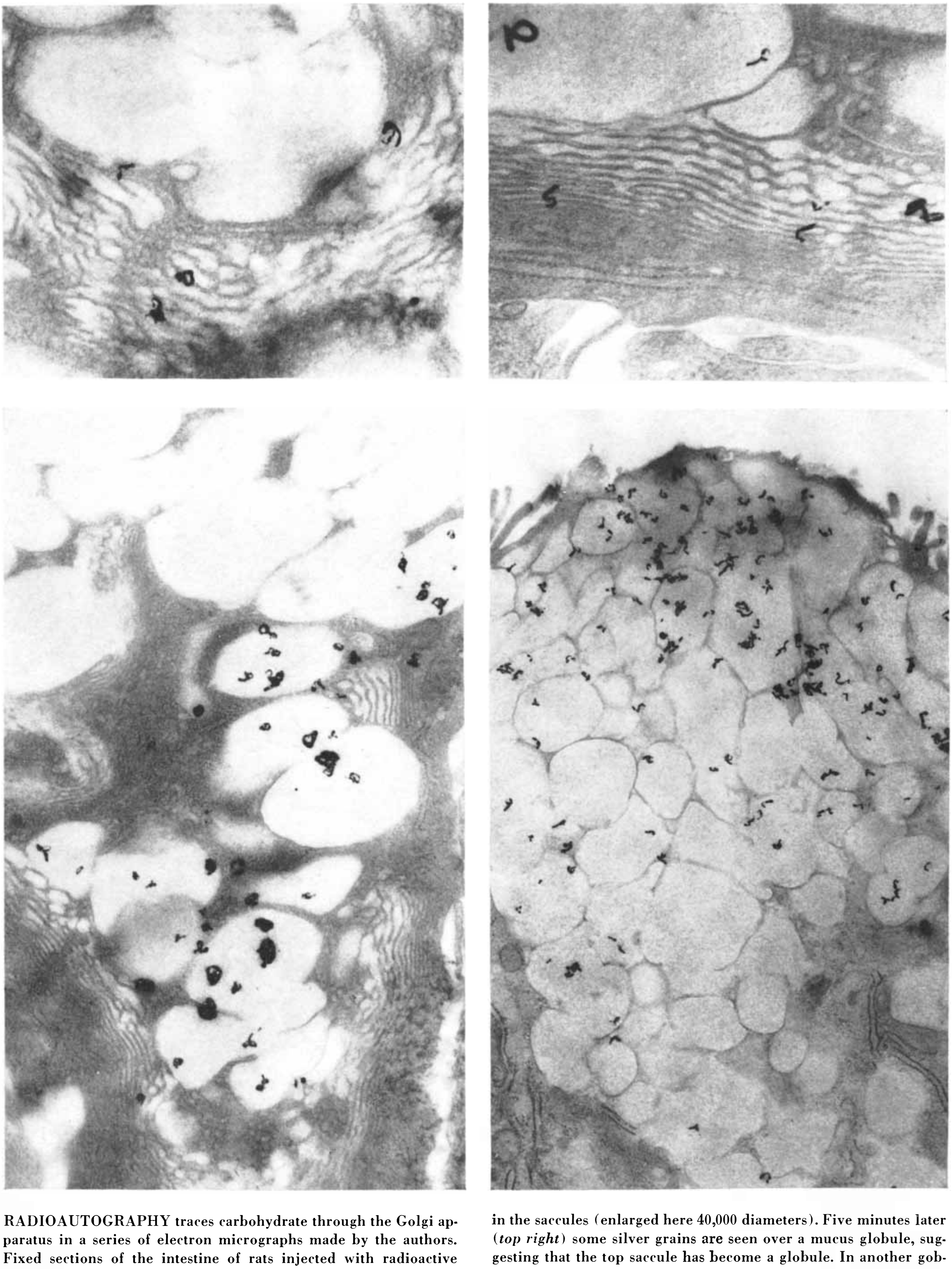
Our photographs showed that by four hours after the formation of radioactive secretion globules in the Golgi apparatus some of the globules had begun to pass out of the cell itself. Once released from the cell the globules burst open their membranes and spread their mucus contents over the lining of the intestine.

Thus our series of "still" photographs depicting the course of developments has given us a fairly comprehensive picture of the activities of the Golgi apparatus in the formation of mucus by the goblet cell [*see illustration on page 107*]. The protein part is first synthesized from amino acids on ribosomes at the base of the cell. It then moves into the Golgi saccules, where carbohydrate, which has been synthesized from simple sugars, is added to the protein. Recent tracer experiments by Margaret Jennings and Sir Howard Florey in Britain and by Gabriel C. Godman and his co-workers at the Columbia University College of Physicians and Surgeons have shown that the Golgi apparatus is also the site where sulfate is added to the carbohydrate part of the new glycoprotein. As the saccules are filled with glycoprotein they bud off the saccule stack as globules, which then migrate to the cell membrane, make their way through the membrane and finally break open and release their glycoprotein.

We have found that in various other types of cell the Golgi apparatus functions in much the same way as it does in goblet cells. For example, it appears to be responsible for the synthesis of the carbohydrate part of the mucus secreted by the salivary glands. Another type of secretion synthesized in the Golgi apparatus, as first reported by Susumu Ito and Jean-Paul Revel of the Harvard Medical School and then confirmed in our laboratory, is the carbohydrate-rich "cell coat" that covers the surface membrane of intestinal columnar cells. Using the sugar galactose as the radioactively labeled substrate, we have identified the Golgi apparatus as the apparent source of the carbohydrate incorporated in the surface coat. The uptake of labeled galactose into glycoprotein has also been located specifically in the Golgi apparatus of parathyroid cells (by Kazuyoshi Nakagami) and the cells that form tooth enamel (by Alfred Weinstock).

With the tracer technique we found that cartilage—the resilient structure embodied in many organs, typically the ears and the windpipe—contains a hard material that is another internal secretion that engages the synthetic machinery of the Golgi apparatus. The radioactivity of the labeled glucose injected into the animals turned up in the region of the Golgi apparatus of cartilage cells within five minutes and in the surrounding hard material about an hour later. Now, cartilage contains not only glycoprotein but also a large amount of mucopolysaccharide (a substance whose protein component has very long carbohydrate side chains with repeating units). Was the Golgi apparatus involved in the synthesis of this compound as well as that of the glycoprotein? To investigate this question we treated the radioactive cartilage with hyaluronidase, an enzyme that breaks down mucopolysaccharide. The treatment promptly removed much of the radioactivity from the Golgi region of the cartilage cells—a convincing indication that mucopolysaccharide was indeed synthesized there.

Finally, it has now been established that the Golgi apparatus is an active organ of synthesis in plant cells as well as



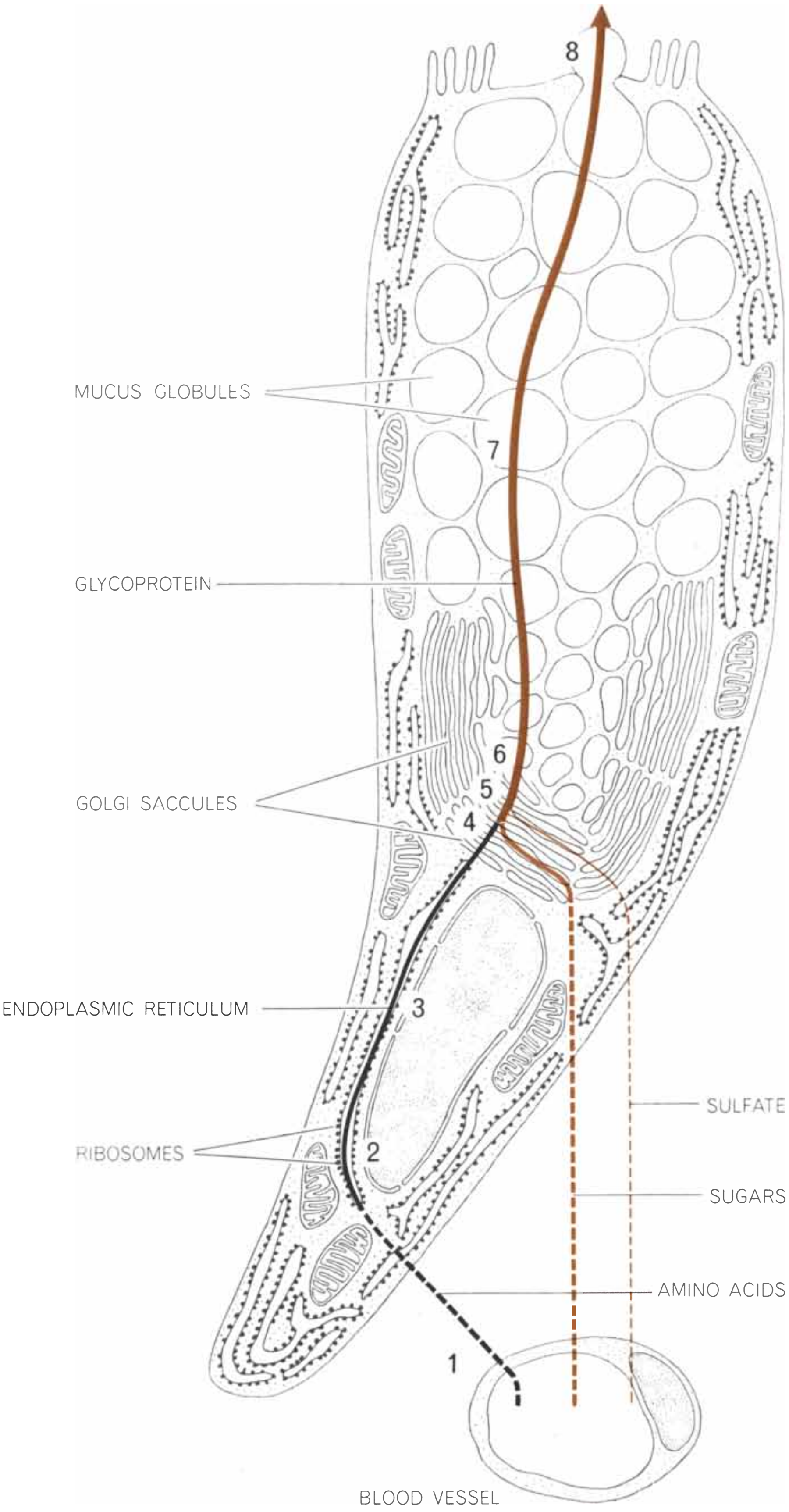
RADIOAUTOGRAPHY traces carbohydrate through the Golgi apparatus in a series of electron micrographs made by the authors. Fixed sections of the intestine of rats injected with radioactive glucose, made at various times after the injection, are coated with photographic emulsion. Radioactivity from the glucose causes silver grains to appear in the emulsion on development, thus locating glucose taken up into glycoprotein. In the first section (*top left*), made 15 minutes after an injection, the grains show the glucose is in the saccules (enlarged here 40,000 diameters). Five minutes later (*top right*) some silver grains are seen over a mucus globule, suggesting that the top saccule has become a globule. In another goblet cell, fixed 40 minutes after an injection and enlarged 20,000 diameters (*bottom left*), almost all the saccules that had taken up radioactive glucose have become mucus globules and are moving up in the cell. Four hours after an injection radioactive globules (enlarged 15,000 diameters) are about to be excreted (*bottom right*).

in animal cells. Donald Northcote and J. P. Pickett-Heaps in Britain investigated the formation of the carbohydrate material (containing cellulose and pectin) that is secreted by plant cells to build the wall around the cell. Supplying young plant cells with tritium-labeled glucose and then tracing the radioactivity by means of electron-microscope radioautography, they found that the pectic material of the cell wall was synthesized in the Golgi apparatus.

Recently biochemical studies using glucosamine as tracer showed that its uptake into glycoprotein took place not only in the smooth-membrane fraction (which includes the Golgi apparatus) but also in the ribosome-rich membrane fraction. Similar observations were also made for the formation of mucopolysaccharides.

More recently, working with Paul Whur and Annette Herscovics on radioautographic studies of the formation of a glycoprotein of the thyroid gland, we found that labeled galactose is taken up in the Golgi apparatus but labeled mannose (another sugar) is not. Instead mannose is taken up close to the ribosome site, where the protein is formed. Chemists who have analyzed the side chains of thyroid glycoprotein have found that mannose units are located close to the protein, whereas galactose units are near the end of the side chains. Presumably individual carbohydrate units are added to the chains in a stepwise manner. It therefore seems that the Golgi apparatus is not the exclusive site for the formation of carbohydrate side chains in glycoproteins and mucopolysaccharides. The formation of the side chain may begin as soon as the protein backbone is formed, with the bulk of it being built up in the Golgi apparatus.

Research in a number of laboratories is developing a detailed picture of busy and varied activity in the once mysterious Golgi apparatus of cells. In some cells the apparatus gives rise to lysosomes, enzyme-filled granules that are found in the cytoplasm of the cells. There are cells in which the Golgi apparatus displays a versatile capability, discontinuing the production of one type of granule and switching to the synthesis of another type. All in all, it looks as if the Golgi apparatus is a creative mechanism in the cell ranking in importance with the ribosome. Just as the ribosomes are responsible for the construction of proteins, so the Golgi apparatus seems to be the main agency for building a variety of large carbohydrates that serve many vital purposes.



COURSE OF EVENTS in a goblet cell during mucus formation is shown in this schematic diagram. Precursors of the mucus enter the cell from a blood vessel (*1*). Amino acids are synthesized on ribosomes (*2*) into proteins, which move up through the endoplasmic reticulum (*3*) to enter the Golgi saccules. Meanwhile simple sugars are taken up into the saccules, there to combine with the incoming protein (*4*) to form glycoprotein, to which sulfate from the blood is also added (*5*). The saccules in which the glycoprotein is put together are transformed into globules of mucus (*6*). The globules migrate to the top of the cell (*7*), ultimately leaving the cell and releasing the mucus to coat the surface of the intestine (*8*).

