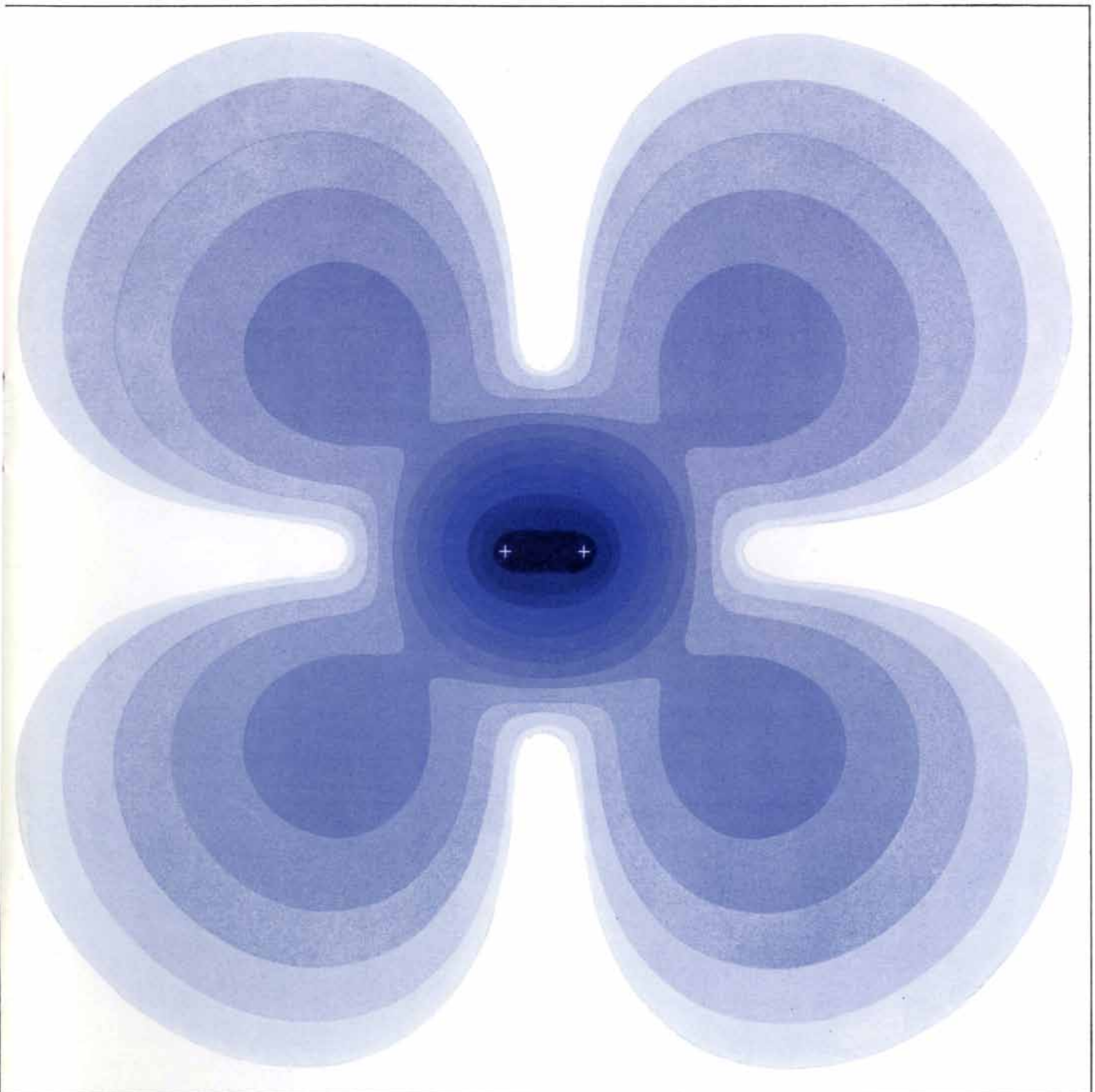
SCIENTIFIC AMERICAN

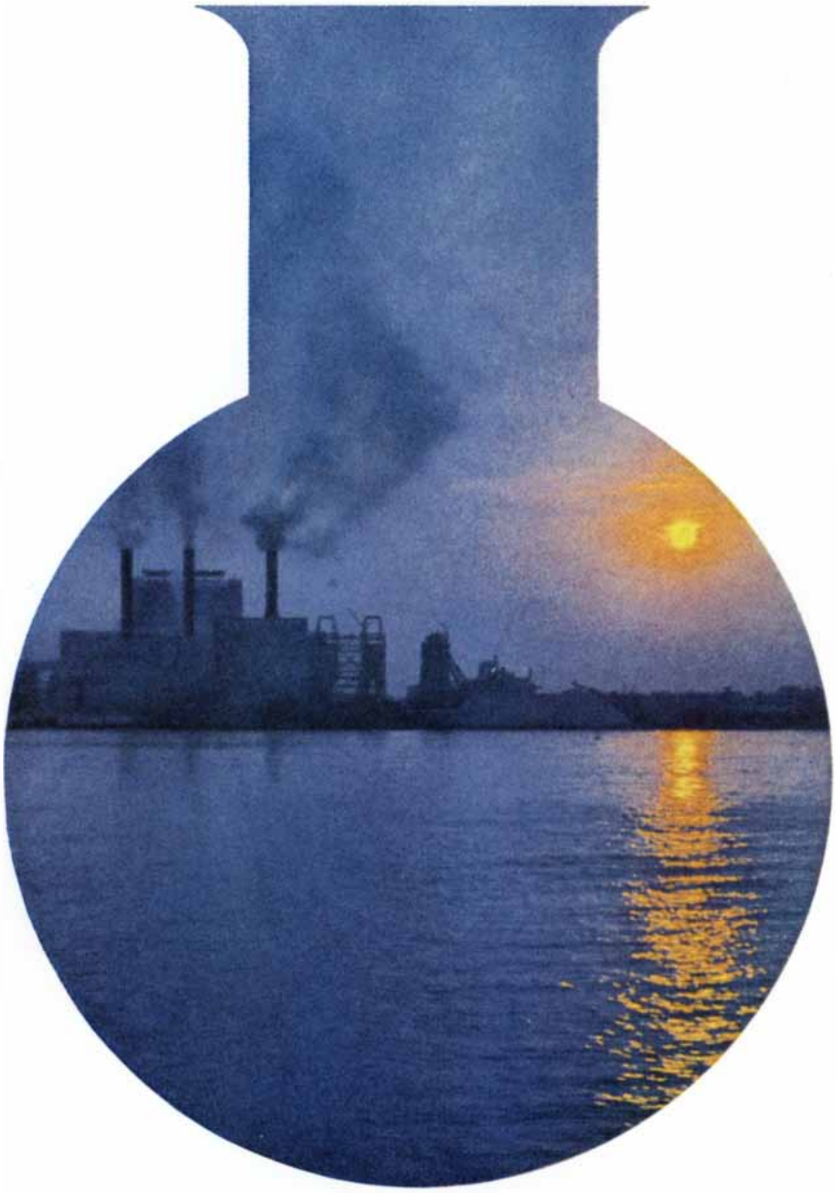


HYDROGEN ELECTRON CLOUD

ONE DOLLAR

April 1970

from anti-pollution



UOP has a piece

We're all against pollution. We'd better be. The impact of polluted air and water on man and his environment is growing more severe all the time. We need more and better action. Now.

Universal Oil Products Company offers some practical ways to cope with this acknowledged menace. UOP Air Correction Division is a leader in offering source testing service. This specialized survey studies problems in depth, analyzes the solid or gaseous pollutants and prescribes the exact equipment needed for control. Economically. With flexibility for the future.

Meanwhile UOP Process Division is

to problem solution

of the action in your life.

solving the big problem of how to desulfurize fuels to eliminate noxious fumes from residential and industrial furnaces.

At the same time work is far advanced against the overwhelming problems of cleaning up fumes from automotive and diesel exhaust systems. UOP has practical answers ready. Now.

Water contamination is another target of UOP scientists who are commercializing unique chemical processes that help free rivers and streams of foaming detergents. And UOP Johnson Division is an innovator in the development of high efficiency screens for water purifying systems.

What makes possible the solving of big problems like these? Well, at the center is a deep reservoir of scientific knowledge, stretching back into history, reaching into the future. This practical kind of research-in-search-of-results is also being used by UOP "family members" working in fabricated metal products; air and ground transportation equipment; construction services; plastic laminates and chemicals.

On the research and development horizon there is no end in sight. Wherever you are, whoever you are, UOP has a piece of the action in your life.

"Max, how fast can you guarantee a car reservation?"

Max, our computer, gets a little carried away sometimes. Just the same, he's a mechanical marvel. He's on duty 24 hours a day, keeping a constant inventory of all our cars. That's why only National can *guarantee* reservations.

Wherever you are, when you call National toll-free at 800-328-4567, we just ask Max if there'll be a car waiting for you.

Max knows, at the instant you call, what cars are available at every National location. When he says yes, he isn't guessing.

National features all new Chevys, Pontiacs, Buicks, Oldsmobiles, and Cadillacs, and other fine cars, at 2400 worldwide locations.* And in the U.S. you'll get a fist full of S&H Green Stamps, too. So please excuse Max's conceit. After all, Max knows he's the only computer that guarantees car reservations. And only National has Max. Let Max do it.

*Tilden-Rent-A-Car in Canada.

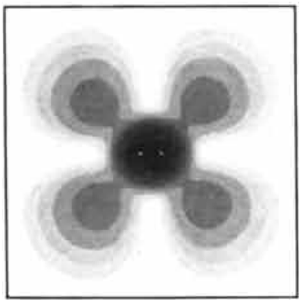
We make the customer No. 1.