Our man in Ketchikan.

MATHEMATICAL GAMES

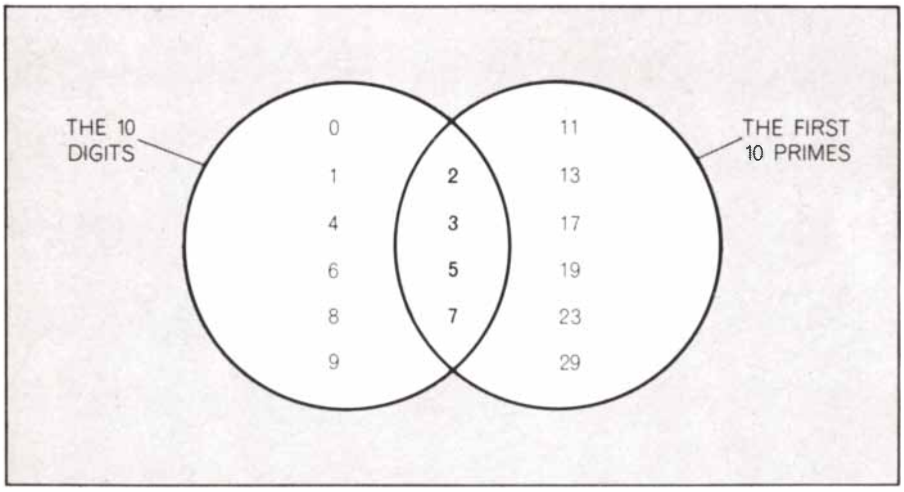
Boolean algebra, Venn diagrams and the propositional calculus

by Martin Gardner

Aristotle deserves full credit as the founder of formal logic even though he restricted his attention almost entirely to the syllogism. Today, when the syllogism has become a trivial part of logic, it is hard to believe that for 2,000 years it was the principal topic of logical studies, and that as late as 1797 Immanuel Kant could write that logic was "a closed and completed body of doctrine."

"In syllogistic inference," Bertrand Russell once explained, "you are supposed to know already that all men are mortal and that Socrates is a man; hence you deduce what you never suspected before, that Socrates is mortal. This form of inference does actually occur, though very rarely." Russell goes on to say that the only instance he ever heard of was prompted by a comic issue of *Mind,* a British philosophical journal, that the editors concocted as a special Christmas number in 1901. A German philosopher, puzzled by the magazine's advertisements, eventually reasoned: Everything in this magazine is a joke, the advertisements are in this magazine, therefore the advertisements are jokes. "If you wish to become a logician," Russell wrote elsewhere, "there is one piece of sound advice which I cannot urge too strongly, and that is: Do *not* learn the traditional logic. In Aristotle's day it was a creditable effort, but so was the Ptolemaic astronomy."

The big turning point came in 1847 when George Boole (1815–1864), a modest, self-taught son of a poor English shoemaker, published *The Mathematical Analysis of Logic.* This and other papers led to his appointment (although he had no university degree) as professor of mathematics at Queens College (now University College) at Cork in Ireland, where he wrote his treatise *An Investigation of the Laws of Thought, on Which are Founded the Mathematical Theories of Logic and Probabilities* (London, 1854). The basic idea—substituting symbols for all the words used in formal logic—had occurred to others before, but Boole was the first to produce a workable system. By and large neither philosophers nor mathematicians of his century showed much interest in this remarkable achievement. Perhaps that was one reason for Boole's tolerant attitude toward mathematical eccentrics. He wrote an article about a Cork crank named John Walsh (*Philosophical Magazine,* November, 1851) that Augustus De Morgan, in his *Budget of Paradoxes,* calls "the best biography of a single hero of the kind that I know."



Venn diagram for set intersection

The few who appreciated Boole's genius (notably the German mathematician Ernst Schröder) rapidly improved on Boole's notation, which was clumsy mainly because of Boole's attempt to make his system resemble traditional algebra. Today Boolean algebra refers to an "uninterpreted" abstract structure that can be axiomized in all kinds of ways but that is essentially a streamlined, simplified version of Boole's system. "Uninterpreted" means that no meanings whatever—in logic, mathematics or the physical world—are assigned to the structure's symbols.

As in the case of all purely abstract algebras, many different interpretations can be given to Boolean symbols. Boole himself interpreted his system in the Aristotelian way as an algebra of classes and their properties, but he greatly extended the old class logic beyond the syllogism's narrow confines. Since Boole's notation has been discarded, modern Boolean algebra is now written in the symbols of set theory, a set being the same as what Boole meant by a class: any collection of individual "elements." A set can be finite, such as the numbers 1, 2, 3, the residents of Omaha who have green eyes, the corners of a cube, the planets of the solar system or any other specified collection of things. A set also can be infinite, such as the set of even integers or possibly the set of all stars. If we specify a set, finite or infinite, and then consider all its "proper subsets" (they include the set itself as well as the empty set of no members) as being related to one another by inclusion (that is, the set 1, 2, 3 is included in the set 1, 2, 3, 4, 5), we can construct a Boolean set algebra.

A modern notation for such an algebra uses letters for sets, subsets or elements. The "universal set," the largest set being considered, is symbolized by U. The empty, or null, set is $\varnothing$. The "union" of sets a and b (everything in a and b) is symbolized by $\cup$, sometimes called a cup. (The union of 1, 2 and 3, 4, 5 is 1, 2, 3, 4, 5.) The "intersection" of sets a and b (everything common to a and b) is symbolized by $\cap$, sometimes called a cap. (The intersection of 1, 2, 3 and 3, 4, 5 is 3.) If two sets are identical (for example, the set of odd numbers is the same as the set of all integers with a remainder of 1 when divided by 2), this is symbolized by $=$. The "complement" of set a—all elements of the universal set that are not in a—is indicated by a'. (The complement of 1, 2, with respect to the universal set 1, 2, 3, 4, 5, is 3, 4, 5.) Finally, the basic binary relation of set inclusion is symbolized by ϵ; $a \epsilon b$ means that a is a member of b.

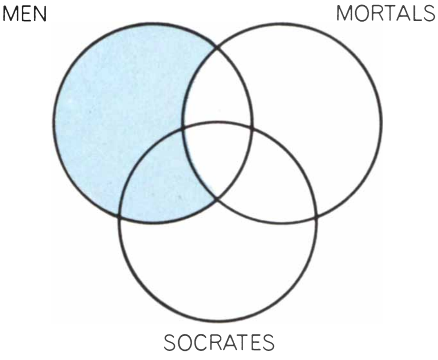
As a matter of historical interest, Boole's symbols included letters for elements, classes and subclasses, 1 for the universal class, 0 for the null class, + for class union (which he took in an "exclusive" sense to mean those elements of two classes that are *not* held in common; the switch to the "inclusive" sense, first made by the British logician and economist William Stanley Jevons, had so many advantages that later logicians adopted it), $\times$ for class intersection, = for identity, and the minus sign, −, for the removal of one set from another. To show the complement of x, Boole wrote $1 - x$. He had no symbol for class inclusion but could express it in various ways such as $a \times b = a$, meaning that the intersection of a and b is identical with all of a.

The Boolean algebra of sets can be elegantly diagrammed with Venn circles (after the English logician John Venn), which are now being introduced in many elementary school classes. Venn circles are diagrams of an interpretation of Boolean algebra in the point-set topology of the plane. Let two overlapping circles symbolize the union of two sets [*see illustration on opposite page*], which we here take to be the set of the 10 digits and the set of the first 10 primes. The outer rectangle contains the universal set. This includes the area outside both circles, which is shaded to indicate that it is the null set; it is empty because we are concerned solely with the elements inside the two circles. These 16 elements are the union of the two sets. The overlapping area contains the intersection. It consists of the set 2, 3, 5, 7: digits that are also among the first 10 primes.

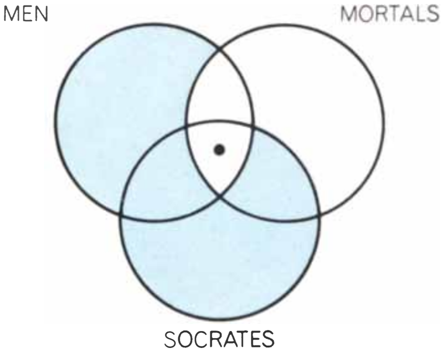
Adopting the convention of shading any area known to represent an empty set, we can see how a three-circle Venn diagram proves the ancient syllogism Russell so scornfully cited. The circles are labeled to indicate sets of men, mortal things and Socrates (a set with only one member). The first premise, "All men are mortal," is diagrammed by shading the men circle to show that the class of nonmortal men is empty [*see illustration at top left on this page*]. The second premise, "Socrates is a man," is similarly diagrammed by shading the Socrates circle to show that all of Socrates, namely himself, is inside the men circle [*see illustration at top right on this page*]. Now we inspect the diagram to see if the conclusion, "Socrates is mortal," is valid. It is. All of Socrates (the unshaded part of his circle marked by a dot) is inside the circle of mortal things. By exploiting the topological properties of simple closed curves we have a method of diagramming that is isomorphic with Boolean set algebra.

The first important new interpretation of Boolean algebra was suggested by Boole himself. He pointed out that if his 1 were taken as truth and his 0 as falsehood, the calculus could be applied to statements that are either true or false. Boole did not carry out this program but his successors did. It is now called the propositional calculus. This is the calculus concerned with true or false statements connected by such binary relations as "If p then q," "Either p or q but not both," "Either p or q or both," "If and only if p then q," "Not both p and q" and so on. The chart below shows the symbols of the propositional calculus that correspond to symbols for the Boolean set algebra.

It is easy to understand the isomorphism of the two interpretations by considering the syllogism about Socrates. Instead of saying "All men are mortal," which puts it in terms of class properties or set inclusion, we rephrase it as, "If x is a man then x is a mortal." Now we are stating two propositions and joining them by the "connective" called "implication." This is diagrammed on Venn circles in exactly the same way we diagrammed "All men are mortal." Indeed, all the binary relations in the propositional calculus can be diagrammed with Venn circles and the circles can be used for solving simple problems in the calculus. It is shameful that writers of most introductory textbooks on formal logic



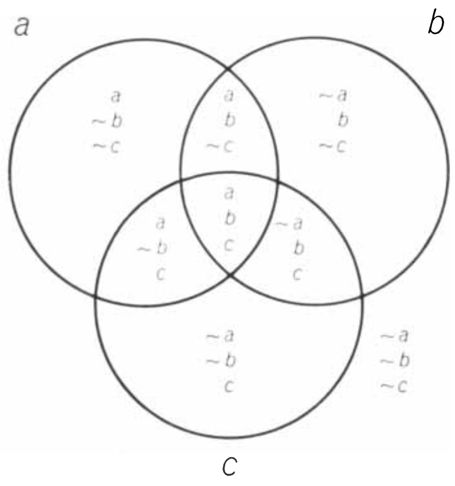
Premise: "All men are mortal"



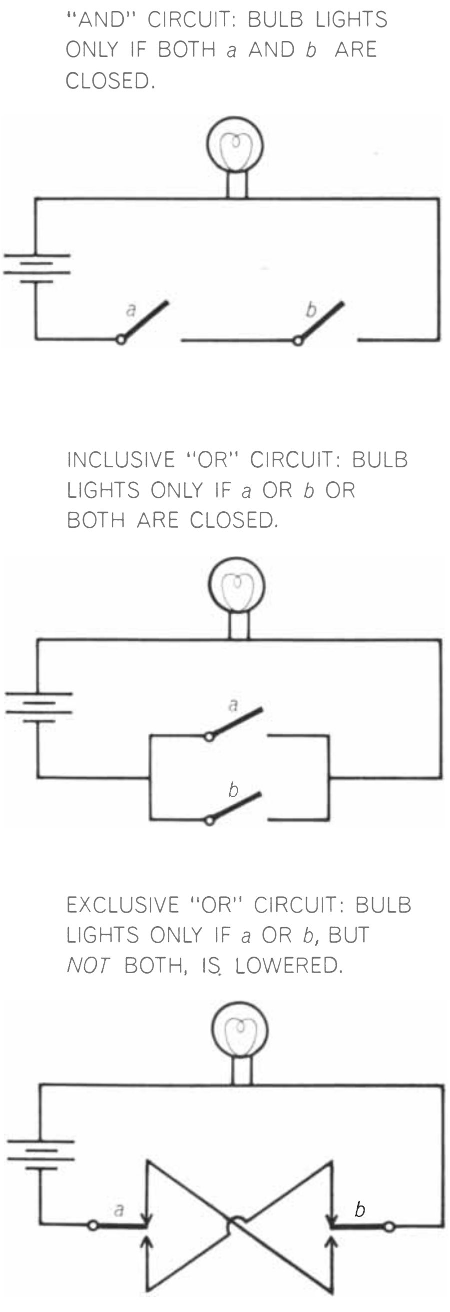
Premise: "Socrates is a man"

BOOLEAN SET ALGEBRA	PROPOSITIONAL CALCULUS
U (UNIVERSAL SET)	T (TRUE)
ϕ (NULL SET)	F (FALSE)
$a, b, c, \ldots$ (SETS, SUBSETS, ELEMENTS)	$p, q, r, \cdots$ (PROPOSITIONS)
$a \cup b$ (UNION: ALL OF a AND b)	$p \vee q$ (DISJUNCTION: EITHER p ALONE OR q ALONE, OR BOTH, ARE TRUE.)
$a \cap b$ (INTERSECTION: WHAT a AND b HAVE IN COMMON)	$p \bullet q$ (CONJUNCTION: BOTH p AND q ARE TRUE.)
$a = b$ (IDENTITY: a AND b ARE THE SAME SET.)	$p \equiv q$ (EQUIVALENCE: IF AND ONLY IF p IS TRUE, THEN q IS TRUE.)
a' (COMPLEMENT: ALL OF U THAT IS NOT a)	$\sim p$ (NEGATION: p IS FALSE.)
$a \in b$ (INCLUSION: a IS A MEMBER OF b.)	$p \supset q$ (IMPLICATION: IF p IS TRUE, q IS TRUE.)

Corresponding symbols in two versions of Boolean algebra



Venn diagram for martini puzzle



Circuits for three binary relations

have not yet caught on to this. They continue to use Venn circles to illustrate the old class-inclusion logic but fail to apply them to the propositional calculus, where they are just as efficient. Indeed, they are even more efficient, since in the propositional calculus one is unconcerned with the "existential quantifier," which asserts that a class is not empty because it has at least one member. This was expressed in the traditional logic by the word "some" (as in "Some apples are green"). To take care of such statements Boole had to tie his algebra into all sorts of horribly complicated knots.

To see how easily the Venn circles solve certain types of logic puzzles, consider the following premises about three businessmen, Abner, Bill and Charley, who lunch together every working day:

1. If Abner orders a martini, so does Bill.
2. Either Bill or Charley always orders a martini, but never both at the same lunch.
3. Either Abner or Charley or both always order a martini.
4. If Charley orders a martini, so does Abner.

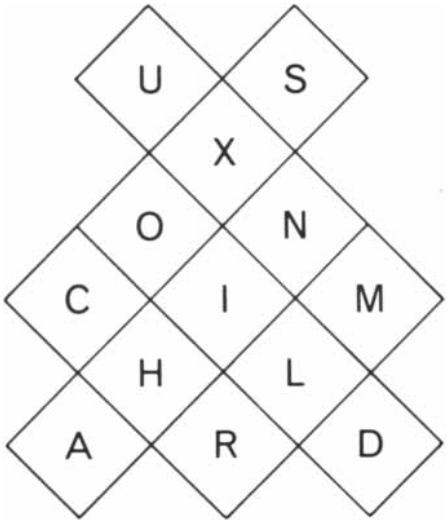
To diagram these statements with Venn circles we identify having a martini with truth and not having one with falsehood. The eight areas of the overlapping circles shown in the top illustration at the left are labeled to show all possible combinations of truth values for *a, b, c,* which stand for Abner, Bill and Charley. Thus the area marked *a, ∼b, c* represents Abner's and Charley's having martinis while Bill does not. See if you can shade the areas declared empty by the four premises and then examine the result to determine who will order martinis if you lunch with the three men. The answer will be given next month.

There are many other ways to interpret Boolean algebra. It can be taken as a special case of an abstract structure called a ring, or as a special case of another type of abstract structure called a lattice. It can be interpreted in combinatorial theory, information theory, graph theory, matrix theory and metamathematical theories of deductive systems in general. In recent years the most useful interpretation has been in switching theory, which is important in the design of electronic computers but is not limited to electrical networks. It applies to any kind of energy transmission along channels with connecting devices that turn the energy on and off, or switch it from one channel to another.

The energy can be a flowing gas or liquid, as in modern fluid control systems [see "Fluid Control Devices," by Stanley W. Angrist; SCIENTIFIC AMERICAN, December, 1964]. It can be light beams. It can be mechanical energy as in the logic machine Jevons invented for solving four-term problems in Boolean algebra. It can be rolling marbles, as in several computer-like toys now on the market: Dr. Nim, Think-a-Dot and Digi-Comp II. And if inhabitants of another planet have a highly developed sense of smell, their computers could use odors transmitted through tubes to sniffing outlets. As long as the energy either moves or does not move along a channel there is an isomorphism between the two states and the two truth values of the propositional calculus. For every binary connective in the calculus there is a corresponding switching circuit. Three simple examples are shown in the bottom illustration at the left. The bottom circuit is used whenever two widely separated electric light switches are used to control one light. It is easy to see that if the light is off, changing the state of either switch will turn it on, and if the light is on, either switch will turn it off.

This electrical-circuit interpretation of Boolean algebra had been suggested in a Russian journal by Paul S. Ehrenfest as early as 1910 and independently in Japan in 1936, but the first major paper, the one that introduced the interpretation to computer designers, was Claude E. Shannon's "A Symbolic Analysis of Relay and Switching Circuits" in the *Transactions of the American Institute of Electrical Engineers,* Volume 57, December, 1938. It was based on Shannon's 1937 master's thesis at the Massachusetts Institute of Technology, where he is now professor of mathematics.

Since Shannon's paper was published, Boolean algebra has become essential to computer design. It is particularly valuable in simplifying circuits to save hardware. A circuit is first translated into a statement in symbolic logic, the statement is "minimized" by various clever methods and the simpler statement is translated back to the design of a simpler circuit. Of course in modern computers the switches are no longer magnetic devices or vacuum-tube diodes but transistors and other tiny semiconductors. For a while after the publication of Shannon's historic paper much of the work on the logic of computer design was done with almost no communication between the experts of various countries. Gerard Piel, in his book *Science in the Cause of Man* (Knopf, 1961), reports that American mathematicians employed by several big corporations



Solution to spelling matrix

worked for five years, at a cost of about $200,000, to duplicate work that had already been published in Russia before they started.

Now for one final interpretation of Boolean algebra that is a genuine curiosity. Consider the following set of eight numbers: 1, 2, 3, 5, 6, 10, 15, 30. They are the factors of 30, including 1 and 30 as factors. We interpret "union" as the least common multiple of any pair of those numbers. "Intersection" of a pair is taken to be their greatest common divisor. Set inclusion becomes the relation "is a factor of." The universal set is 30, the null set 1. The complement of a number a is $30/a$. With these novel interpretations of the Boolean relations it turns out that we have a consistent Boolean structure! All the theorems of Boolean algebra have their counterparts in this curious system based on the factors of 30. For example, in Boolean algebra the complement of the complement of a is simply a, or in the propositional-calculus interpretation the negation of a negation is the same as no negation. More generally, only an odd series of negations equals a negation. (In *The New York Times* in 1965 I saw the headline "Albany Kills Bill to Repeal Law Against Birth Control." It took me a while to realize that the three negatives made this a decision *against* birth control.) Let us apply this Boolean law to the number 3. Its complement is $30/3 = 10$. The complement of 10 is $30/10 = 3$, which brings us back to 3 again.

Consider two famous Boolean laws called De Morgan's laws. In the algebra of sets they are

$$(a \cup b)' = a' \cap b'$$
$$(a \cap b)' = a' \cup b' .$$

In the propositional calculus they look like this:

$$\sim(a \vee b) \equiv \sim a \cdot \sim b$$
$$\sim(a \cdot b) \equiv \sim a \vee \sim b .$$

If the reader will substitute any two factors of 30 for a and b, and interpret the symbols as explained, he will find that De Morgan's laws hold. The fact that De Morgan's laws form a pair illustrates the famous duality principle of Boolean algebra. If in any statement you interchange (if and wherever they appear) union and intersection and interchange the universal and the null sets, and also reverse the direction of set inclusion, the result is another valid law. Moreover, these changes can be made all along the steps of the proof of one law to provide a valid proof of the other! (An equally beautiful duality principle holds in projective geometry with respect to interchanges of lines and points.)

The numbers 1, 2, 3, 5, 6, 7, 10, 14, 15, 21, 30, 35, 42, 70, 105, 210—the 16 factors of 210—also form a Boolean algebra when interpreted in the same way, although of course 210 is now the universal set and the complement of a is $210/a$. Can the reader discover, before it is revealed next month, a simple way to generate sets of 2^n numbers, where n is any positive integer, that will form Boolean systems of this peculiar kind?

One solution to last month's problem—placing the 13 different letters of RICHARD MILHOUS NIXON in the cells of a given matrix in such a way that the President's full name can be spelled by the moves of a chess king—is given at the top of this page. As reader Bethaviva Cohen was the first to point out, the C and L and the N and X can be interchanged.

One method of finding the eight different ways 16 pearl and jade beads can be arranged in a bracelet to show all 16 possible quadruplet combinations is as follows. Represent the bracelet as a row of binary digits, 1 = jade, 0 = pearl. The chain is considered cyclic, its end joining the front. Combinations 1111 and 0000, which must be on the chain, can be adjacent or separated by 1, 2, 3 or 4 beads. These five possibilities are shown by the black binary digits in the illustration below. Since each of the two quadruplets must be bounded on both sides by digits of the other type, we must add the digits shown in color. The second row is immediately eliminated because either 1 or 0 in the shaded cell will duplicate 0000 or 1111. Row 5 is eliminated by trying the four doublets (00, 01, 10, 11) in the two shaded cells and noting that in each case a quadruplet is duplicated.

The remaining rows all have solutions. Row 1 has four, shown below in complementary pairs. Each is obtained from the other by changing all 1's to 0's and all 0's to 1's, which is equivalent to exchanging pearl and jade beads.

1111000010011010
0000111101100101

1111000010110100
0000111101001011

Row 3 has one complementary pair:

1111010000110010
0000101111001101 .

Row 4 has one complementary pair:

1111011000010100
0000100111101011 .

These eight solutions are unique in the sense that their reversals are obtained by turning over the bracelet or by circling it in the opposite direction. A simple algorithm for constructing a minimum-length chain for any desired n-tuplet begins by making a list of all possible n-tuplets. Start the chain with an n-tuplet of all 0's. Add 1 if it makes a new n-tuplet, then check this new n-tuplet off the list. If the 1 fails to make

1	1	1	1	1	0	0	0	0	1							0
2	1	1	1	1		0	0	0	0	1						0
3	1	1	1	1	0	1	0	0	0	0	1					0
4	1	1	1	1	0		1	0	0	0	0	1				0
5	1	1	1	1	0			1	0	0	0	0	1			0

Chart for solving bracelet problem

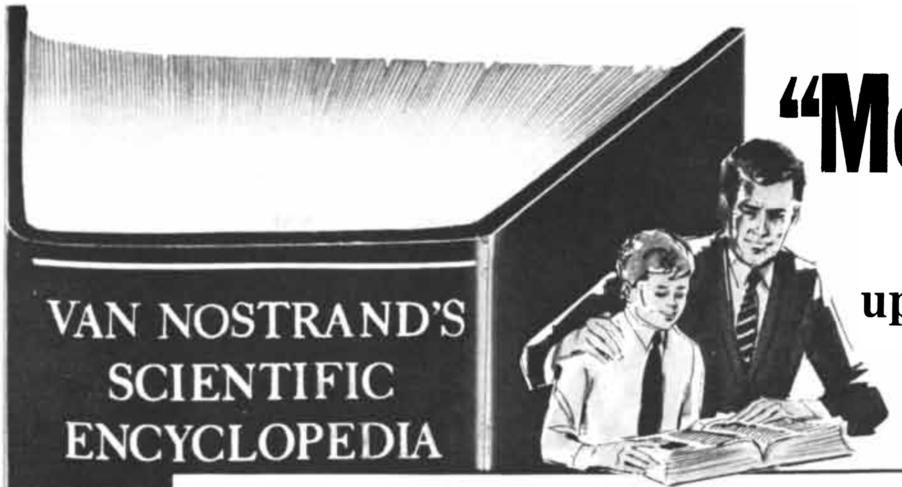
a new n-tuplet, add 0 and cross the new n-tuplet off the list. Continue this procedure to generate a solution.

This algorithm is a special case of a beautiful general procedure, discovered in 1934 by Monroe H. Martin of the University of Maryland, that covers minimum-length bracelets showing all n-tuplets for beads of m different colors. For example, if there are three colors, 0, 1, 2, and we want a bracelet showing all 27 triplets, we start with 000 and proceed to add digits, always selecting the highest digit that will not duplicate a triplet that has already been formed. The result is 000222122021121020120011101. The procedure is given in exercise No. 17, page 33, of the second volume of Donald E. Knuth's monumental continuing series, *The Art of Computer Programming* (Addison-Wesley, 1969). The book is as rich in recreational material and little-known historical sidelights as last year's first volume, and I recommend it highly. In Volume I (answer to exercise No. 23, page 379) Knuth gives a remarkable formula (due to N. G. de Bruijn of Holland) that provides the number of minimum-length bracelets of n-tuplets and m colors, including reversals as different. Knuth tells me that when reversals are *not* considered different (as in the problem given here), the formula is

$$\frac{\frac{1}{2}(m!)^{m^{n-1}}}{m^n}.$$

If reversals are considered different, the formula is simply doubled. It is not hard to prove, Knuth adds, that no bracelets are symmetrical in the sense that they are identical with their reversals. The only exception is the four-bead doublet bracelet of two colors; in its case the above formula gives 1/2 as the number of different bracelets instead of 1, the correct number.

Different methods of constructing such bracelets and other fascinating aspects of cyclic chains of this type are discussed in Chapter 9 of Sherman K. Stein's *Mathematics: The Man-made Universe* (W. H. Freeman and Company, 1963). The chapter is an expansion of Stein's article in this magazine for May, 1961. It includes a fascinating history of the problem, beginning with the use of such chains by poets in India 1,000 years ago (as mnemonic devices for remembering combinations of long and short beats) and ending with current applications, particularly in the construction of what communication theorists call error-correcting codes.