Established 1845 **SCIENTIFIC AMERICAN** April 1970 Volume 222 Number 4

ARTICLES

DEPARTMENTS

PUBLISHED MONTHLY BY SCIENTIFIC AMERICAN, INC., 415 MADISON AVENUE, NEW YORK, N.Y. 10017. COPYRIGHT © 1970 BY SCIENTIFIC AMERICAN, INC. ALL RIGHTS RESERVED. SECOND-CLASS POSTAGE PAID AT NEW YORK, N.Y., AND AT ADDITIONAL MAILING OFFICES. AUTHORIZED AS SECOND-CLASS MAIL BY THE POST OFFICE DEPARTMENT, OTTAWA, CANADA, AND FOR PAYMENT OF POSTAGE IN CASH. SUBSCRIPTION RATE: $10 PER YEAR.



THE COVER

The pattern on the cover shows the spatial distribution of the negative electric charge for the two electrons in an excited state of the hydrogen molecule (H_2) in terms of contours of equal electron density. The darker the color, the higher the probability of finding the electrons in that region of space. (The two plus signs near the center indicate the location of the two positively charged atomic nuclei, which in the case of the H_2 molecule are simply two protons.) The cover picture, which was adapted from an uncolored computer-generated contour-line diagram, is based on a mathematical model of molecular structure in which the molecule's electrons are assumed to occupy a set of distinct molecular "orbitals." (In the actual electron "cloud" the charge density changes continuously.) This particular diagram corresponds to an excited state of the hydrogen molecule called the singlet π_g state; typically when a molecule is excited into such a higher-energy state from its "ground," or lowest-energy, state by absorbing energy in discrete quanta from outside, its electron cloud becomes more diffuse and more complicated in shape. The use of large, high-speed computers to perform the vast amounts of algebra and arithmetic required to calculate such mathematical models of atomic and molecular structure is making it possible to obtain reliable and comprehensive chemical information independently of experiment (see "Chemistry by Computer," page 54).

THE ILLUSTRATIONS

Cover photograph by Photo Lettering, Inc.

Page	Source
16–17	Jon Brenneis
18	Sidney R. Garfield, Kaiser Foundation Hospitals
19	Jon Brenneis
20–22	Graphic Presentation Services, Inc.
24–31	Jim Egleson
32	Jerome Kuhl
33	Woods Hole Oceanographic Institution
34–39	Jerome Kuhl
40	Woods Hole Oceanographic Institution
41–42	Eric Mose
55–70	Argonne National Laboratory and Dan Todd
72	Joseph R. Jehl, Jr.
74–77	Tom Prentiss
84	Christopher C. Ashley and Ellis B. Ridgway, University of Oregon
86–87	Bunji Tagawa
88–89	Patricia McNeill, University of Oregon
90–93	Bunji Tagawa
95	Dr. Heinrich Hoffmann, Frederick Ungar Publishing Company
96	Graphic Presentation Services, Inc.
100–101	William Vandivert
102–105	Dan Todd
106	William Vandivert
108	New York Public Library
109	Alan D. Iselin
110–111	New York Public Library
115–120	Roger Hayward

LETTERS

Sirs:

To describe "The Assessment of Technology" [Scientific American, February] as a disappointing performance, coming from the National Academy of Sciences, would be praise indeed. One wonders not only how many panel members have any interest in the sociological and philosophical implications of technological *laissez faire* but also how many have ever read anything like *Brave New World* and how many thought Huxley was advocating his own utopia.

Nowhere in the article does there seem to be any recognition that technological developments, even without pollution or other kinds of material cost, can—and often do—make life worse by increasing centralization and top-down direction and by making people less able to control, influence or even understand decisions that are vital in their lives, thus making people less human and increasing alienation and frustration. Not having recognized this, the panel could not suggest that this inhumanity, alienation and frustration may increase the demand for technological gadgetry, whether in better and more sophisticated equipment for police, prisons, doctors, hospitals, etc., or in more frantic traveling about, more elaborate television sets (with the same miserable programs), and generally more of those possessions that, advertised on our improved television sets, increasingly seem to possess us.

That technology is subject to laws of diminishing return, that it may increasingly be counterproductive, that it may encourage a bad attitude of regarding people as elements of a system and the system as an end in itself, that it has taken on the trappings of a superstition in that, although its workings may not be understood, it is widely regarded as holding the solution to all problems, that scientific research is valuable and interesting for its own sake, regardless of applications—all these possibilities seem worth some discussion but nothing like them seems to be mentioned. Instead the public is mildly rebuked for its opposition to highways, airports and larger and faster airplanes, as though the disruption of neighborhoods, the noise and smoke and an increasingly frantic way of life are worth the millions spent. Did anybody on the panel ever ask if all this travel is desirable or necessary, or whether we might do better by doing things differently, by paying more attention to factors other than gross national product?

Or does the panel just not want to rock the boat? Perhaps this is why, although rejecting "the concept of a highly centralized process of technology assessment," the panel finally recommends little but the addition of strings to the Federal Government's bow. Even assuming that the recommended agencies can avoid both emasculation and capture by special interests, the effect will be to weaken local initiative and control still further....

Allan Oaten

Department of Statistics
Stanford University
Stanford, Calif.

Sirs:

Limitations of space prevent us from dealing with more than a few points raised in Mr. Oaten's letter. Most of the questions he raises are covered in the full National Academy of Sciences report *Technology: Processes of Assessment and Choice.* Condensation of the material for *Scientific American* may have led to an inadequate treatment of them in our article.

In our opinion Mr. Oaten has seriously defective vision. He sees with great clarity the negative effects of technology that occur in all areas of life—human, social and environmental. He seems totally blind, however, to the beneficial effects of technology. Surely technology has also been a liberating force, often freeing man for higher aspirations and providing a greater freedom of choice. Few of us would be willing to forgo many of its benefits. Our article is based on the view that both benefit and injury may flow from technology, and the Academy study attempted to devise means for guiding technology in more beneficial directions. This is not what most people mean by *laissez faire*.

The technology versus society debate is an old one; some perspective can be gained by consulting the literature of the early 19th century dealing with the effects of the Industrial Revolution on rural England. The poet laureate Robert Southey wrote: "The spirit which built and endowed monasteries is gone. Are you one of those persons who think it has been superseded for the better by that which erects steam engines and cotton mills?" The historian Thomas Babington Macaulay asks: "Does Mr. Southey think that the body of the English peasantry live, or ever lived, in substantial or ornamented cottages, with box-hedges, flower gardens, beehives and orchards?"

It is not clear what Mr. Oaten would propose for a technology-assessment mechanism that would, to use his words, "rock the boat." (It is relatively easy to rock a boat; sailing in a desired direction takes much more skill.) He seems to hint that he would consider an all-powerful centralized control mechanism for technology, but this would lead us in the direction of a technocracy and would aggravate the very conditions he wishes to improve. In our study we have attempted to design a system that will increase the effectiveness and representation of what Mr. Oaten calls "local power." Our proposals might well be inadequate, and we hope he will propose more effective ones.

Raymond Bowers

Cornell University
Ithaca, N.Y.

Harvey Brooks

Harvard University
Cambridge, Mass.

Scientific American, April, 1970; Vol. 222, No. 4. Published monthly by Scientific American, Inc., 415 Madison Avenue, New York, N.Y. 10017; Gerard Piel, president; Dennis Flanagan, vice-president; Donald H. Miller, Jr., vice-president and treasurer.

Editorial correspondence should be addressed to The Editors, Scientific American, 415 Madison Avenue, New York, N.Y. 10017. Manuscripts are submitted at the author's risk and will not be returned unless accompanied by postage.

Advertising correspondence should be addressed to Allan Wittman, Advertising Manager, Scientific American, 415 Madison Avenue, New York, N.Y. 10017.

Offprint correspondence and orders should be addressed to W. H. Freeman and Company, 660 Market Street, San Francisco, Calif. 94104. For each offprint ordered please enclose 20 cents.

Change of address (or other subscription correspondence) should be addressed to Circulation Manager, Scientific American, 415 Madison Avenue, New York, N.Y. 10017. Please notify us four weeks in advance of change. If possible, kindly furnish an address imprint from a recent issue. Send both old and new addresses or complete and mail Post Office Form 357B.

Please enter change of address ☐
Please enter subscription ☐
☐ 1 year, $10 ☐ 2 years, $18 ☐ 3 years, $25

NAME

NEW ADDRESS

OLD ADDRESS

50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

APRIL, 1920: "Popular interest in Dr. Goddard's rocket for reaching high altitudes was excited by the claim that this projectile could actually be made to travel to the moon and there flash a signal that would show that it had completed its journey. There is something romantic in the thought of crossing the intervening hundreds of thousands of miles to the faithful satellite that is our closest companion in the infinite reaches of space. To be sure, there would be little, if any, astronomical value in such an accomplishment. It would serve merely as a demonstration of the power of man to overcome seemingly insurmountable handicaps."

"The rapid developments that have recently taken place in the Throop College of Technology at Pasadena, Calif., have just been signalized by the act of changing the institution's name to the California Institute of Technology. The institution, while maintaining its regular four-year undergraduate courses, has conspicuously developed its facilities for advanced study and research. The faculty has also been greatly strengthened. Thus Dr. Arthur A. Noyes, late of the Massachusetts Institute of Technology, has become director of chemical research at the California institution; Dr. R. A. Millikan of the University of Chicago has arranged to spend one term of each year there in charge of instruction and research in physics, and Prof. A. A. Michelson of the University of Chicago will carry out researches at Pasadena on earth tides with equipment now being installed for this special purpose."

"Alfred W. Lawson, a pioneer in American aviation and the designer of the splendid Lawson liner which has made an excellent showing in several exhibition flights, has set July 1st next as the date for starting the operation of a trans-continental New York to San Francisco passenger airplane line. The first airplane is scheduled to leave New York at 1:00 A.M., Mr. Lawson states, with accommodations, including sleeping berths, for 26 passengers. The schedule calls for a 36-hour trip with stops at Syracuse, Buffalo, Cleveland, Toledo, Chicago, Des Moines, Omaha, Cheyenne, Salt Lake City and Reno."