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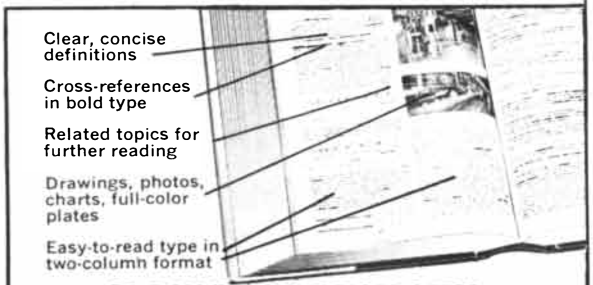

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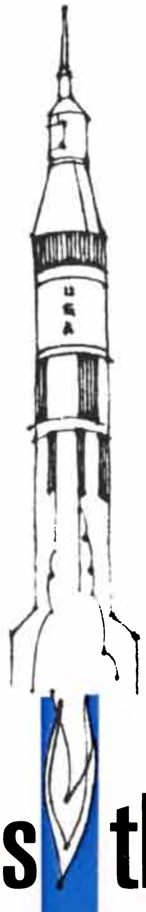

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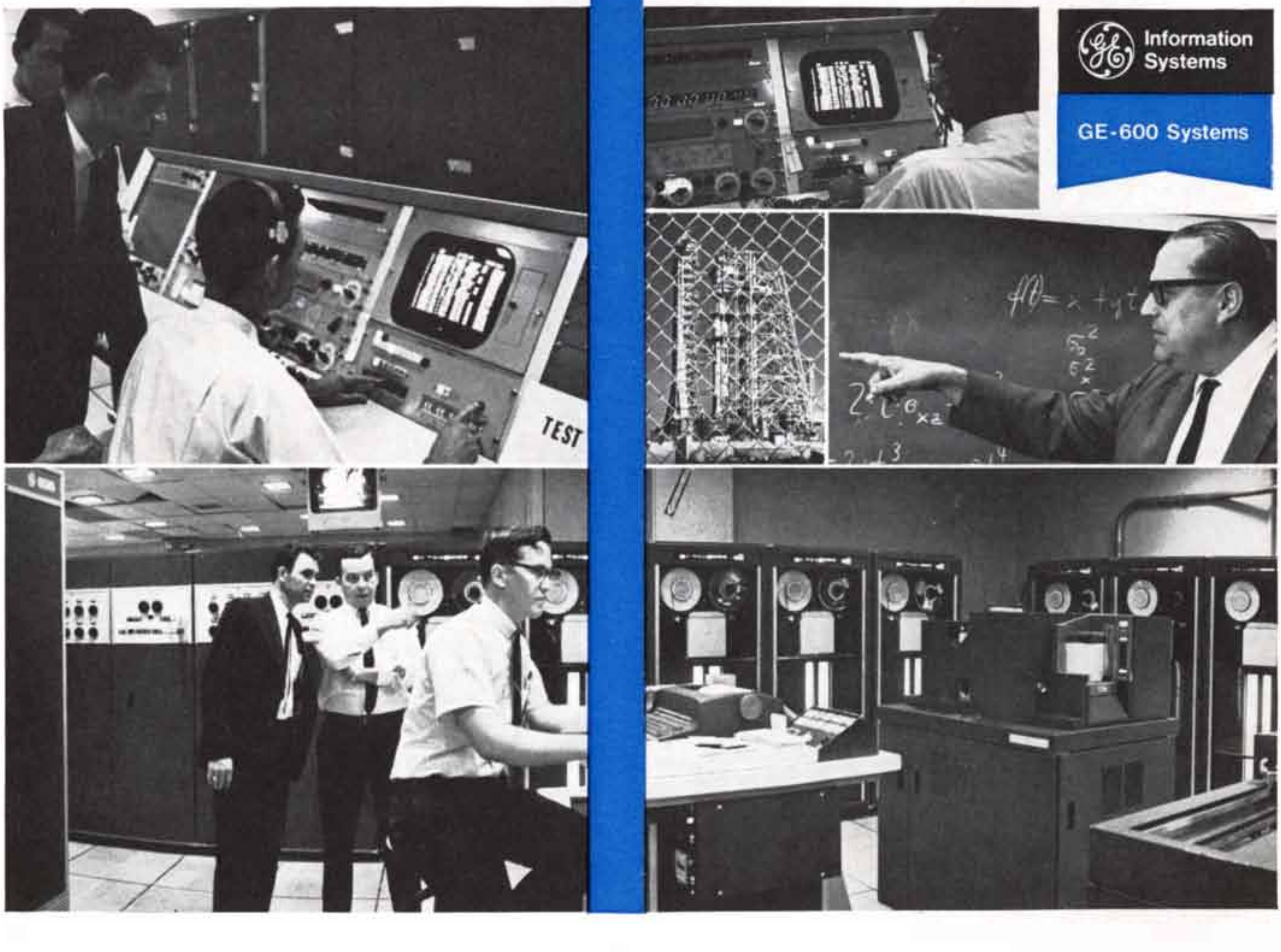

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GENERAL ELECTRIC

THE AMATEUR SCIENTIST

How to construct an argon gas laser with outputs at several wavelengths

Conducted by C. L. Stong

During the past four years several thousand amateurs have built helium-neon gas lasers of the kind described in this department for September, 1964, December, 1965, and February, 1967. Amateurs have used the lasers, which emit a reddish-orange beam of coherent light at a wavelength of 6,328 angstroms, for such diverse purposes as demonstrating the physical properties of light, testing the optical quality of lenses and mirrors, precisely measuring length and velocity and making holograms. Recently other kinds of lasers that can be built at home have been developed. One of them is the argon gas laser, which emits coherent light of several colors in the green, blue and violet regions of the spectrum and thus greatly enlarges the scope for experimentation.

The argon laser is no more difficult to build than the helium-neon type, although in general the construction of lasers makes a considerably more severe demand on the craftsmanship of the experimenter than most of the projects that have been described in these columns do. Such demands are minimized, however, by an argon laser that has been designed recently for amateur construction by Sylvan Heumann of 410 Eucalyptus Avenue, Hillsborough, Calif. 94010. Heumann writes:

"The argon laser resembles the helium-neon laser in many ways. It consists essentially of a gas-discharge tube about two feet long, the ends of which are closed by a pair of flat windows of fused quartz that face a pair of small dielectric mirrors [*see top illustration on opposite page*]. The tube glows dark blue when the gas is energized by a pulsed electric current of 15 to 20 amperes. Depending on the amount of the current, the energy of the ionized atoms is increased one or more levels above that of the ground state, which is the level of energy that characterizes electrically neutral atoms of argon gas. The electrical discharge is said to pump the atoms to an excited state. After a short time the atoms spontaneously fall to a lower energy state, one at a time, simultaneously emitting a quantum, or pulse, of light. The color of the emitted light varies according to the amount of energy that is liberated during the fall. Quanta of relatively low energy appear red and those of increasingly higher energy appear yellow, green, blue and so on.

"Occasionally a quantum of light that has been liberated spontaneously from an excited atom encounters another energized atom. The resulting interaction may cause the energized atom to fall to a lower energy level and simultaneously liberate a quantum of precisely the same color as the stimulating quantum. This is the phenomenon called stimulated emission. The initial photon causes the excited atom to fall somewhat earlier than it would if it were not disturbed. The two photons merge and proceed through space as a train of coherent, monochromatic light waves.

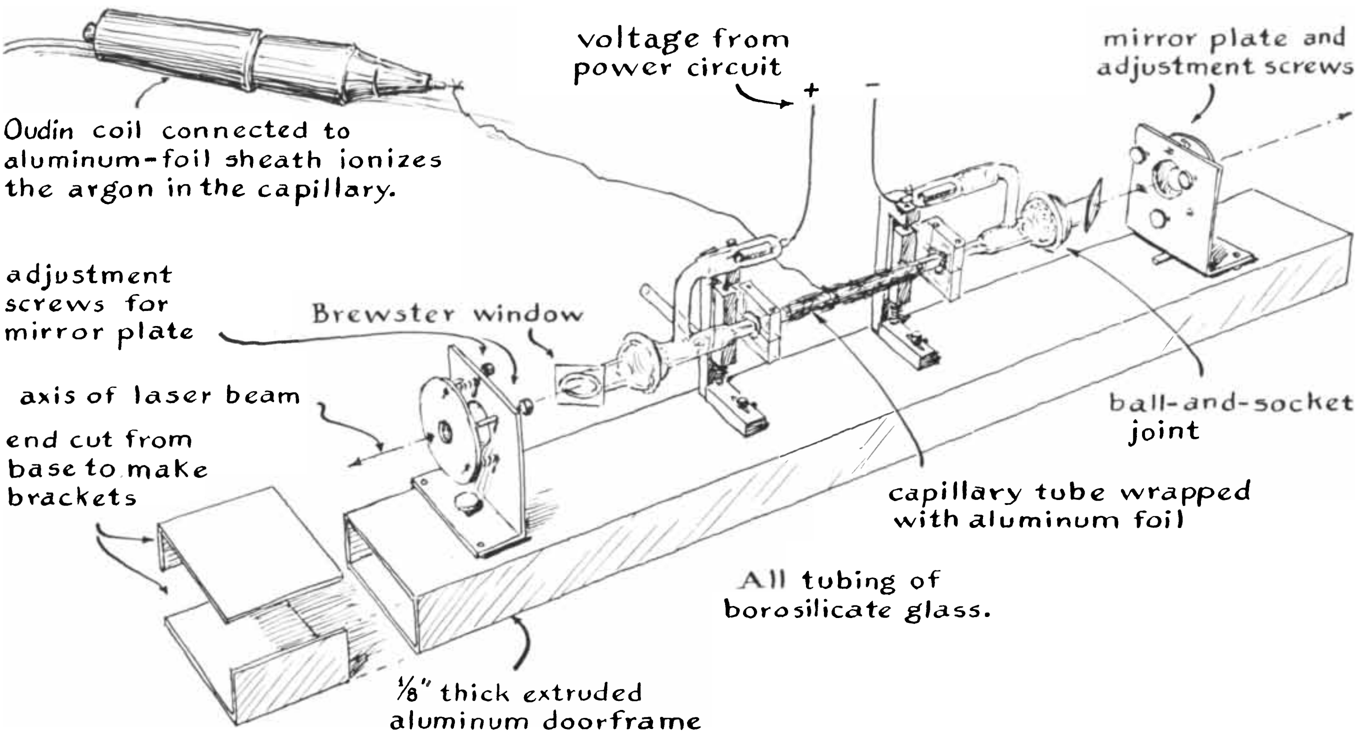
"The train may encounter a third excited atom and similarly cause it to contribute a photon to the growing packet of energy. Indeed, the train of waves may continue to accumulate energy by stimulated emission until it travels out of the gas. The argon laser is merely an apparatus designed to encourage the continued growth of the train by causing it to travel back and forth through the gas many times. This effect is achieved by the flat windows and the pair of dielectric mirrors associated with the laser tube. An occasional train of coherent light waves may travel along the axis of the tube and make its way through one of the windows and thence to the adjacent mirror. If the mirror is of high optical quality, it reflects most of the light directly back through the window and into the tube, where the light accumulates still more energy by the process of stimulated emission. The intensified light proceeds through the opposite window, and the cycle of events is repeated.

"Not all the energy of the beam is reflected by the mirrors. Mirrors of perfect reflectivity cannot be made. Some of the energy is absorbed by the reflecting material and transformed into heat. Another portion, perhaps a few thousandths of 1 percent, makes its way through the reflecting material. This small portion constitutes the output of the laser.

"To create the current of 15 to 20 amperes that excites the gas a potential of some 2,000 volts must be applied to the electrodes of the tube. The resulting expenditure of power amounts to several kilowatts—enough to heat the tube beyond the melting point of the glass. In order to prevent destructive heating, power is applied to the laser in short, rather widely spaced pulses. In the design that I recommend the tube is so energized 120 times per second. The pulses persist only a few millionths of a second. Pulses of coherent light are emitted at the same rate and persist for less than 50 millionths of a second. The beam appears continuous to the eye, however, because the relatively sluggish chemical processes of vision cause each pulse to be seen for about a fiftieth of a second.

"The laser consists of a base assembly that supports a capillary tube 50 centimeters long with a bore of two millimeters. Each end of the capillary tube is sealed to a 15-millimeter tube that includes a quartz window and a neon-sign electrode. A ball-and-socket joint of glass in the 15-millimeter tube permits adjustment of the angle the windows make with the axis of the capillary. Air is pumped from the assembly and argon gas is admitted to it through a short length of seven-millimeter tubing sealed into the 15-millimeter tube at one end [*see bottom illustration on opposite page*]. All parts are made of borosilicate glass except the quartz windows.