"That manufacturers throughout the country are awakening to the realization of the thorough training along technical lines that the Army is now giving its men is evidenced by the following letter received by Lieut.-Col. D. D. Eisenhower from a motor manufacturer: 'Thank you for your favor of the 27th inst., which the writer has carefully read. Should any of the men, after graduating and receiving their certificate, present themselves here and make application for employment at any time, and presenting their discharge papers from the Tank Corps with the notation "Character excellent" and a certificate showing them to be qualified mechanics, we will be very glad to give them the best available positions which may be open at that time. We can use a number of such men immediately. We very much appreciate your interest and trust we will soon have a number of your graduates in our employ.' "

SCIENTIFIC AMERICAN

APRIL, 1870: "After all the surveys and reconnaissances that have been made of the narrow strip which divides North and South America, extending between and inclusive of Tehuantepec and Darien, general opinion seems to have settled upon the latter Isthmus as the point for an interoceanic canal. Admiral Davis in his report to Congress says: 'It is evident that to this point we must look for the solution of the great problem of a union of the two oceans. On this Isthmus the two great waters are divided only by a distance of 27 miles, and waters flowing into the Pacific Ocean actually come within three miles of the Atlantic Ocean; tradition says in days gone by that, in some of the great tidal waves which volcanic action heaves up from the quiet Pacific, they have been united. Certain it is that at this point is not only the narrowest part but also the lowest elevation between the two continents.' "

"In accordance with our general desire to give both sides of every question a candid hearing, we publish in another column a letter from Mr. Hutchings, who claims to have been a *bona fide* settler in the Yosemite valley prior to its cession to the State of California. If his claims are valid, he is entitled to compensation, but we maintain that it would be disastrous to allow such a natural wonder to pass from the control of responsible and disinterested hands into the hands of private parties for purposes of speculation. We should as soon think of admitting a private claim to Niagara. If Mr. Hutchings is injured by the action of the government, by all means let him receive ample remuneration, but this great natural wonder should be, as Congress designed, held forever in trust for the people."

"The New-York Historical Society is about to give the most gratifying proof of being alive to the interests of art and of the public improvement. According to the *Evening Post* it proposes to establish in the Central Park a Museum of History, Antiquities and Art. By an act of the legislature of the state of New York, the Central Park Commissioners are authorized to set apart and appropriate to the Historical Society such portion of the grounds lying near the Fifth avenue between 81st and 84th streets as may be required for the erection of suitable buildings for this museum."

"For a long time efforts have been made to get rid of the famous astronomer Leverrier as director of the Paris Observatory, but he was so popular with the Emperor and Empress that the ministers were afraid to move in the matter, and he was a man of such violent temper that everybody kept out of his way. They tried to keep him in check by appointing a board of advisers, without whose consent and recommendation nothing could be done. There was not a member of the board with whom Leverrier was on speaking terms. He refused for six months to have anything to do with this body; finding that this would not do, finally in the seventh month he attended a meeting. It is said that this meeting ended by three of the advisers kicking M. Leverrier out of the room. All of the meetings he attended ended in a row; the scientific men began to be very tired of such a state of things, and all of the assistants employed in the observatory sent in their resignations, accompanied by the worst accusations and complaints that could be imagined. There was nothing left after such an exposure but a summary dismissal. M. Delaunay has been appointed in his place."

CalComp presents a brilliant new film producer.

Up until now, you could buy your computer either a brilliant and versatile microfilm plotter.

Or a brilliant and high speed microfilm printer.

But you couldn't buy, for any reasonable amount of money, one film output system that was both.

Now you can.

CalComp presents the 1670 COM system. It's a plotter.

CalComp's new offline 1670 COM system is the finest Computer Output Microfilm plotter you can buy.

It draws at a rate of 500,000 increments a second.

Features a programmable raster of 16,384 by 16,384 positions. The finest resolution available.

And cuts tape write time to a tenth or better over previous microfilm systems.

With twenty usable line widths, the 1670 COM system is ready to draw practically anything.

And with the support of CalComp's extensive library of basic, functional and application software, it practically can.

CalComp presents the 1670 COM system. It's a printer.

If your primary need is for a high speed printer, the CalComp 1670 COM system is that, too.

System throughput, using hardware character generation, is 7,000 to 12,000 lines per minute.

And with CalComp software you can put it in any type font, size, or language you like.

With an optional forms projector, you have 16 program selectable forms.

And take your choice of cameras. 16 or 35mm. Sprocketed or unsprocketed. Even a 105mm microfiche option.

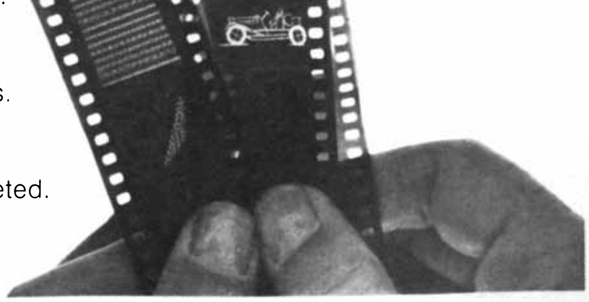
So if you haven't been able to decide between a microfilm system that *plots* or one that *prints*, call your nearest CalComp man today. (CalComp has offices in 34 cities.)

And tell him you want to discuss the brilliant new producer that produces both.

CALCOMP

TEACH YOUR COMPUTER TO DRAW.

California Computer Products, Inc., Dept. N-4
305 No Muller Street, Anaheim, California 92803



What can computerized systems do to improve your life...or extend it?

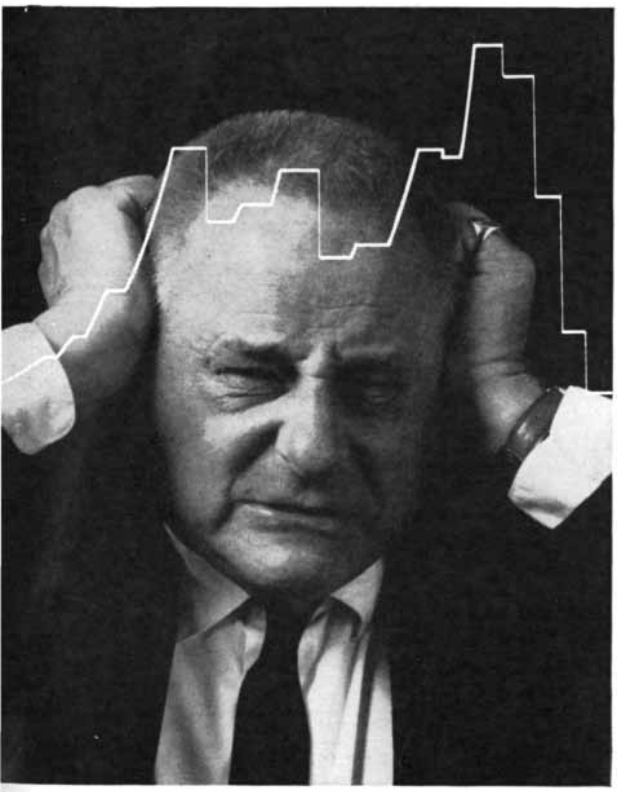
How to make airports quieter.

Jet aircraft are not designed to be noisy. The sound level depends more on how and where they're flown. And whether anybody cares. Around airports, people usually do. At Stuttgart, Germany, for example, after Hewlett-Packard installed an airport noise monitoring system, the level of noise dropped immediately. The pilots themselves became more "noise conscious" and exerted their own controls.

Actually, a number of things can be done—if you know when and where the noise is building up. Airport officials can change flight patterns to avoid sleeping neighborhoods; they can require new engine settings and approach angles; or redesign the airport!

Besides statistical analysis of airport noise, another boon for the future is that an offending aircraft can be detected in flight and brought to heel immediately. Chronic complainers can be mollified with statistics showing that aircraft are within their proper limits. This is all made possible by the speed and versatility of the HP 80500A Aircraft Noise Monitoring System, a combination of computer, real-time audio spectrum analyzer, and multiple remote monitors. This system can be programmed, with software provided, for any type of analysis the airport needs. The cost of a typical system would run about $70,000.

Airports can be easier to live around. For more information on how an HP airport system could help your community, write for Bulletin Number 80500A. Also yours for the asking is our 116-page Acoustics Handbook.



How to make the sound of music sweeter.

While integrated and thick film circuitry has contributed much to the listening pleasure you receive from ever smaller and more durable AM/FM radios, it's also introduced new problems with testing.

But now there's a system that makes possible and economically feasible complete checks of all IC's. One major manufacturer is using it to make the testing process 10 to 60 times faster than previously possible.

Complete circuit tests, including RF, IF, audio, local oscillators and other stages, can be made in less than 10 seconds. Individual steps can be checked in milliseconds. And the beauty of this fast, extensive testing

is that it also improves the quality of the set.

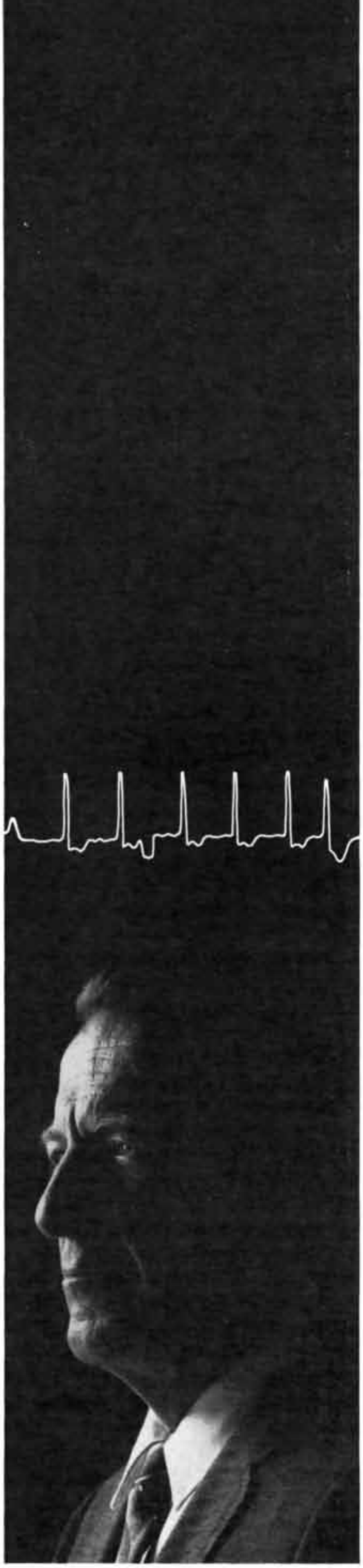
The automatic test system is the 9500A, typical of those delivered by the special HP Systems Division. It consists of several standard Hewlett-Packard instruments, controlled by one of our computers. The computer controls stimuli and the IC connections to which they're applied, then accepts and records measurement data.