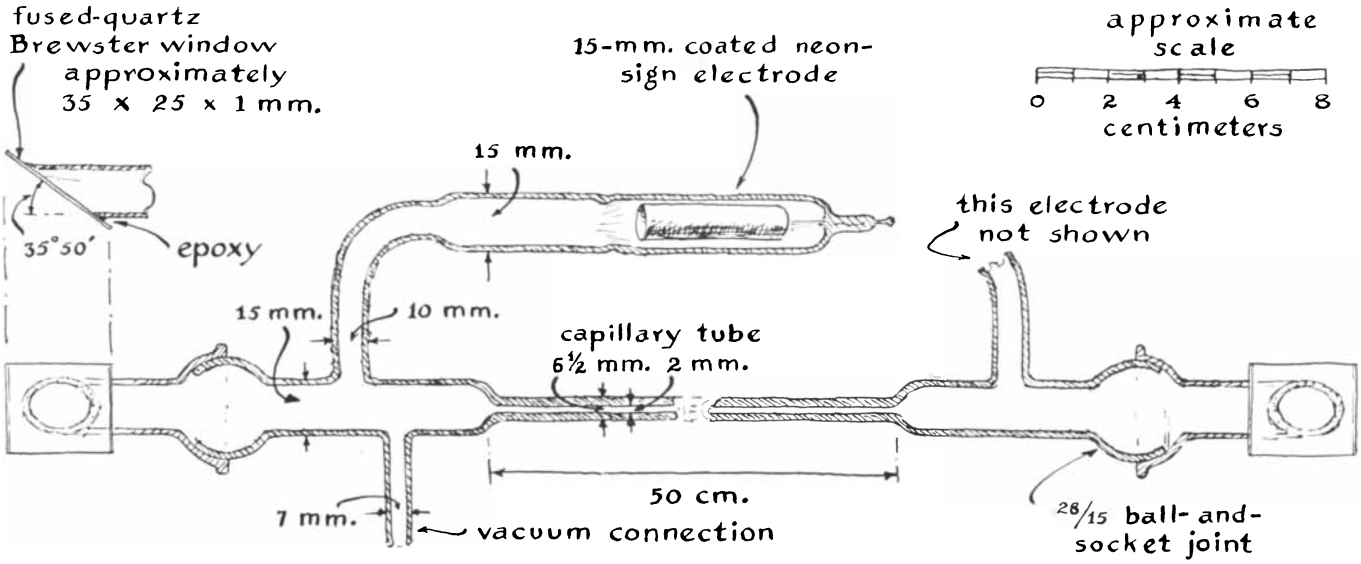
"Begin the construction by cutting a 51-centimeter length of capillary tubing. This tubing comes in standard lengths of four feet. With a corner of a flat file make a crosswise nick in the glass at the specified length, grasp the tubing on each side of the nick and pull it apart. Do not bend the glass. With a blowtorch that burns a



Overall view of the laser designed by Sylvan Heumann

mixture of oxygen and household gas, heat the cut ends just enough to round the sharp edges. When the glass cools, reheat one end until the bore closes. Blow into the opposite end to form a bulb about 18 millimeters in diameter. Let the bulb cool until it solidifies. Reheat the outer hemisphere of the bulb to softness, then blow forcefully to explode the softened glass. Strike off with the flat face of the file any tissue-thin fragments that cling to the expanded end of the capillary. Rotate the expanded end of the tube in the fire until the edge shrinks to a diameter of 15 millimeters. Similarly expand the other end of the capillary.

"Next, select a cork that fits 15-millimeter tubing and bore an axial hole through it to fit a pencil-sized length of wooden dowel rod. Insert the end of the rod completely through the cork from the top. Insert the small end of the cork into the ball end of the ball member of the ball-and-socket joint. Align the dowel with the axis of the ball member so that when the dowel is rotated between the thumb and fingers, the glass turns without wobbling, as though it were in a lathe. Grasp the dowel in one hand and the capillary in the other. Bring the 15-millimeter tubing of the ball member into axial alignment with the capillary. While rotating the glasses back and forth synchronously, move the ends of both pieces into the edge of the flame on opposite sides and heat the glass until about one millimeter of each edge softens. Remove the glasses from the fire and, while maintaining the back-and-forth rotation, press the aligned ends lightly together so that they fuse. Return the fused joint to the fire. Continue rotating the glass back and forth. Never let it stop. When it becomes soft, remove the work from the fire, stretch the joint about five millimeters and blow into the open end of the capillary until the glass expands into a rounded contour. You have



Details of the laser tube

now made a 'butt seal.' In the same way seal the remaining ball member to the opposite end of the capillary.

"By means of the same technique seal a 25-centimeter length of 10-millimeter tubing to a 25-centimeter length of 15-millimeter tubing. At a point three centimeters from the seal, cut the 15-millimeter tubing and seal to its end a 15-millimeter neon-sign electrode of the type that is coated internally with a mixture of barium carbonate and strontium carbonate. Similarly prepare a second electrode. Bend the 10-millimeter tubing of each electrode assembly to a right angle by softening a three-centimeter zone of the glass adjacent to the seal. Bend the softened glass by turning the ends upward. (Let gravity work with you.) When the bend is completed, promptly blow into the open end of the tubing to restore the original diameter of the curved portion. When the glass cools, cut the 10-millimeter tubing to the illustrated proportions.

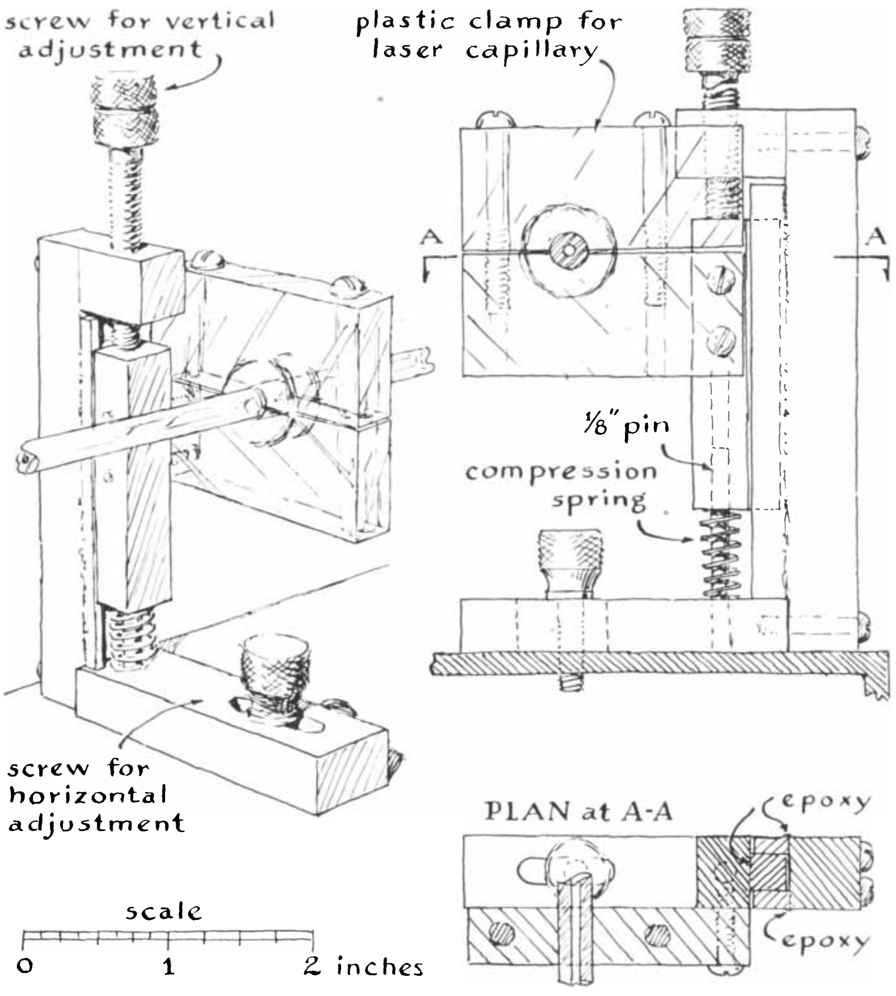
"Seal the electrode subassemblies into the ball members of the capillary assembly. To make this seal blow a hole in the 15-millimeter tubing of the ball member by placing a stopper in the opening of the ball and heating a spot about 12 millimeters in diameter in the middle of the 15-millimeter tubing. Blow the softened spot into a hemisphere. Reheat about 70 percent of the hemisphere and blow forcefully to explode the upper part of the bulb. Butt-seal an electrode subassembly to the hole. Transfer the stopper to the opposite end and seal the second electrode subassembly. Finally, with the same procedure, seal a four-inch length of seven-millimeter tubing into the assembly at the position indicated by the drawing. (The basic techniques of making glass apparatus by hand are fully explained in *Creative Glass Blowing*, by James E. Hammesfahr and Clair L. Stong, W. H. Freeman Company, 1968.)

"The tube is completed by cementing the quartz windows to the socket members of the ball-and-socket joints. The windows transmit the laser beam with substantially no loss of light only if they are cemented to the glass tube at an angle of approximately 35 degrees 50 minutes with respect to the axis of the tube. My tubing was cut to this angle by a diamond saw of the type used by amateur mineralogists. The cuts can also be made with a blade of soft metal, such as brass, that is fed a slurry of No. 120 grit Carborundum and water. The blade, a strip of brass about .02 inch thick and 10 inches long, can be mounted for use in a hacksaw frame. The angle of the cut can be maintained with an improvised miter box. The cut end of the glass must be lapped smooth and flat by grinding the tubing against a sheet of plate glass with a slurry of No. 600 grit Carborundum.

"To cement the quartz windows in place, coat the mating surfaces of the balls and sockets lightly with high-vacuum stopcock grease, connect the laser tube to the vacuum pump through the seven-millimeter inlet and start the pump. Place the previously cleaned windows in contact with the cut ends of the socket members and assemble the sockets simultaneously to the balls. Suction will hold the joints and the windows in place. If this two-handed manipulation proves difficult, have an assistant position one of the windows while you position the other one. If the cut ends have been lapped flat, the tube assembly will be airtight. With a toothpick gently apply a bead of epoxy cement completely around the junction of the tube and window. The cement should not flow into the junction and it will not if the end of the tube has been lapped flat. Let the vacuum pump run until the cement solidifies. This operation completes the laser tube.

"The mechanical assembly can be improvised from almost any available materials. For the base I used a scrap of rectangular aluminum tubing four inches wide, two inches thick and 36 inches long of the type found in metal doors. The laser tube is attached to the base with a pair of adjustable fixtures that are convenient for aligning the tube coaxially with the mirrors. The fixtures can be made with ordinary hand tools. The mirrors are mounted in adjustable cells that include micrometer screws spaced radially at 120 degrees. The optical axis of the mirrors can be positioned as desired by manipulating the screws. Several of the accompanying illustrations give details of the supporting fixtures and mirror cells.

"It is possible to prepare the laser for operation with a fairly crude vacuum system. A mechanical pump capable of exhausting the tube to a pressure of .01 torr is adequate. (One torr is equal to the pressure exerted by a column of mercury one millimeter high.) The useful life of the tube tends to increase, however, with the effectiveness of the vacuum sys-

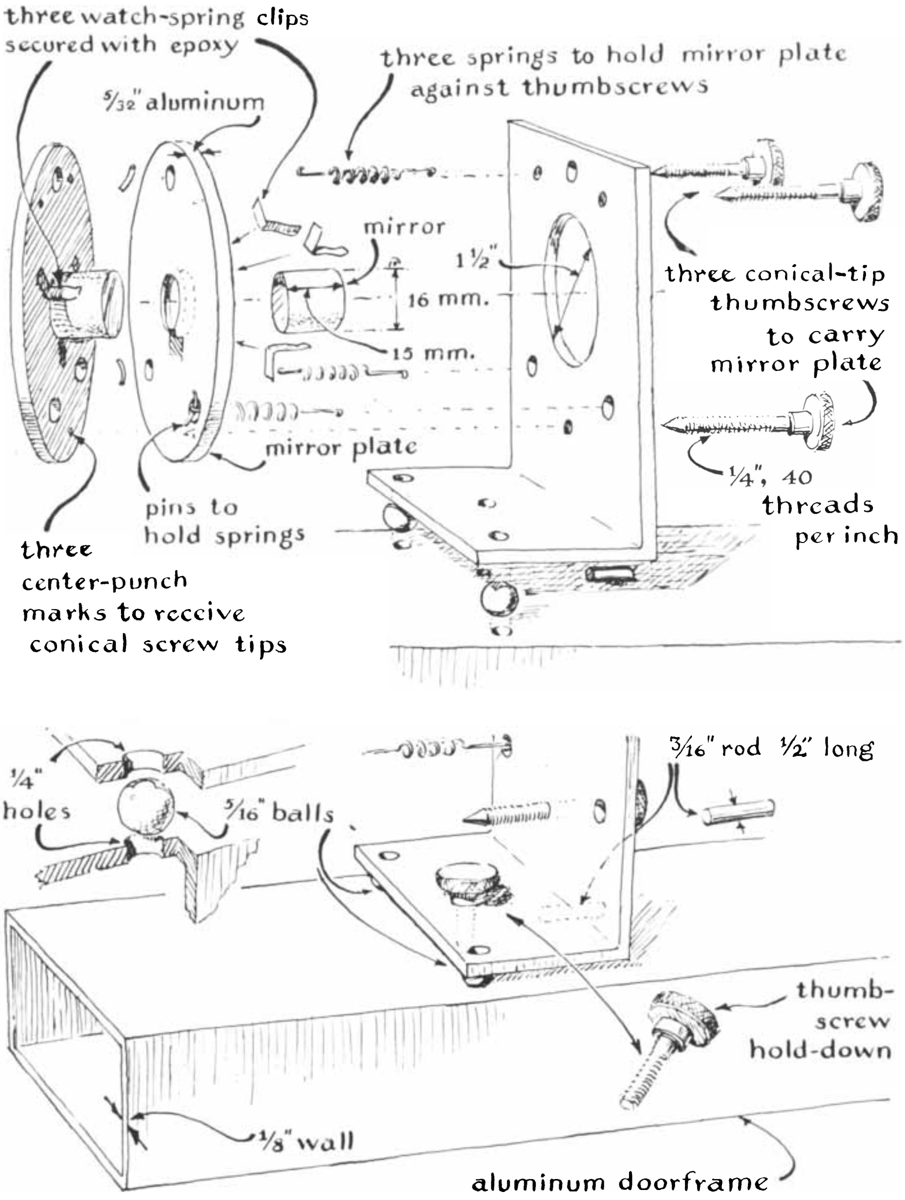


Adjustable fixture that supports the laser tube tem. My laser operates for about 30 minutes on a charge of gas. I rarely disconnect it from the vacuum system. When laser action begins to fail, I replace the argon by opening a stopcock that lets the used gas flow into the pumps. Then I close the stopcock and open another one that admits fresh argon from the reservoir. The apparatus now operates for another 30 minutes.