This computer-controlled stimulus-response system can be applied to a wide range of production and quality control situations. It makes a previously complicated task a simple matter for any technician.

A detailed report on the 9500A system, which costs from $50,000, is given in the August 1969 Hewlett-Packard Journal. Write us for a copy.

How to keep track of unstable hearts.

The chances of complete recovery for patients who have suffered a common type of heart attack called myocardial infarction are generally good. But complications after this trauma can greatly complicate the physician's job, to say nothing of threatening his patient's life. Some 40% of all fatalities in the hospital due to myocardial infarction are caused by arrhythmias—electrical disturbances within the heart causing irregularities in the beat such as speed-ups, pauses or double-beats.



Since monitoring for medicine is part of Hewlett-Packard's business, we've been searching for a means to help doctors detect smaller arrhythmias, to give them a head start on treating major ones. The new 7822A Arrhythmia Monitor is such a means. When inserted into a patient monitoring system, it measures a pattern of heart signals that the physician establishes as "normal" for a particular patient. Characteristics of this "normal" pattern are stored in the instrument's memory, and each subsequent beat is compared to it instantaneously.

Beats which are abnormal as compared with this stored "normal" are classed as ectopic or out-of-place. Any excessive ectopic activity will trigger alarms to indicate a more serious condition.

This "extra ounce" of prevention can make monitoring even more effective toward achieving a complete recovery from myocardial infarction. If you would like a definitive description of this new instrument, drop us a note asking for publication No. 7822A. We'll also send you our pamphlet, "How Patients are Helped by Intensive Care Monitoring."

Why not call on Hewlett-Packard if a computerized system might help solve some of your problems. Hewlett-Packard, 1502 Page Mill Road, Palo Alto, California 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

HEWLETT hp PACKARD

Measurement, Analysis, Computation

00006A

THE AUTHORS

SIDNEY R. GARFIELD ("The Delivery of Medical Care") is a director of the Kaiser Foundation Health Plan and Hospitals. He was the originator of the system and served as its medical director from 1952 to 1958 and vice-president in charge of facilities and design from 1958 to 1969. Garfield did premedical and graduate work at the University of Southern California and obtained his M.D. at the University of Iowa in 1928. He is a diplomate of the American Board of Preventive Medicine and also is a fellow of the American Public Health Association.

ROY J. BRITTEN and DAVID E. KOHNE ("Repeated Segments of DNA") are in the biophysics section of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Britten was graduated from the University of Virginia in 1940 and received his Ph.D. from Princeton University in 1951. At Princeton, where he worked on nuclear physics, he discovered that a particle beam from a cyclotron could be focused with a spaced pair of astigmatic lenses—an arrangement that was a precursor of the quadrupole lenses now extensively used, although he points out that no one then foresaw that this was the principle necessary for strong-focusing accelerators, which were independently invented soon afterward. Britten has designed and is now building a 26-foot cruising catamaran; he notes that it dissociates into two hulls ("like a DNA molecule"), so that he can transport it readily by trailer. Kohne writes: "After spending my high school years as a novice naturalist, largely because my father was a wholesaler of live fish bait who collected much of his own bait, I enrolled at Wabash College in 1955. A year's vacation as a teller at the Bank of America in California convinced me that 'working' for a living was not for me. I reentered Wabash and was graduated in 1960. My Ph.D. in developmental biology was received from Purdue University in 1965."

EGON T. DEGENS and DAVID A. ROSS ("The Red Sea Hot Brines") are geologists at the Woods Hole Oceanographic Institution. They are both interested in the application of geochemical and geophysical techniques to problems of the ocean. Degens, who was born in Germany, received his Ph.D. from the University of Bonn in 1955 and did postdoctoral research at Pennsylvania State University and the California Institute of Technology. In 1958 he returned to Germany as a docent at the University of Würzburg in geology and paleontology. In 1960 he joined the faculty of Cal Tech, leaving there in 1964 to become a member of the staff at Woods Hole. Ross, who was graduated from the City College of New York, obtained his master's degree at the University of Kansas and his Ph.D. from the Scripps Institution of Oceanography. He joined the Woods Hole staff in 1965.

ARNOLD C. WAHL ("Chemistry by Computer") is associate chemist at the Argonne National Laboratory. His main research interest is in the use of mathematical models and large, high-speed computers for calculating the physical properties of molecules and for determining the nature of chemical processes and representing them pictorially. He is also interested in improving the ease of use of such large-scale computational systems. He has prepared a number of films and wall charts pictorially representing atomic and molecular structure and is the author of a forthcoming book employing a pictorial approach to the teaching of chemistry on its atomic and molecular level. Wahl was graduated from Rensselaer Polytechnic Institute in 1959 and received his Ph.D. from the University of Chicago in 1964.

DAVID B. PEAKALL ("Pesticides and the Reproduction of Birds") is senior research associate in the section of ecology and systematics at Cornell University. He was born in England and received his Ph.D. in physical chemistry from the University of London in 1956. He was assistant professor in the department of pharmacology at the Upstate Medical Center of the State University of New York in Syracuse for several years before he went to Cornell. Peakall writes: "I have had a lifelong interest in ornithology and now combine my interests by studying the effects of pesticides on birds."

GRAHAM HOYLE ("How Is Muscle Turned On and Off?") is professor of biology at the University of Oregon. Originally trained as a chemist at the University of London, he switched to experimental zoology after World War II, becoming interested in comparative nerve and muscle physiology after hearing a series of lectures by Bernhard Katz. Hoyle taught comparative physiology at the University of London and the University of Glasgow and then spent a year at the California Institute of Technology and two years as a Royal Society Research Fellow before going to Oregon in 1961. In addition to his work on muscle contraction Hoyle is interested in the ultrastructure of muscle and the neural basis of behavior at the cellular level in the locust and the giant sea slug *Tritonia*.

MARK A. STEWART ("Hyperactive Children") is associate professor of psychiatry and pediatrics at the Washington University School of Medicine in St. Louis. Beginning in July he will be chairman of the department of psychiatry at the Hershey Medical Center of Pennsylvania State University. Born in England, he obtained his bachelor's degree at the University of Cambridge in 1952 and was graduated from St. Thomas's Hospital Medical School of the University of London in 1956. He joined the staff of the medical school at Washington University in 1957 and works primarily on neurochemistry. As avocations he enjoys reading contemporary American poetry and getting out into the countryside.

GEORGE H. HEILMEIER ("Liquid-Crystal Display Devices") is head of research on solid- and liquid-state devices at the RCA Laboratories, which he joined in 1958 after his graduation from the University of Pennsylvania. While working at RCA he attended Princeton University and obtained three advanced degrees in electrical engineering: master of science in 1960, master of arts in 1961 and Ph.D. in 1962. On three occasions he has received the RCA Laboratories award for outstanding research: in 1960 for work on parametric and tunnel-diode amplifiers, mixers and harmonic generators; in 1962 for work in organic semiconduction, and in 1965 for work on liquid-crystal phenomena. Apart from his work Heilmeier engages in a number of community activities. Among them is athletics; he was playing captain of the softball team that won the Philadelphia amateur championship in 1958, 1959 and 1960 and the Pennsylvania amateur championship in 1959, and he still plays in community leagues.

S. GOPAL, who in this issue reviews *Gandhi's Truth: On the Origins of Militant Nonviolence*, by Erik H. Erikson, is director of the Historical Division of the Ministry of External Affairs of the Government of India.

Established 1845 SCIENTIFIC AMERICAN April 1970 Volume 222 Number 4

The Delivery of Medical Care

Medical care in the U.S. is expensive and poorly distributed, and national health insurance will make things worse. What is needed is an innovative system in which the sick are separated from the well

by Sidney R. Garfield

The U.S. system of high-quality but expensive and poorly distributed medical care is in trouble. Dramatic advances in medical knowledge and new techniques, combined with soaring demands created by growing public awareness, by hospital and medical insurance and by Medicare and Medicaid, are swamping the system by which medical care is delivered. As the disparity between the capabilities of medical care and its availability increases, and as costs rise beyond the ability of most Americans to pay them, pressures build up for action. High on the list of suggested remedies are national health insurance and a new medical-care delivery system.

National health insurance, an attractive idea to many Americans, can only make things worse. Medicare and Medicaid—equivalents of national health insurance for segments of our population—have largely failed because the surge of demand they created only dramatized and exacerbated the inadequacies of the existing delivery system and its painful shortages of manpower and facilities. It is folly to believe that compounding this demand by extending health insurance to the entire population will improve matters. On the contrary, it is certain that further overtaxing of our inadequate medical resources will result in serious deterioration in the quality and availability of service for the sick. If this country has learned anything from experience with Medicare and Medicaid, it is that a rational delivery system should have been prepared for projects of such scope.

The question then becomes: What are the necessary elements of a rational medical-care delivery system? Many have proposed that prepaid group practice patterned after the Kaiser-Permanente program, a private system centered on the West Coast, may be a solution. We at Kaiser-Permanente, who have had more than 30 years' experience working with health-care problems, believe that prepaid group practice is a step in the right direction but that it is far from being the entire answer. Lessons we have learned lead us to believe there is a broader solution that is applicable both to the Kaiser-Permanente system and to the system of private practice that prevails today.

The heart of the traditional medical-care delivery system is the physician. Whether he practices alone or in a group, he is still directly involved in the care of the patient at every important stage, from the initial interview to the final discharge. Any realistic solution to the medical-care problem must therefore begin by facing up to the facts about the supply of physicians.