"My vacuum system includes both a mechanical pump and a diffusion pump, a cold trap, a closed-end manometer, a vacuum gauge, a flask of argon and five stopcocks [*see illustration on page 123*]. (The diffusion pump, cold trap and gauges may be omitted.) The stopcock that connects the gas reservoir to the system should be of the high-vacuum type and need not have a bore larger than two millimeters. Remove the plug of this stopcock. With a file make a scratch about a third of the way around the plug beginning at the hole. Turn the plug clockwise and, by reducing the pressure on the file, let the depth of the scratch taper gradually to the surface. Make a similar scratch that extends in the same direction from the other end of the hole. Apply a thin film of high-vacuum stopcock grease to the plug and replace it. When the stopcock is operated, gas flows through the scratches slowly, enabling you to fill the tube with argon at a precisely controlled rate.

"Current for exciting the laser tube is drawn from a power supply at the rate of 120 pulses per second. The power supply consists of a variable transformer that feeds a neon-sign transformer. The high-voltage output of the neon-sign transformer is converted to direct current for charging a capacitor. Pulses of current are drawn from the capacitor by the tube when the argon gas is ionized by an Oudin coil, which generates a potential of 30,000 volts at a very high frequency. The amount of current depends on the adjustment of the variable transformer. Any neon-sign transformer can be used that is rated at an output potential of between 4,000 and 9,000 volts and a current of not more than 50 milliamperes. The variable transformer must be rated at a current of at least two amperes. The capacitor may be rated at one microfarad and at a breakdown voltage at least equal to that of the neon-sign transformer.

"A higher potential than is provided by the power supply is required to ionize argon gas; it can be developed from an Oudin coil of the type used for detecting leaks in the glass parts of vacuum systems. An example is the No. 15–340–75V3 Vacuum Tester distributed by the



Details of the mirror cell

Fisher Scientific Company, Springfield, N.J. 07081. Connect a wire from the high-voltage terminal of the coil to a piece of aluminum foil wrapped around the middle of the capillary tube. The high potential of the Oudin coil triggers pulses of pumping current from the capacitor. Place the capacitor within a few inches of the tube to minimize the length of the leads that connect it to the electrodes.

"When the laser has been assembled, connect the tube to the vacuum system and install the dielectric mirrors in their cells. One mirror should be spherical and have a radius of 120 centimeters. The other mirror should be flat. Ordinary silvered or aluminized mirrors will not work. With the mirrors installed, place a small incandescent lamp near the end of the tube so that the light that passes through the glass is reflected into the bore of the capillary by the inclined inner face of the quartz window. Look into the bore of the capillary through the mirror nearest the lamp and adjust the micrometer screws that control the distant mirror until the circles of light that are reflected from the walls of the tube and the bright spot from the distant mirror are concentric. Transfer the lamp to the distant end of the tube and adjust the mirror there.

"Close the stopcock of the gas reservoir and the stopcock leading to the air inlet. Open all stopcocks between the vacuum pump and the tube. Start the pump. With a low-temperature flame of the kind delivered by a propane gas torch heat all parts of the tube except the ball-and-socket joints and the quartz windows. The glass should be made hot enough to turn a piece of white tissue yellow in about 20 seconds. The heat drives adhering gases from the inner walls of the glass.

"The electrodes must now be brought to a dark red heat. I heat them one at a time by sliding over the glass envelope of the electrode a coil of wire that is connected to the output of a 75-watt amateur-radio transmitter. A variable capacitor is connected across the coil for tuning it to resonance with the frequency of the transmitter. The size of the variable capacitor and of the coil depends on the frequency at which the transmitter operates, but a coil of nine turns that is an inch wide and 1½ inches long will work with most transmitters when it is tuned by a variable capacitor of about 150 picofarads.

"The electrode will begin to heat as the circuit approaches resonance. At full resonance the electrode may become hot enough to melt, so tune the circuit cautiously. Stop tuning at the point where the electrode becomes red hot. The heated electrode will liberate an astonishing amount of gas, enough to alter the characteristic sound of the vacuum pump. Maintain the metal at red heat for about three minutes, then similarly 'outgas' the second electrode. In addition to liberating gas from the metal, the heat burns away the nitrocellulose binder used for coating the interior of the electrode and converts some of the barium carbonate to metallic barium. Part of the metallic barium then combines with chemically active gases and vapor, such as oxygen, nitrogen, carbon dioxide and water vapor, that remain in the tube.

"To fill the tube with argon turn on the power supply and the Oudin coil, adjust the variable transformer for an output of approximately 70 volts and close the stopcock to the vacuum pump and the one to the trap. Open the stopcock to the argon flask just enough to allow a flow of gas. As argon enters the system the tube will begin to glow faintly and will increase in brightness as the gas pressure increases. The rate of gas flow differs with various stopcocks and must be determined experimentally.

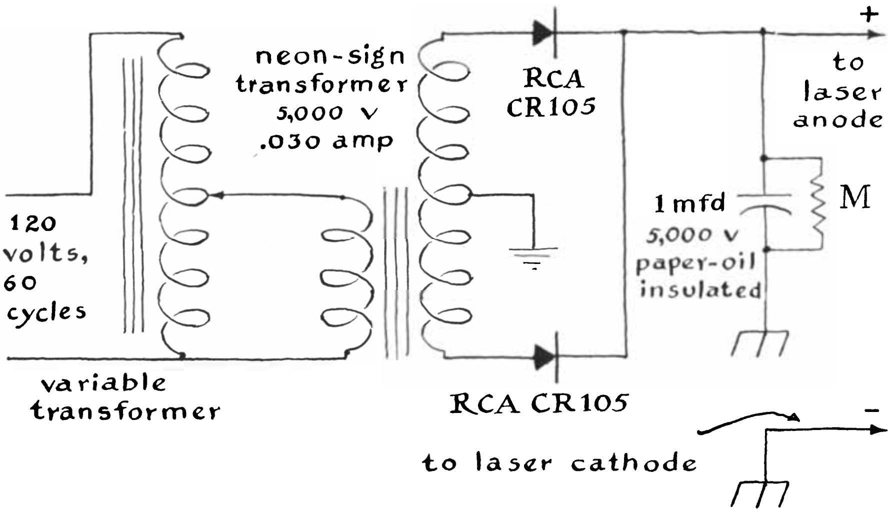
"The tube may flash intermittently and the gas may change from light blue to a pinkish hue. The color change indicates the presence of an unwanted gas, such as oxygen. If the color change occurs, shut off the gas supply, let the tube operate for about a minute and then shut off the power. Open the stopcock to the vacuum pump and exhaust the system for about five minutes. Repeat the sequence of operations until the tube glows dark blue and retains this color for at least five minutes. Pump out the gas.

"The apparatus is now ready for laser action. With the variable transformer turned on and adjusted for an output of about 70 volts, admit argon gas to the tube as slowly as possible. The tube may glow dimly and flicker. Continue to add argon just to the point where the tube stops flickering. If the mirrors have been adjusted perfectly, a beam of greenish-blue coherent light will be emitted at the ends of the tube.

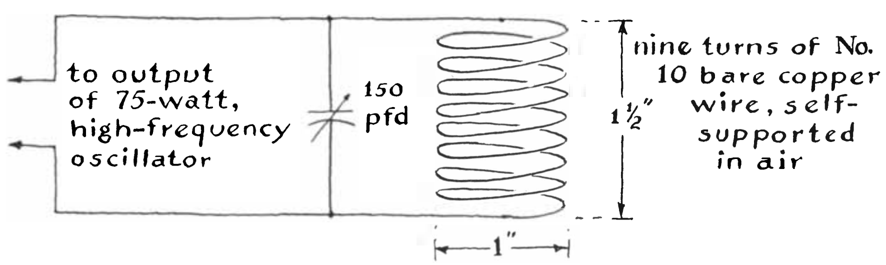
"If the beam does not appear, twist the micrometer screws (one at a time) back and forth about two or three angular degrees. This operation is known as 'fiddling' with the screws. Watch the ends of the tube carefully as you rock the screws. Stop when the beam appears. Then adjust the system for maximum beam intensity. Increase the output voltage of the variable transformer. Beyond a certain maximum voltage the intensity of the beam will decrease. Then, assuming that you have installed the quartz windows so that the faces are at right angles to the vertical plane, you will observe two spots of light on the ceiling. Rotate the windows so that the spots lie in the vertical plane that includes the bore of the capillary. Then tilt each window up or down to the angle at which the beam becomes most intense. Both of these adjustments are made possible by the ball-and-socket joints.

"Next, vary the gas pressure. Add gas slowly. Up to a certain pressure the intensity of the beam will increase. Thereafter it will decrease. Lower the pressure by pumping out gas. After 20 or 30 minutes of operation at maximum intensity the brightness of the beam may begin to decline. This indicates that atoms of argon are being buried under particles of eroded electrode materials, an effect known as 'sputtering.' The sputtering effect lowers the pressure of the gas. At this point I usually pump out the tube and refill it with fresh argon.

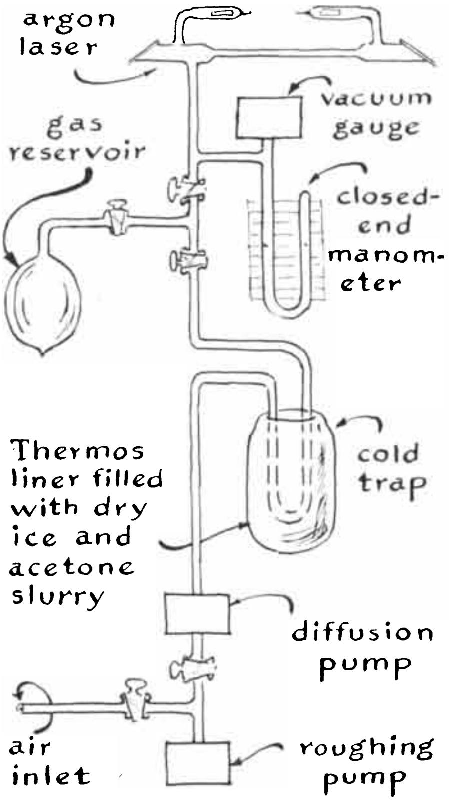
"You will observe that the color of the beam changes as the input voltage is increased. The change is caused by the successive appearance of coherent light at various wavelengths as current in the tube is increased. Laser action begins when the current reaches 1.45 amperes per pulse. The tube then emits coherent light at a wavelength of 4,880 angstroms, the wavelength for which the dielectric mirrors are coated. At 3.6 amperes laser action also begins at 5,145 angstroms. Thereafter light appears at the following wavelengths: 3.8 amperes, 7,465 angstroms; 4, 4,965; 5.2, 4,579; 6, 5,017; 6.9, 4,658; 10.5, 5,287, and 15 amperes, 4,727 angstroms. Each color can be separated into an individual beam by passing the output of the laser through a 60-de-



Circuitry of the power supply



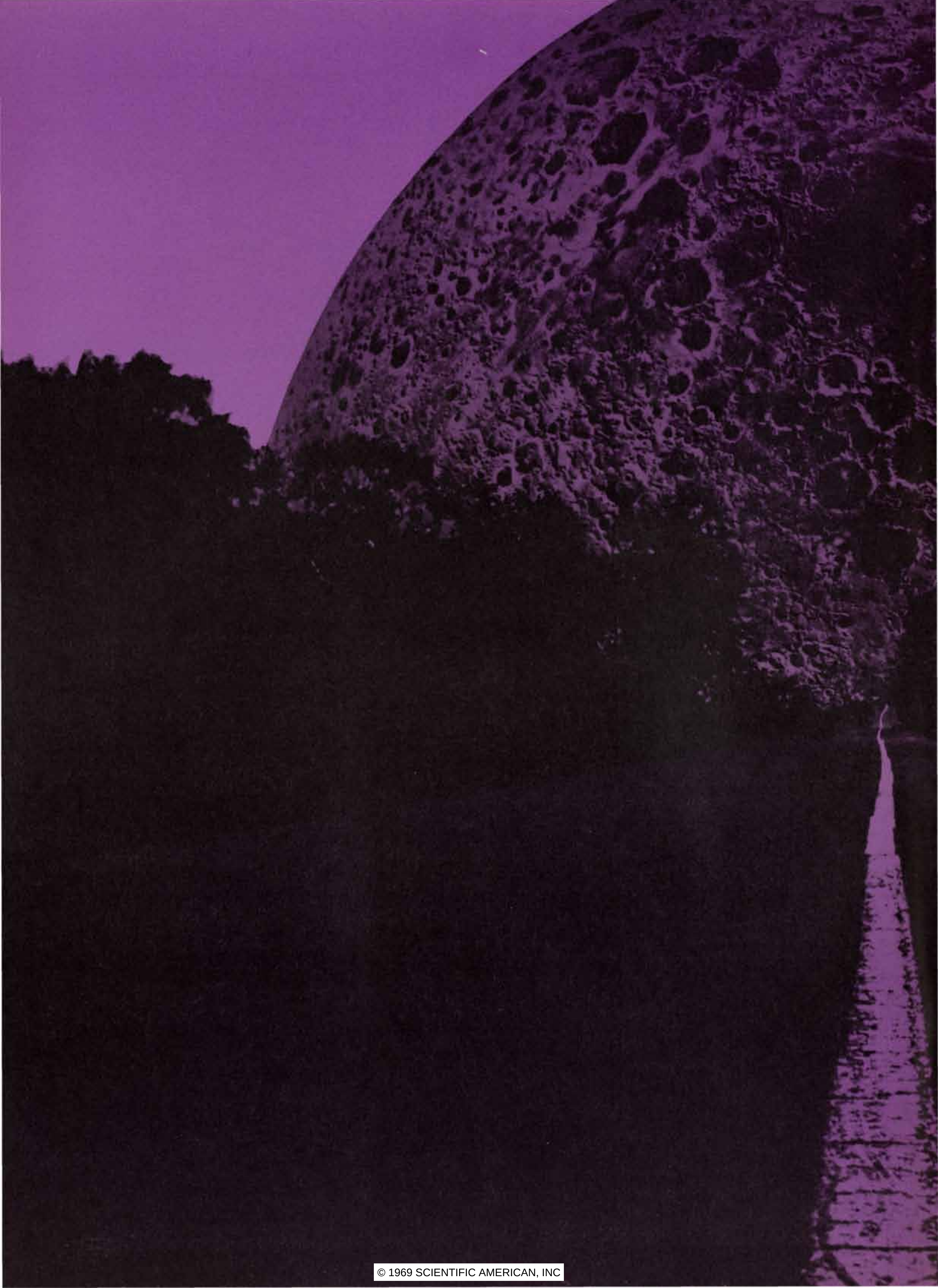
Radio-frequency circuit for heating the electrodes



The vacuum system

gree glass prism. The individual beams can be used for the precise measurement of length. Collectively they will serve as a series of known wavelengths for calibrating apparatus and making numerous other experiments. Krypton gas can be used in this laser and will demonstrate still other spectral lines, but with lesser beam intensity.