Of the active doctors in the U.S. a great many are engaged in research, teaching and administration. Those actually giving patient care, in practice and on hospital staffs, number about 275,000 (approximately 135 per 100,000 of population), and they are far from evenly distributed throughout the population. A preponderance are in urban areas, and within those areas they tend to be concentrated where people can best afford their services. Increasing specialization accentuates the shortage of doctors. If we were to augment the output of our medical schools from the present level (fewer than 9,000 doctors a year) to twice that number (which is scarcely possible), we would barely affect this supply in 20 years, considering the natural attrition in our existing physician complement. The necessity of living with a limited supply of physicians in the face of increasing demand forces us to focus on the need for a medical-care delivery system that utilizes scarce and costly medical manpower properly.

The traditional medical-care delivery system has evolved over the years with little deliberate planning. At the end of the 19th century medical care was still relatively primitive: there was the doctor and his black bag and there were hospitals—places to die. People generally stayed away from the doctor unless they were very ill. In this century expanding medical knowledge soon became too much for any one man to master, and specialties began developing. Laboratories, X-ray facilities and hospitals became important adjuncts to the individual physician in his care of sick people. Since World War II a chain reaction of accelerated research, expanding knowledge, important discoveries and new technology has brought medical care to the level of a sophisticated discipline, offering much hope in the treatment of illness, yet requiring the precise and costly teamwork of specialists operating in expensively equipped and highly organized facilities [*see illustrations on pages 20 and 21*].

Throughout these years of remarkable medical achievement the delivery system has remained relatively unchanged, as though oblivious to the great need for new forms of organization equal to the task of applying new techniques and knowledge. Physicians have clung to individualism and old traditions. Their individual hospitals have continued on their individual ways, striving to be all things to their doctors and patients, creating their own private domains, largely ignoring the tremendous need to merge their highly specialized services and facilities. It is only in comparatively recent years that group practice by doctors has been considered respectable (and as yet only some 12 percent of all physicians practice in groups) and that regional-facility planning boards have appeared to force some semblance of cooperation on hospital construction.

It is amazing that the traditional delivery system functioned as well as it did for so long, considering the stresses between old methods and new technology. Much of its inefficiency was absorbed by dedicated physicians working long hours and donating additional hours; much was absorbed by office and hospital personnel working for extremely low pay. Only recently, under the joint impact of soaring demands for service and demands for competitive wages, has the system begun to break down, but it has been faltering for some time. In 1967 the National Advisory Commission on Health Manpower reported that "medical care in the U.S. is more a collection of bits and pieces (with overlapping, duplication, great gaps, high costs and wasted effort) than an integrated system in which need and efforts are closely related."

Let us look at another medical-care delivery system: the Kaiser-Permanente plan. This program had its origin in southern California in the depression years from 1933 to 1938. I was then in private practice, and I became involved in providing medical and hospital services and facilities for several thousand

HEALTH TESTING is depicted at the Kaiser-Permanente Multitest Laboratory in Oakland. After registering (*1*), the patient is assigned to a dressing room (*2*), where he partially undresses and puts on a paper gown. An electrocardiogram is made and his pulse and blood pressure are measured (*3*). Height and weight are recorded (*4*), a skin-fold test measures body fat (*5*) and a tendon reflex is checked (*6*). The chest is X-ray'd (*7*). (Women have a breast X-ray examination.) After dressing, the patient drinks a

construction workers. Unable to make ends meet by depending for remuneration on the usual fee for service, I finally tried prepayment and thus happened on our basic concepts of health care. Prepayment to a group of physicians in integrated clinic and hospital facilities proved to be a remarkably effective system for providing comprehensive care to workers on a completely self-sustaining basis. At the Grand Coulee Dam from 1938 to 1942, with the warm interest and counsel of Henry J. Kaiser and his son Edgar, these basic concepts were further developed, tested and broadened into a complete family plan for the entire temporary community built around that construction job.

World War II expanded our health-plan concept into care for 90,000 workers of the Kaiser wartime shipyards in the San Francisco Bay area and a similar number of workers in the Portland and Vancouver area. At the end of the war these workers returned to their homes, leaving us with facilities and medical and hospital organizations. We decided to make our services available to the community at large. Since 1945 the plan has grown of its own impetus, without advertising, to its present size: more than two million subscribers served by outpatient centers, 51 clinics and 22 hospitals in California, Oregon, Washington and Hawaii and in Cleveland and Denver. The plan provides comprehensive care at an annual cost of $100 per capita, which is approximately two-thirds the cost of comparable care in most parts of the country.

The plan is completely self-sustaining. Physical facilities and equipment worth $267 million have been financed by health-plan income and bank loans (except for gifts and loans to the extent of about 2 percent). The plan income provides funds for teaching, training and research and pays competitive incomes to 2,000 physicians and 13,000 nonphysician employees.

The health plan and the hospitals are organized as nonprofit operations and the medical groups in each area are autonomous partnerships. This organization gives our physicians essentially the same incentives as physicians in private practice have; they are motivated, in addition, by their belief in the rightness of this way of practicing medicine.

In addition to prepayment, group

glucose solution (*8*) in preparation for a blood test an hour later. His visual acuity is tested (*9*) and his eyes are checked for glaucoma (*10*). Lung capacity is measured (*11*) and hearing is tested electronically (*12*). The patient is given punched cards (*13*) for a self-administered medical questionnaire. A blood sample is taken (*14*) for analysis, as is a urine specimen (*15*). After returning his question cards (*16*) the patient gets another set for a psychological test (*17*) and later finishes with a talk with a doctor (*18*).

```
TEST, PATIENT                                              DR. SMITH
M.R. NO.  2258590      BIRTHDATE   7-18      FEMALE        S.F.      J1

LAST MHC  6/16/68. RANGES ARE LOW-HIGH VALUES FOR PATIENT MHC EXAMS, 1967-66

     (TEST)                       (NORMAL)     (VALUE)      (1968)       (1967-1966)
   HEIGHT: IN.                                  63.8         64.0        63.5-  63.9
   WEIGHT: LB.                                 133.5        132.0       131.5- 133.5
   TRICEPS SKINFOLD: MM.         UNDER 43       23.0         18.0        19.0-  20.0
   CIRCULATORY:
**   B.P. SUPINE:             90-159/50-89   164/100      154/104     135-144/ 86-098
     RAD. PULSE SUPINE:          60-95          68           76          66  -  74
   RESPIROMETRY:
     FEV 1 SEC: L.              OVER  1.2       2.1          2.0         1.9-   2.3
     FEV 2 SEC: L.                              2.4          2.5         2.2-   2.6
     TOTAL FEV: L.              OVER  2.1       2.8          2.7         2.5-   2.9
     PEAK FLOW: L.                              4.1          4.0         3.9-   4.4
   ACHILLES REFLEX: MS.     250.0 -400.0       290          270          280  - 310
   PAIN RESPONSE:             8.0 - 35.0        18           22           20  -  32
   BLOOD:
     WHITE CELL COUNT:      3,500-12,000       7,700        6,600       5,500 - 7,700
     RED CELLS (MILLIONS):   4.0 -  5.5         4.5       NOT DONE      NOT DONE
**   HEMOGLOBIN GM:         12.0 - 16.0         9.2         11.2        13.1-  13.9
     HEMATOCRIT:            35.0 - 49.0        36.0       NOT DONE      NOT DONE
     MEAN CORP VOL:         80    -100         80         NOT DONE      NOT DONE
**   MEAN CORP HG:          26.0 - 34.0        20.6       NOT DONE      NOT DONE
**   MCH CONC:              32.0 - 38.0        25.6       NOT DONE      NOT DONE

     SODIUM MEQ/L:         133   -145          140        NOT DONE      NOT DONE
     POTASSIUM MEQ/L:        3.0 -  5.0         3.7       NOT DONE      NOT DONE
     CALCIUM MG%:            8.0 - 10.5         9.9          9.5         9.0-  10.8
     PHOSPHORUS MG%:         1.5 -  4.5         3.2       NOT DONE      NOT DONE
**   GLUCOSE 1 HR: MG.      UNDER 263         332.0        234.0       212.0- 247.0
**   GLUCOSE 2 HR: MG.      UNDER 150         164.0       NOT DONE      NOT DONE
     BUN MG%:               UNDER- 22.0        15.2       NOT DONE      NOT DONE
     CREATININE MG%:        UNDER-  1.4          .9           .9          .8-   1.2
     URIC ACID MG%:          2.0 -  7.3         3.5       NOT DONE      NOT DONE
     BILIRUBIN TOT MG%:     UNDER-  1.5          .9       NOT DONE      NOT DONE
     BILIRUBIN DIR MG%:     UNDER-   .6          .1       NOT DONE      NOT DONE
     ALK PHOSPHATASE UNITS:UNDER- 15.0          6.0       NOT DONE      NOT DONE
     SGOT UNITS:            UNDER- 40          36           25           23  -  38
     SGPT UNITS:            UNDER- 50          25         NOT DONE      NOT DONE
     PROTEIN TOTAL GM%:      6.0 -  8.0         7.5          7.6         7.6-   8.0
     ALBUMIN GM%:           OVER  - 3.0         4.0          4.1         3.9-   4.2
     LIPIDS TOTAL GM%:        .3 -  2.0          .7       NOT DONE      NOT DONE
     BETA-LIPOPROT UNITS:   UNDER- 47.0        12.0       NOT DONE      NOT DONE
     CHOLESTEROL MG%:       90    -330         275          200          195  - 220
¬    IRON MCG%:             50    -180      NOT DONE      NOT DONE      NOT DONE
¬    FE BIND CAP MCG%:     190    -425      NOT DONE      NOT DONE      NOT DONE
     LATEX AGGLUT.R.F.:            NEG.        NEG.         NEG.        NEG.-NEG.
**   VDRL:                         NEG.        POS.         NEG.        NEG.-NEG.
**   QUANTITATIVE VDRL:                       RRWWWN
     BLOOD GROUP:                               0            0           0 -  0
   URINE:
     PH:                                        6.0          7.0         7.0-   7.0
**   GLUCOSE:                      NEG.        MED.         NEG.        NEG.-NEG.
**   CLINITEST:                    NEG.         3+
**   ACETONE:                      NEG.         +
     PROTEIN:                      NEG.        NEG.         NEG.        NEG.-NEG.
     BLOOD:                        NEG.        NEG.         NEG.        NEG.-NEG.
     URINE BACILLI:                NEG.        NEG.         NEG.        NEG.-NEG.

   CHEST X-RAY:     NO SIGNIFICANT CHANGE FROM PRIOR X-RAY
     1968: NO SIGNIFICANT CHANGE FROM PRIOR X-RAY
     1967: NO SIGNIFICANT CHANGE FROM PRIOR X-RAY
** BREAST X-RAY:    FIBROCYSTIC DIFFUSE CHANGES
     1968: NO SIGNIFICANT CHANGE FROM PRIOR X-RAY
     1967: NSA
   ECG:             NO SIGNIFICANT CHANGE FROM PRIOR ELECTROCARDIOGRAM
     1968: NO SIGNIFICANT CHANGE FROM PRIOR ELECTROCARDIOGRAM
     1967: NSA
** HEARING:         CLINICALLY IMPAIRED HEARING IN LEFT EAR.
**   1968: CLINICALLY IMPAIRED HEARING IN LEFT EAR.
**   1967: CLINICALLY IMPAIRED HEARING IN LEFT EAR.
   VISUAL ACUITY:  L.E. 20/40 OR BETTER.     R.E. 20/40 OR BETTER.
     1968: L.E. 20/40 OR BETTER.     R.E. 20/40 OR BETTER.
     1967: L.E. 20/40 OR BETTER.     R.E. 20/40 OR BETTER.
   OCULAR TENSION: L.E. NORMAL.       R.E. NORMAL.
     1968: L.E. NORMAL.       R.E. NORMAL.
¬    1967: TEST_NOT_DONE RIGHT
¬          TEST_NOT_DONE LEFT
¬          L.E. NO VALUE.    R.E. NO VALUE.
   PUPIL. ESCAPE:  NO ESCAPE
     1968: NO ESCAPE
     1967: NO ESCAPE
** RETINAL PHOTO:  SUGGESTS ACTIVE OCULAR DISEASE
¬    1968: TEST_NOT_INDICATED
¬    1967: TEST_NOT_INDICATED

¬  PATIENT RECEIVED FOLLOWING (ADVICE RULE) DIRECTIONS:
   700-REQUEST PT RETURN AMS LAB FOR 2 HR SERUM SUGAR.
   901-REFER DROP-IN CLINIC - URINE SUGAR,ACETONE,SERUM GLUCOSE.
   801-ROUTINE, PHYSICIAN WILL CONSIDER EARLY APPTMT.

¬  CONSIDER REFER TO ASYMPTOMATIC DIABETES RESEARCH STUDY
    IF FOLLOW-UP CONFIRMS DIABETES.
PATIENT ANSWERED YES TO THESE QUESTIONS ON THE MHC 1969 FORM:
   HAD BAD REACTION OR SENSITIVITY TO ASPIRIN OR SALICYLATES
   HAD BAD REACTION OR SENSITIVITY TO SULFA DRUGS
¬  IN PAST YEAR, USUALLY HAD 6 OR MORE ALCOHOLIC DRINKS A DAY
¬  IN PAST 6 MONTHS BAD HEADACHES NOT HELPED BY ASPIRIN, EMPIRIN, ETC
   IN PAST YEAR SPELLS OF WEAKNESS OR PARALYSIS OF ARMS OR LEGS
¬  IN PAST YEAR BLURRING OF EYESIGHT LASTING OVER A FEW MINUTES
¬  IN PAST YEAR ANY TIMES WHEN YOU WERE CROSS-EYED OR WALL-EYED
   IN PAST YEAR ANY LOSS OF HEARING WHICH IS STILL PRESENT
   IN PAST 6 MONTHS OFTEN HAD PAIN IN THE EAR
¬  IN PAST 6 MONTHS 2 OR MORE NOSE BLEEDS NOT FROM INJURY OR A COLD
¬  IN PAST YEAR COUGHED UP ANY BLOOD
   IN PAST YEAR HAD ANY ASTHMA
   HAS VARICOSE VEINS IN LEGS
¬  NEEDS MORE CLOTHES IN COLD WEATHER

¬  TO THESE QUESTIONS, ANSWERED YES ON THIS MHC AND NO ON LAST MHC.

**  CONSIDER POSSIBLE ABNORMAL.
¬   NOTE.
NSA NO SIGNIFICANT ABNORMALITY.
```