"The dielectric mirrors, ball-and-socket joints, electrodes sealed in Pyrex, transformers, gas and other supplies can be bought from Henry Prescott, 116 Main Street, Northfield, Mass. 01360. A note of warning: The laser beam is hazardous. It can burn and destroy the retina of the eye. Two intense beams are emitted from the ends of the tube and two beams of lesser intensity are reflected into the room by the faces of the quartz windows. Mask all beams close to the tube except those with which you are experimenting. Avoid spurious reflections of the experimental beam by objects in the room. The power supply develops lethal voltages and the capacitor stores charge at high voltage. Handle them accordingly. When the apparatus is turned off, always short-circuit and thus discharge the capacitor by means of a wire supported in an insulating handle. As an added precaution it is well to connect a one-megohm, two-watt resistor permanently across the terminals of the capacitor to 'bleed off' automatically any charge that may accumulate spontaneously."



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BOOKS

A compendium of biochemistry

by Alexander Rich

COMPREHENSIVE BIOCHEMISTRY, edited by Marcel Florkin and Elmer H. Stotz. American Elsevier Publishing Company, Inc.

Biochemistry has come of age. This is evident in developments ranging from the elucidation of the structure of enzyme molecules to the breaking of the genetic code. One reads in the newspapers almost daily about such advances, their promise for man's control of biological processes and the profound hazards of such control. One more manifestation of the ripeness of biochemistry is the production of the 31-volume compendium *Comprehensive Biochemistry*.

This set of books represents an attempt to describe the scope and diversity of biochemistry as it exists today. It reminds one somewhat of the *Handbuch der Physik* of the early 1920's. Physics at that time had had a long history of substantial achievements that could be thoroughly documented. Still, it was only a short time after the Bohr theory of the atom had been put forward, and although this revolutionary development was described in the *Handbuch*, its real significance was not appreciated. Today biochemistry is in a similar period of revolutionary development, and whereas this period is reflected in parts of *Comprehensive Biochemistry*, its full significance too will become apparent only in the future.

Comprehensive Biochemistry is a broadly conceived work in which the 31 volumes are divided into five sections. Twenty-two of the volumes have already been published in the seven years since the first volume came out, and it is likely that the remaining ones will appear within the next few years. It does not surprise this reviewer that it takes so long to bring out such an encyclopedic work. The problems of coordinating the activities of well over 100 different authors is in itself a monumental chore. The 22 volumes that have been published are useful in themselves; the individual volumes are not interdependent but stand as independent surveys of a selected province of the subject.

The first of the five sections includes four volumes devoted to physical, chemical and organic aspects of biochemistry. Biochemistry is a derivative science in the sense that it was historically dependent on the evolution of chemistry. It was the development of physical and organic chemistry that provided the tools with which investigators began to probe into the molecular nature of biological phenomena. The origins of biochemistry go back to the origins of organic chemistry. Friedrich Wöhler's synthesis of urea in 1828, which is regarded as a landmark in the evolution of organic chemistry, is also one of the first steps in the development of biochemistry. In the beginning organic chemistry was largely dependent on products of biological origin; only later did it evolve into a broader discipline dealing with the chemistry of all carbon compounds.

Today biochemistry too is a broad and heterogeneous discipline. Indeed, some provinces of biochemistry merge almost directly into organic and physical chemistry. These subjects are well treated in the volumes of the first section, but it is an almost impossible task to survey, for example, the biochemically relevant reaction mechanisms of organic chemistry in one volume. Inevitably the reader who wants to use *Comprehensive Biochemistry* as a primary reference in these areas must also refer to other sources.

Another volume in the first section deals with the general methodology for studies of molecular structure. Such studies will someday completely change our understanding of biochemical processes. This has become quite clear during the past few years with the successes of X-ray diffraction methods in revealing the molecular structure of the first few enzymes. X-ray methods are now sufficiently powerful to provide a static view of protein molecules at a resolution that shows the location of individual atoms. This in turn provides a framework for interpreting in detail the molecular mechanisms underlying enzymatic activity. Since catalysis by enzymes is one of the most striking features of biological systems, it is unfortunate that *Comprehensive Biochemistry* does not include a recent survey of the methods that have proved successful in the determination of protein structure, nor a description of the results. This is not possible without another edition, because these volumes were published six years ago, well before most of the current results of protein crystallography had been obtained.

The chemistry of the biological compounds is taken up in a seven-volume section. These volumes contain lengthy discussions of the chemistry of carbohydrates, lipids and proteins; they also deal handsomely with some of the small molecules of biochemistry, such as isoprenoids, pyrrole pigments and steroids. This section is probably the most up to date in that the chemistry of these substances is largely fixed and will not be drastically modified. It is surprising, however, that the chemistry of the nucleic acids occupies only a small part of one volume; the treatment is too limited for an encyclopedia of such scope.

Biological systems are characterized by continuous change. This is particularly true of events on the molecular level, where many chemical reactions proceed at a rapid rate and the situation can best be described as being in a state of flux. It is convenient to divide the flux of living systems into three categories: a flux of matter, a flux of energy and a flux of information. This description is useful not only from a didactic point of view but also because it reflects the evolution of biochemistry as a discipline.

The material flux in biochemical systems is represented by the molecules that are taken in by living cells and the ways they are transformed into other molecules. Classical biochemistry deals with these chemical transformations and the enzymes that bring them about. Biochemical systems have evolved in such a way that the most important control elements in the system are the protein enzymes that catalyze specific chemical reactions by their presence; when these enzymes are absent, the reactions proceed very slowly or not at all.

The earliest years of biochemistry at the end of the last century and the first two or three decades of this one were largely concerned with the identification of the small molecules that are transformed and with the isolation and characterization of the corresponding enzymes. It was observed that all living organisms—plant, animal and microbial—have much the same chemistry in that they take up the same kinds of molecules and have similar (although not identical) ways of metabolizing them. This discovery, which was not made at any one time or place, led to a molecular statement of the basic Darwinian hypothesis that all life is related through a common ancestry. This in turn has given rise to the study of molecular evolution, which is now being pursued in many laboratories. *Comprehensive Biochemistry* has a full treatment of the flux of matter in biochemical systems in terms of the chemistry of the individual molecules, the reaction mechanisms and the metabolic characteristics. One of the volumes yet to appear will deal with comparative biochemistry and molecular evolution, which should round out this subject.

Another way to describe biochemical systems is in terms of a flow of energy. Our understanding of these phenomena is more recent; it was only in the early 1940's that the fundamental role of the cellular "fuel" adenosine triphosphate (ATP) was fully recognized. Accompanying each reaction in a metabolic chain there is an exchange of chemical energy that is usually coupled with a molecular system serving to activate molecules that can act as energy carriers. There is a substantial description of energy transformations in *Comprehensive Biochemistry*.

Neither chemical transformations nor energy transformations, however, are unique to living systems. Such changes are common to all chemical reactions, and a formal description of them could be considered a part of chemistry as well as of biochemistry. It is in the flow of information that biochemical phenomena have their most unique features. The important point about the chemical activities of the living cell is that they have a certain directionality. Some reactions proceed and others do not. Metabolism is a flow, and the flow is regulated by the ensemble of enzymes within the cell. This regulation reflects a pattern of information that is diffused throughout the cell and is replicated during cell division. The fundamental information-transferring reactions have been recognized only during the past 15 years, and accordingly there is not a great deal about them in *Comprehensive Biochemistry*.

Broadly speaking, the information in living systems flows from the nucleotide sequences of the genetic material DNA to the closely related molecule RNA and eventually to the specific sequence of amino acids in proteins. This is the core of our general view of life processes. We know a good deal about the mechanism of DNA replication, about the enzymes and cofactors that are important in the synthesis of RNA and about the genes that specify this process. In addition, knowledge is being accumulated at a fantastic rate concerning the mechanism of protein synthesis. This material should probably be covered in a full section of *Comprehensive Biochemistry* and occupy several volumes. Instead the subject of biological information transfer will be taken up in only one of the unpublished volumes, and this volume will be shared with the biochemistry of viruses and chemical immunology.

The growth of biochemistry has been such that it has expanded toward and become essentially contiguous with a variety of neighboring disciplines. Genetics, for example, is no longer a subject independent of biochemistry but one that is joined to it by the recent biochemical analysis of the genetic code. This research of the past few years has related the sequence of nucleotides in DNA to the detailed sequence of amino acids in proteins. Mutations are now clearly understood as being changes in the sequence of bases in DNA, which are in turn reflected in changes in the sequence of amino acids in proteins. The confluence of genetics and biochemistry will give rise to a growing stream of biochemical thought and research. It is in this area that the editors of *Comprehensive Biochemistry* might consider extending their coverage by the inclusion of additional volumes.

Shorter Reviews

by Philip Morrison

A Portrait of Isaac Newton, by Frank E. Manuel. Harvard University Press ($11.95). Learned yet graceful, punctilious about presenting evidence yet speculative in conclusion, this work tries to make plain the unconscious emotional and psychological content of that mind which built the great system of the world and by extension supported the philosophical framework of the whole Enlightenment. Professor Manuel is neither psychiatrist nor scientist; his method is that of the careful literary scholar, although his elusive quarry is not influences so much as motives. Such a hunt is almost bound to prove surprising, a little scandalous and inconclusive. So it proves here; the writing is deft and candid, the subject grand, so that the volume makes fascinating reading, even though its larger aim is wide of the target. Newton remains subtler than his analyst.

The life of Newton is periodized by the events themselves. Until 24 he was the quiet yet marvelous schoolboy and undergraduate of Lincolnshire; from then the Lucasian Professor at Cambridge, secretive, jealous, producing the great finished treatises on mathematics, mechanics and optics that cashed in the rich intuitive deposits of his youth; from his 54th year energetic high officer of the mint in the Tower of London, nemesis of coiners, autocrat of the Royal Society, faculty politico and private scholar, filling thousands of pages on the blank sides of government documents with meticulous and discerning studies of the chronology of the ancient world and the history of the church.

It is Professor Manuel's aim to show us one person, not three. The lonely boy, dexterously mechanical, sexually and socially repressed, bitter at the elderly stepfather who had stolen away the beloved mother (Newton, born on Christmas Day, was a posthumous child), who saw the apple fall ("It is impossible to ignore the . . . overtones of a theory . . . called forth by the fruit that . . . occasioned man's fall and led to worldly knowledge") in his mother's garden in that apple-growing countryside; the puritanical professor, chaste, touchy in controversy, metallurgist and even alchemist, and finally the cool old tyrant of committee room and law bench, ruling English science, flattered by noble society, artful and tenacious in many a fight for priority—all these are one Newton. Fixated on his mother, Hannah, who left him when he was three in the cold care of her own widowed mother until Newton turned 11, he is seen as being nearly incapable all his life of human love, sacred or profane, with either sex. His early success fed a half-conscious view of himself as the prophet of God, whose truth he alone could infallibly uncover, whether it was written in the motions of the planets, the white light of the sun's hidden hues or in the chronicles of the old poets and the plan of the Temple of Solomon. He brooked no rivals, for who could outstrip the chosen of God? He admitted of no error and no incompleteness; his system of the world, extending from bullet to Bible, forever repairs that terrible loss of the loving Hannah. Writes Professor Manuel: "But the nature of the whole eludes us . . . unlike the wanton block-building of the paranoid, Newton's structures . . . attained to the highest levels of . . . universal significance." Professor Manuel is not self-deceived; this reconstructive act can imply the vagaries of the great troubled mind but hardly the triumphs.

It is remarkable that we have a good deal of evidence from Newton's early years. Most of it is of course the long famous, if now suspect, anecdotes collected from old neighbors considerably after the fact, when Sir Isaac was a name of thunder, or from the memories of the old man himself; there exist, however, four schoolboy notebooks, a treasure for him who would read the heart. One contains lists of a couple of thousand words arranged by meaning, begun by copying sequences from a well-known Latin-English vocabulary used in the schools of that day, here extended with many lists that are nonalphabetical and may be free associations around a subject, for example the touching set Doubting, Dispaire, Distrust, Desire, Dread, Displeasure. There is more: a shorthand confession written at 20. A trivial sin: the Sabbatarian Nestor helped an undergraduate "make his water watch at 12 of the clock on Saturday night," a violation of the Sabbath. Deeper are "threatning my [step] father and mother . . . to burne them and the house over them," and "wishing death and hoping it to some."

The pattern comes clear. It is used to explain the famous scandal Voltaire proclaimed, that the proper and God-fearing Newton seems to have wholly condoned a long-standing illicit liaison between his beautiful and witty young niece, who lived in his own household, and the great Lord Halifax. The 19th-century English defenders spoke of a secret marriage; the French critics gloated over the fortune left the lady in Halifax' will.

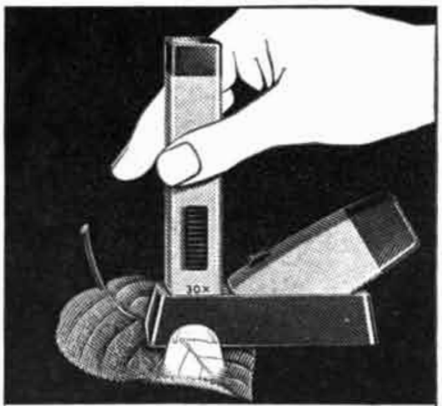
The French contended, unfairly, that Newton had sold his 14-year-old niece in exchange for the mint job; it is less melodramatically true that he never criticized his niece's life, which he certainly understood. One might think only that he had become more worldly and tolerant in noble London than the lonely Puritan scholar could have understood. Professor Manuel wants to invoke—or to suggest—a deeper psychic reason. Had Newton found in the young girl his lost mother, and through his admired friend Halifax possessed her vicariously at last?

So it goes. The system built here is Newtonian in scope, but it resembles more Newton's *Chronology of Ancient Kingdoms* than his *Principia Mathematica*. Its goal is "not mathematical truth but general plausibility." It falls short even of that for a general reader; too many points are extended beyond their foundation, too many remarks left uncompared. Professor Manuel thinks the college accounts show Newton to be a frugal student; another historian, reading the same accounts, finds him "spending his full income in the mild pursuit of luxury and pleasure." We could perhaps judge by comparing other students' bills; we are given none. The mercurial, inductive, carnal Hooke was bested by the single-minded, deductive, puritanical Newton; Professor Manuel's sympathies are plain. But the Hooke citation establishing his prior discovery of the inverse-square law seems, as given here, simply in error. The biographer, who makes no claim to know science, and indeed appears rather to disdain it, does not help us with any comment at all. One may prefer Hooke to Newton, but this method cannot establish "general plausibility," although it provides us with an entire volume of excellent reading.

IONOSPHERIC RADIO COMMUNICATIONS, edited by Kristen Folkestad. Plenum Press ($25). Expensive, technical, set in "cold type" on the typewriter, this volume of proceedings of a NATO Institute meeting in Norway in 1967 seems an unlikely subject for a review for general readers. Nonetheless, it is fascinating and even ironic. The topic is polar radio—across Canada, Greenland and Spitsbergen. The users are diverse: Eskimo villages, Aeroflot and SAS airliners in flight, snowmobile parties with an antenna stretched along the nonconducting snow surface, digital computers talking to radar stations and to satellites, the religious missions, the Mounties and the Search and Rescue Operations of the Canadian Armed Forces. The physical problems of arctic radio are subtle. The aurora, the special solar blackouts, the wide range of sunlight hours—all set peculiar problems for reliable and inexpensive communications, badly needed for humane and military reasons. Planners and engineers, radio physicists and equipment designers take part in this volume, and there is much summarized discussion. Political and economic factors are mainly latent, and are reserved explicitly for a broader meeting.

The ingenuity and resources placed at the service of military communications are extraordinary. The U.S. point-to-point worldwide network has 32 million miles of channel. It includes more than 100 shortwave radio links, by far the largest net in the world on the crowded high frequencies. The rational use of this scarce resource has not been overlooked: an experimental system now working across the Pacific from Okinawa to California maintains automatic continuous ionosphere sounders that constantly probe conditions at many sites. Every 10 minutes the system presents its human controllers with a teletype recommendation of just what frequencies to use for what priority circuits for the most reliable service. (Satellites will doubtless replace all this one year.) Another even more active scheme has reached the prototype stage. At Fort Monmouth the Army and its contractors have developed a radio station in a set of trailers that is not forced merely to choose among nature's ionospheric moods. It stands routinely prepared to send its messages 1,500 miles or so, via the weak scattering provided by normal weather or ionospheric conditions. The messages must be sent slowly; the signal is weak and noise is strong. Then, when solar bursts strengthen the ionosphere for a while or a meteor trail appears, the radio waves can bounce well, and the attentive system dumps a load of messages filed earlier at lower priority out of its memory of a million bits, all sent now in 20 seconds. If such natural events are tardy, and the computer, worried about delays in high-priority traffic, grows impatient, the station sends a two-stage sounding rocket 100 kilometers up with a load of aluminum powder and cesium salt. A man-made clump of ions will reflect the signal day or night, until the "long bursts of high-priority data" have been sent. It is worth pausing to consider what those messages for Garcia will usually be. What hath man wrought?

THE ANIMAL KINGDOM: AN INTRODUCTION TO THE MAJOR GROUPS OF ANIMALS, by George S. Fichter. Illustrations by Charles Harper. Golden Press ($3.95). Intended for young readers, the text of this book devotes a few pages to each of the more primitive phyla of living animals, and then to about 15 of the best-known classes from bivalves to mammals. There is a brief general description and a chatty series of accounts of the interesting features of some members of each group. Technical terms are almost scrupulously avoided, and the whole book is easy to read, although



rather too even. The pictures, however, are not at all like that; they are a tour de force of scientific illustration. There are a couple of hundred of them, in all hues, tones and textures. Each shows an animal or several animals drawn from the entire span of the kingdom, either from a remarkable and apt viewpoint (a floating sea otter eating its seafood dinner from its chest is looking straight up at you), in an impressive environment (the angler fish is seen in the deep-sea dark, nearly all black save for the glowing yellow lure) or in a memorable activity (the anaconda is coiled around a terrified and prostrate jaguar). The technique matches the lively wit of the artist; in gallery talk the style is a hard-edged and well-textured geometrical impressionism. The jaguar's spots are perfect circles; a thousand army ants on the march are each made solely of three sharp spots and six radial lines; a pride of lions in the dark is reduced to staring golden eyes and gray noses and ears. There are those who will not accept this sharp but entirely truthful departure from realism; for those who will receive it, it is illustrative art of fresh and evocative fidelity. The paintings are not childlike, but all adults who have reason to show animal pictures to young people or to view them themselves are urged to look at this unique and rich collection. The vigorous predation shown in the book is not always easy to accept; one macabre scene shows a cow, reduced to a skeleton except for its furry head, in blood red water under the attack of swarming black piranhas.

ICE CREAM, by W. S. Arbuckle. The Avi Publishing Company, Inc. ($11.50). The tissue of this delectable substance is displayed in a photomicrograph looking for all the world like the ones in a histology text: rounded air cells about 150 microns in diameter taking up half the volume, ice crystals like tiny boulders a third that width, and the ground substance that seals the air cells and holds the ice crystals. Increase the emulsifier (often the additive lecithin) and you get smaller air cells and a smoother texture; increase the stabilizer (frequently a seaweed derivative, an alginate) and you prevent the growth of large crystals in storage. Good ice cream ought to contain less than .25 percent of these two types of additive; the soft ice creams run to twice that, with half the ordinary fat content of ordinary ice cream but rather more milk solids. The commercial continuous freezers work just about like Grandma's: a refrigerated surface is repeatedly scraped clean by close-fitting dasher blades. This complete and diversified text is not a designer's aid but rather an operator's. It devotes most of its space to very practical matters: the calculation of mixes, the choice of materials, sanitation, simple tests for quality control and the like. There is only enough general material to supply an adequate background for plant or store management. The schematic banana-split diagram with its numbered components, magnified a dozenfold and reproduced in color, would make a great pop-art poster. There are formulas for twice 29 flavors and more, chapters on frozen novelties and the cold facts about popsicles. The proportion of air in ice cream, an ingredient that is indispensable to flavor and yet notably inexpensive, is a major technical, fiscal and moral problem for operators in this industry. The problem is plainly more rational wherever the stuff is sold (as it is now in Colorado towns) by weight and not by the puffed and then hand-compressed volume. Liquid-nitrogen freezing has been tried, but it needs development. Computer control of the mix is a few years old, and it has not yet made much ice cream of high quality.

AMERICAN INDIAN MYTHOLOGY, by Alice Marriott and Carol K. Rachlin. Thomas Y. Crowell Company ($7.95). These two women, skilled anthropologists, sensitive listeners and lucid writers, have woven a remarkable book out of three dozen tales and almost as many pictures: photographs of men and their artifacts, many taken by one of the authors. The book presents a continuous strand of oral literature, an unbroken tradition from the oldest times, when the Bering Strait may have been dry, to A.D. 1966, when a "big, hard woman and a stubborn one" named Helen died in a city hospital and placed her skeptical sons under a curse. The early stories tell such tales as that of the three Fox hunters and their tiny dog, Hold Tight, who forever pursue around the pole that square of four stars which is the bear, or of the time when First Woman and First Man of the Navajo fought and separated, to unite again when the women had grown hungry for meat and the men for tenderness and love. Helen's curse brought the scissor-tailed flycatcher; "wild and fierce" the little bird flew against the tepee all night long, bruising one of her sons and in the end firing the tepee, destroying it all at the close of the all-night service. (The rosy tail feathers of a dozen such birds made Helen's ritual fan of power.) One can read the frank view Arapaho take of General George Custer. If you live (and some who are not Hopi can and do live) on Third Mesa, carefully watch the children; take no paths they avoid. If you do, you may meet Grandmother Spider and the War Twins in their real form. If she beckons you, you must follow her into the womb of the earth.

The stories are simply and clearly told. Each has a small prologue to provide context and meaning, and most have a listed source, sometimes a book from the days when anthropologists recorded in a state of urgency the dying tradition, sometimes the name of a gifted storyteller who masters his living craft today, one whom the authors have been wise enough and lucky enough to meet and listen to.

This is ethnography of a peculiarly hopeful and vital sort. The book is certainly an adult book, but it is excellent also for those children who need no protection from strong tales of retribution, death or physical love.

GALÁPAGOS: THE FLOW OF WILDNESS. I: DISCOVERY, photographs by Eliot Porter, introduction by Loren Eiseley, with selections from Charles Darwin, Herman Melville and others. Edited by Kenneth Brower. II: PROSPECT, photographs by Eliot Porter, introduction by John P. Milton, text by Eliot Porter and Kenneth Brower. Edited by Kenneth Brower. Sierra Club ($55). In the spring of 1968 the publishers mounted an informal expedition to the Galápagos Islands, now a national park of Ecuador. The photographer, his son and daughter-in-law, the ecologist John Milton, the editor and a film-making couple were the team. These two large and handsome volumes are the account of the trip. They serve mainly to present 140 beautiful photographs Porter made, the island world in form and color displayed in handsome fine-screened reproductions. Everyone who helped in the production of these pictures earns our gratitude: the emulsion and camera makers (not named), the distinguished photographer and his aides, and the Belgian and English firms that made the photographs into a printed book. Darwin's finch inspecting a cactus for a spiny tool, a writhing of black marine iguana-dragons, a lava flow where dragons live (like a sharper plate of a Doré hell), the huge patient tortoise munching the emerald grass, porpoises in an indigo sea—the eye has a bright feast here.

The text is less happy; the selections from worthy predecessors, although splendid, are rather diluted over the pages. Professor Eiseley offers a comprehensive introduction, and Porter's journal is an agreeable travel tale; none of these, however, supports so theatrical and costly a presentation. The details are inadequate, particularly the map; the reader is hindered rather than helped by the apparatus, which is both sparse of useful fact and here and there puffily commercial. This is less a work to read than it is one to view.

CHINESE WRITTEN CHARACTERS: THEIR WIT AND WISDOM, by Rose Quong. Cobble Hill Press ($5.95). That subtle and shapely cipher which is the Chinese written character is here given a half-rational, half-poetic interpretation. This delightful slender book presents and comments in English on some hundreds of characters, vertically displayed in handsome carmine brush strokes. They are arranged to bring out the forms they contain, and a plausible derivation is suggested. The sun and moon are two simple forms; side by side they signify "bright" or "enlightened." The sign for "mouth" enclosed within the two parts of "gateway" means "to ask" or "to inquire." So it flows, with references to ancient pictographs and with occasional charming and fanciful excursions. There is no strong claim that these etymologies are either historical or logical; they are, rather, familiar and traditional after-the-fact constructions, with perhaps a germ of truth, and some personal insights of the author, a well-known translator from the Chinese. The book was first published during World War II.

EXPLORING SPACE WITH A CAMERA, compiled and edited by Edgar M. Cortright. U.S. Government Printing Office ($4.25). Once again the National Aeronautics and Space Administration has given us a beautiful book of pictures—a bargain and a source of excitement. This book is not as pure and elegant as the volume of Gemini color photographs that made so genuine an atlas a year ago; rather it is a proud family album of NASA's unique snapshots. The first plate is a color view of our entire earth from synchronous orbit, the ocher of southwest Africa vivid between blue ocean and white cloud. Many Gemini shots are here, and other earth photographs from high and low orbits, but the specialty is the moon, both from six feet and from high orbit, in the neutral tones that mark that inert world. The cratered face of Mars is also displayed in the photographs that contain all man's knowledge of that distant topography.

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