TEST RESULTS are compiled by a computer and are printed out as in this sample. The computer compares measurements with those from previous tests and with appropriate norms and calls attention to "possible abnormal" results. It also flags any other noteworthy items, orders additional tests and appointments and advises on diagnoses to be considered—in this case one of diabetes.

practice and the integration of hospital and clinic facilities, we can identify three other principles that are essential to the plan's success. One is the institution of what is in effect a new medical economics, which flows simply from the fact that the total health-plan income is turned over to the physicians and hospitals not as a fee for specific services but as a total sum. This reverses the usual economics of medicine: our doctors are better off if our subscribers stay well and our hospitals better off if their beds are empty. Another principle is freedom of choice. We require any group that wants to enroll its members in our program to offer them at least one alternative choice of medical plan, be it Blue Cross or a medical-society plan or something else. Finally, we consider it a fundamental principle that the physicians must be involved in responsibility for administrative and operational decisions that affect the quality of the care they provide.

We believe any group of physicians, or a foundation working with physicians, can easily duplicate the Kaiser-Permanente success. It only requires a dedicated group of physicians with reasonably well-organized facilities, a membership desiring their services on a prepaid basis and strict adherence to all these principles.

All of this is not to say that U.S. medicine should change over to the Kaiser-Permanente pattern. On the contrary, freedom of choice is important; we believe the choice of alternate systems, including solo practice, is preferable for both the public and physicians. Any change to prepaid group practice should be evolutionary, not revolutionary. Physicians in general have too much time and effort invested in their practice to discard them overnight. It will probably be the younger men, starting out in practice, who will innovate. Medical school faculties should point out the advantages and disadvantages of all methods of practice to these young men so that they can choose wisely.

Let us examine the functioning of these two systems—the traditional system and the Kaiser-Permanente one. In the

HEALTH-CARE CENTER is a special building that houses educational exhibits (*above*) as well as clinics, lecture rooms and audio-visual and other facilities. It would be the site of the health-care service to which well people would be referred after health testing.

language of systems analysis, the traditional medical-care system has an input (the patient), a processing unit of discrete medical resources (individual doctors and individual hospitals) and an output (one hopes the cured or improved patient). Customarily the patient decides when he needs care. This more or less educated decision by the patient creates a variable entry mix into medical care consisting of (1) the well, (2) the "worried well," (3) the "early sick" and (4) the sick. This entry mix has markedly increased in quantity and changed in character over the years as medical-care resources have grown in complexity and specialization. One constant throughout this evolution has been the point of entry into the system, which is and always has been the appointment with the doctor. Moreover, in traditional practice the patient enters with a fee.

The Kaiser-Permanente program alters the traditional medical-care delivery system in only two ways. It eliminates the fee for service, substituting prepayment, and it organizes the many units of medical-care resources into a coordinated group practice in integrated clinic and hospital facilities. We have come to realize that ironically the elimination of the fee has created a new set of problems. The lessons we have learned in seeking to solve these problems have a direct bearing on the difficulties besetting the country's faltering medical-care system.

The obvious purpose of the fee is remuneration of the physician. It has a less obvious but very significant side effect: it is a potent regulator of flow into the delivery system. Since nobody wants to pay for unneeded medical care, one tends to put off seeing the doctor until one is really sick. This limits the number of people seeking entry, particularly the number of well and early-sick people. Conversely, the sicker a person is, the earlier he seeks help—regardless of fee. Thus the fee-for-service regulator tends to limit overall quantity, to decrease the number of the healthy and early sick and to increase the number of the really sick in the entry mix.

Elimination of the fee has always been a must in our thinking, since it is a barrier to early entry into sick care. Early entry is essential for early treatment and for preventing serious illness and complications. Only after years of costly experience did we discover that the elimination of the fee is practically as much of a barrier to early sick care as the fee itself. The reason is that when we removed the fee, we removed the regulator of flow into the system and put nothing in its place. The result is an uncontrolled flood of well, worried-well, early-sick and sick people into our point of entry—the doctor's appointment—on a first-come, first-served basis that has little relation to priority of need. The impact of this demand overloads the system and, since the well and worried-well people are a considerable proportion of our entry mix, the usurping of available doctors' time by healthy people actually interferes with the care of the sick.

The same thing has happened at the broad national level. The traditional medical-care delivery system, which has evolved rather loosely over the years subject to the checks and balances of the open market, is being overwhelmed because of the elimination of personally paid fees through the spread of health insurance, Medicare and Medicaid. This floods the system not only with increased numbers of people but also with a changed entry mix characterized by an increasing proportion of relatively well people. For this considerable segment of patients the old methods of examining and diagnosing used by the doctor become very inefficient. He spends a large portion of his time trying to find something wrong with healthy people by applying the techniques he was taught for diagnosing illness. This reverse use of sick-care technology for healthy and comparatively symptomless people is wasteful of the doctor's time and boring and frustrating for him.

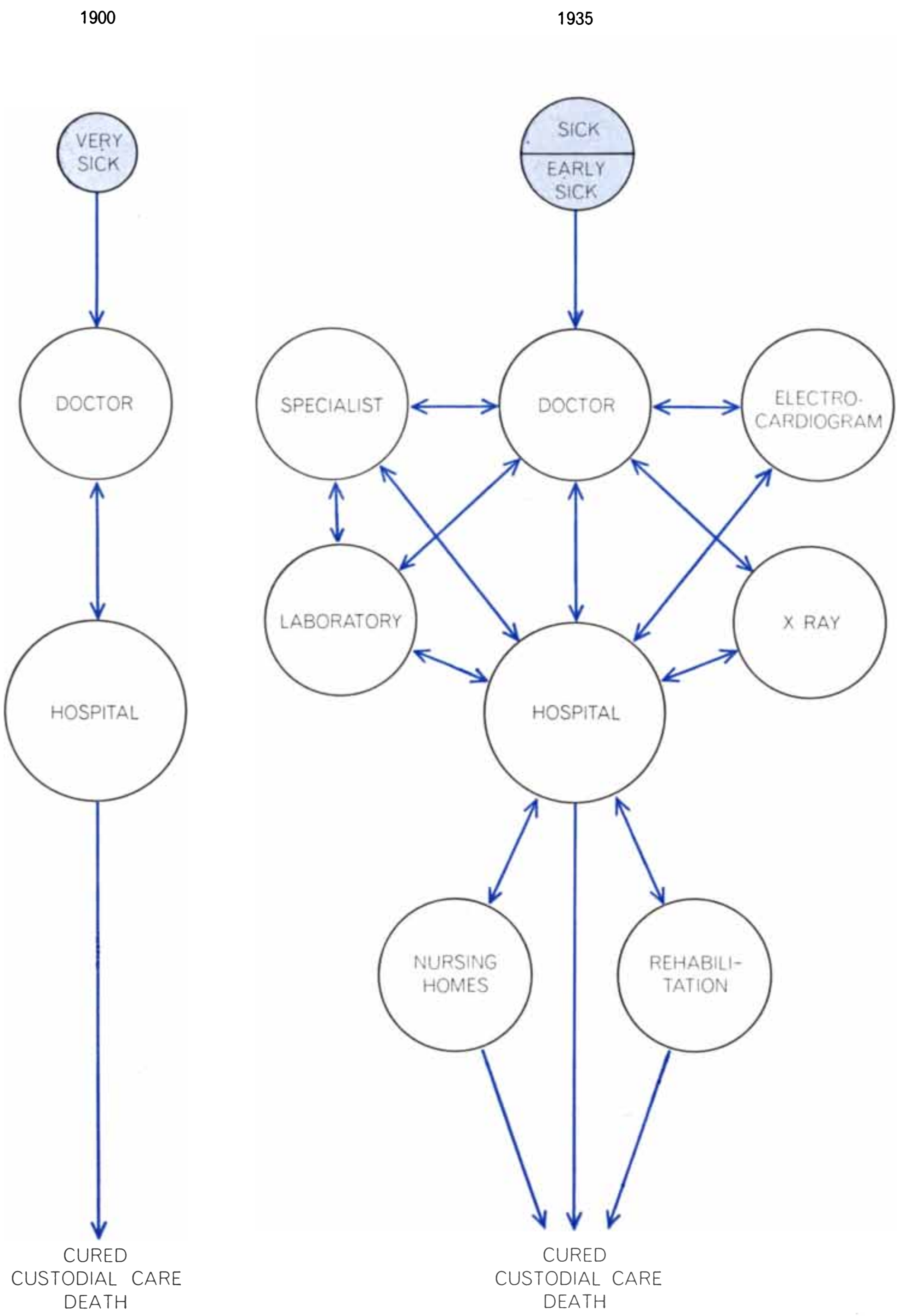
The obvious solution is to find a new regulator to replace the eliminated fee at the point of entry, one that is more sensitive to real medical need than to ability to pay and that can help to separate the well from the sick and establish entry priorities for the sick. We believe we have developed just such a regulator. Our Medical Methods Research Department, headed by Morris F. Collen, who is an electrical engineer as well as a physician, has successfully developed and tested techniques for evaluating the health of our members. The system that has been developed, which is variously called multiphasic screening, health evaluation or simply health testing, promises to solve the problem of a new regulator of flow into our medical-care delivery system.

Originally designed to meet our ever increasing demand for periodic health checkups, health testing combines a detailed computerized medical history with a comprehensive panel of physiological tests administered by paramedical personnel. Tests record the function of the heart, thyroid, neuromuscular system, respiratory system, vision and hearing. Other tests record height and weight, blood pressure, a urine analysis and a series of 20 blood-chemistry measurements plus hematology. The chest and (in women) the breasts are X-ray'd. By the time the entire process is completed the computerized results generate "advice" rules that recommend further tests when needed or, depending on the urgency of any significant abnormalities, an immediate or routine appointment with a physician. The entire record is stored by the computer as a health profile for future reference.

This health-testing procedure is ideally suited to be a regulator of entry into medical care. Certainly it is more sophisticated than the usual fee for service or our present first-come, first-served method. As a new entry regulator, health testing serves to separate the well from the sick and to establish entry priorities. In addition it detects symptomless and early illness, provides a preliminary survey for the doctors, aids in the diagnostic process, provides a basic health profile for future reference, saves the doctor (and patient) time and visits, saves hospital days for diagnostic work and makes possible the maximum utilization of paramedical personnel. Most important of all, it falls into place as the heart of a new and rational medical-care delivery system [*see illustration on page* 22].

As I have indicated, much of the trouble with the existing delivery system derives from the impact of an unstructured entry mix on scarce and valuable doctor time. Health testing can effectively separate this entry mix into its basic components: the healthy, the symptomless early sick and the sick. This clear separation is the key to the rational allocation of needed medical resources to each group. With health testing as the heart of the system, the entry mix is sorted into its components, which fan out to each of three distinct divisions of service: a health-care service, a preventive-maintenance service and a sick-care service. Compare this with the existing process, where the entire heterogeneous entry mix empties into the doctor's appointment, a sick-care service.

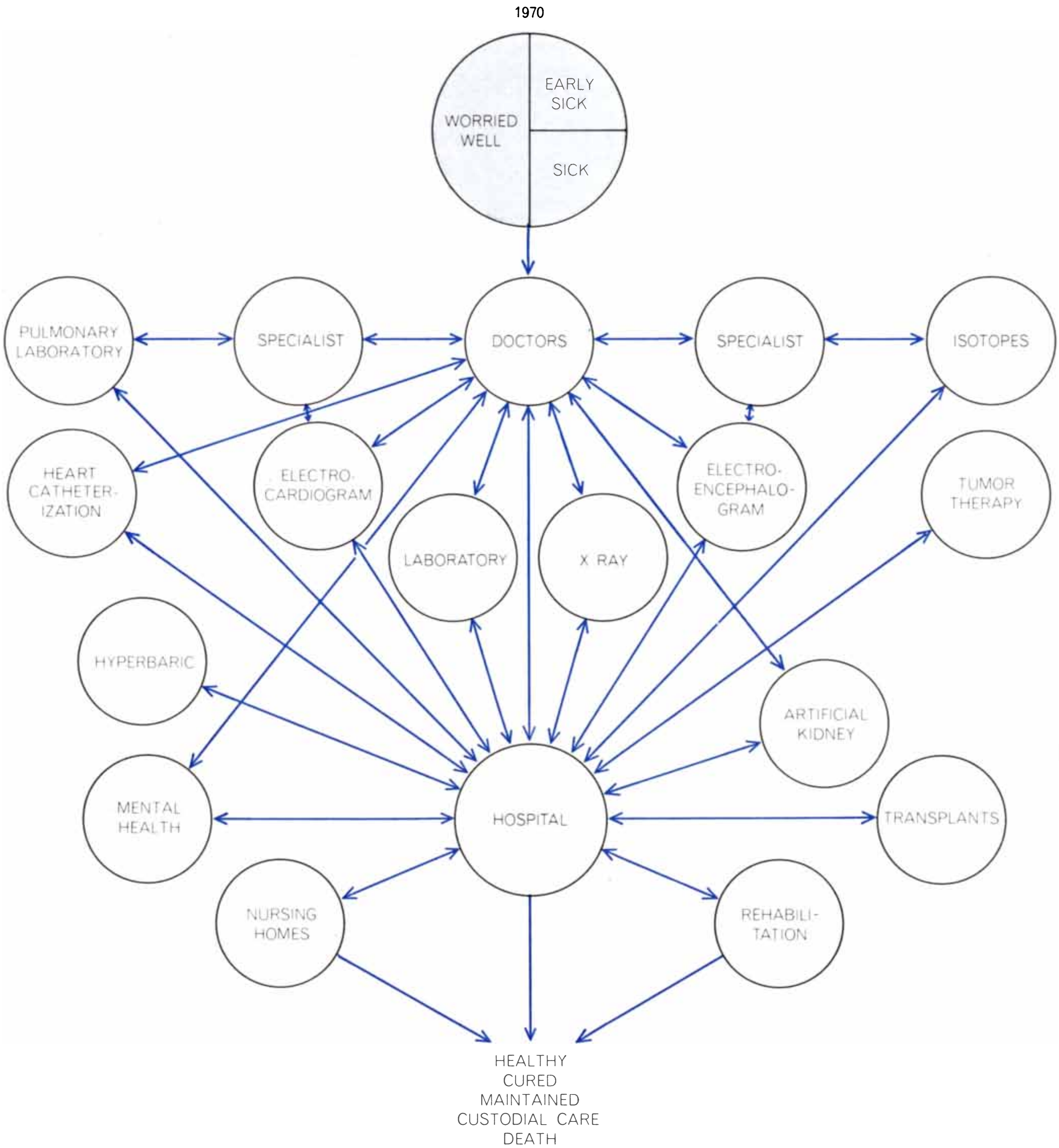
Health-care service is a new division of medicine that does not exist in this country or in any other country. Medical planners have long dreamed of the day when resources and funds could be channeled into keeping people healthy, in contrast to our present overwhelming preoccupation with curing sickness. Yet health care has been an elusive concept, and understandably so: well people entering medical care have been hopelessly mixed into and submerged in sick care, the primary concern of doctors. Doctors trained and oriented to sick care have been much too busy to be involved in the



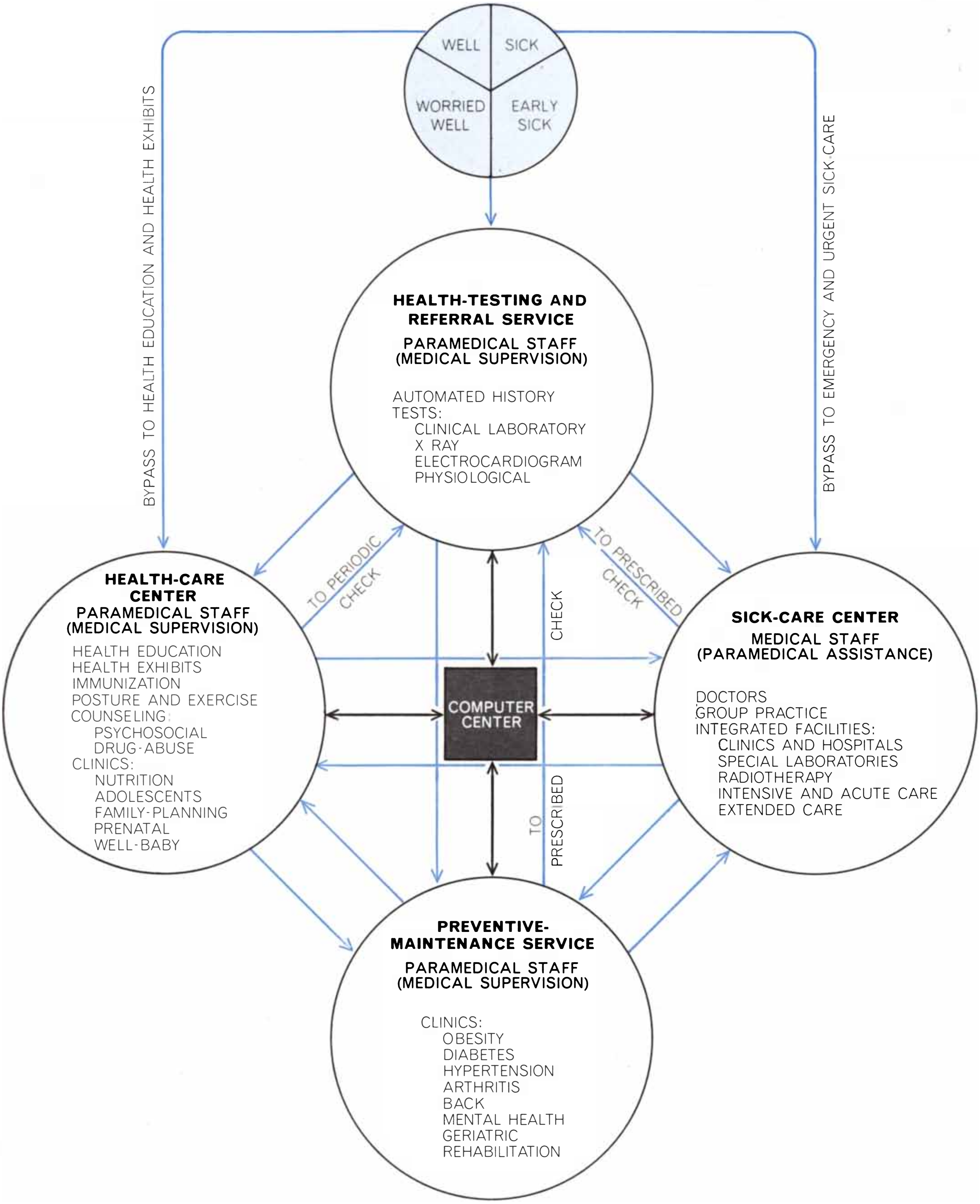
MEDICAL CARE has become more complex in this century and as it has become more effective the entry mix of people has changed significantly. Yet the entry point is still the doctor's appointment. Before 1900 (*left*) medicine had little to offer and only sick people care of well people. True health care never had a chance to develop in that environment. In fact, not even the highly socialized governments with socialized medicine have created any significant services for the healthy other than sanitation and immunization. These governments swamp the doctor with the entire entry mix of well and sick and thus are unable to provide adequate care for either.

The clear definition of a health-care service, made possible by health testing, is a basic first step toward a positive program for keeping people well. It should be housed in a new type of health facility where in pleasant surroundings lectures, health exhibits, audio-visual tapes and films, counseling and other services would be available. Whether or not one believes in the possibility of actually keeping people well, however, is now beside the point; this new health-care service is absolutely essential in order to meet the increasing demand for just this kind of service and to keep people from overloading sick-care resources.

Preventive-maintenance service, like health-care service, has been submerged in sick care. Essentially it is a service for high-incidence chronic illness that requires routine treatment, moni-



entered medical care. By 1935, as medicine began to have more to offer and as insurance plans appeared, some "early sick" people were entering the system (*middle*). Since World War II medical technology has proliferated, as indicated by the partial display of treatment components (*right*), and well people enter, largely because of prepayment, insurance plans, Medicare and Medicaid.



NEW DELIVERY SYSTEM proposed by the author would separate the sick from the well. It would do this by establishing a new method of entry, the health-testing service, to perform the regulating function that was performed, more crudely, by the fee for service. After health testing the patient would be referred for sick care, health care or preventive maintenance as required and would be transferred among the services as his condition changed. The computer center would regulate the flow of patients and information among the units, coordinating the entire system, which would depend heavily on paramedical personnel to save doctors' time.

toring and follow-up; its object is to improve the patient's condition or prevent progression of the illness, if possible, and to guard against complications. This type of care, performed by paramedical personnel reporting to the patient's doctor, can save a great deal of the doctor's time and (because it allows more frequent visits) provide closer and better surveillance.

The use of paramedical personnel with limited knowledge and limited but precise skills to relieve the physician of minor routine and repetitious tasks requires that such tasks be clearly defined and well supervised. Procedures are automatically defined and structured in the new system by the clear separation of services. Three of the four divisions of the proposed system—health-testing service, health-care service and preventive-maintenance service—are primarily areas for paramedical personnel. Supervising physicians will be involved in varying degrees: least in health testing and most in preventive maintenance. This leaves sick care, with its judgments on diagnosis and treatment, clearly in the physician's realm. Even here, however, he will be aided by the three other services: in diagnosis, by health testing; in follow-up care, by preventive maintenance; in repetitive explanations and instructions to patients and relatives, by the audio-visual library of the health-care service. We believe, incidentally, that the doctor-patient relationship, which is suffering from the pressure of crowded schedules today, would gain under this system. Giving the doctor more time for care of the sick can help to preserve the relationship at the stage where it counts most.

Implementing the new delivery system should be relatively simple in the Kaiser-Permanente program, since there are no basic conflicts: The subscribers will benefit from better and prompter service to both the well and the sick; the doctors will have more time for their sick patients and their work will be more interesting and stimulating. Although the complete system remains to be tested and evaluated at each step, our hypothesis, on the basis of our research to date, is that we can save at least 50 percent of our general practitioners', internists' and pediatricians' time. This should greatly enhance our service for the sick and improve our services for the well.

Implementing this new medical-care delivery system in the world of traditional medical practice will be more difficult, but it still makes sense. Many forward-looking physicians will see in these new methods an opportunity to improve their services to patients. Most doctors these days have more work than they can handle and begrudge the time they must spend on well people. The assistance they could get from health-testing and health-care services will be welcome to many of them if such services are carefully designed and planned to help them. The sponsorship of health-testing and health-care services for private practice logically falls to the local medical societies. Some have already moved in the direction of health evaluation. A few local medical societies in northern California have for several years been operating a mobile unit evaluating the health of cannery workers. Some leaders of other medical societies have expressed interest in health testing as an entry into medical care. They realize that improvement of the delivery system is essential for the preservation of the private enterprise of medicine in this country.

The proposed delivery system may offer a solution to the hitherto insoluble problem of poverty medical care in many areas. The need is to make health services accessible to poor people. To this end neighborhood clinics are established, but staffing these clinics with physicians has proved virtually impossible. Physicians in general want to be in a stimulating medical environment; they like to associate with well-trained colleagues in good medical centers and tend to avoid isolated clinics.

In the system being proposed a central medical center, well staffed and equipped, would provide sick care. It could have four or five "outreach" neighborhood clinics, each providing the three primarily paramedical services: health testing, health care and preventive maintenance. Staffing these services with paramedical personnel should be much less difficult than staffing clinics with doctors; many of the workers could be recruited from the neighborhood itself. Such outreach clinics, coordinated with the sick-care center, could provide high-quality, personal service—better service, perhaps, than is available to the affluent today—at a cost probably lower than the cost of the inferior service poor people now receive.

The concept of medical care as a right is an excellent principle that both the public and the medical world have now accepted. Yet the words mean very little, since we have no system capable of delivering quality medical care as a right. This is hardly surprising. Picture what would happen to, say, transportation service if fares were suddenly eliminated and travel became a right. What would happen to our already overtaxed airports and what chance would anyone have of getting anywhere if he really needed to? National health insurance, if it were legislated today, would have the same effect. It would create turmoil. Even if sick care were superbly organized today, with group practice in well-integrated facilities, the change from "fee" to "free" would stagger the system.

Quality medical care as a right cannot be achieved unless we can establish need, separate the well from the sick and do that without wasting physicians' time. It follows that to make medical care a right, or national health insurance possible, it is mandatory that we first make available health testing and health-care services throughout the country. It is our conviction that these services should be provided or arranged for by the physicians themselves in order to be responsive to their needs and not just a commercial operation.

A basic cause-and-effect relationship is directly responsible for much of today's medical-care problems. The cause is the elimination of a personally paid fee for medical service. The effect is a changed, unstructured entry mix into the delivery system that wastes scarce medical manpower. The suggested solution, a new method of entry through health testing, serves as the heart of a new medical-care delivery system for the future.

The entry of healthy people into the medical-care system should not be considered undesirable. It opens the door to a great opportunity for American medicine: If these well people are guided away from sick care into a new, meaningful health-care service, there is hope that we can develop an effective preventive-care program for the future. The concomitant release of misused doctors' time can significantly slow the trend toward the inflation of costs and the maldistribution and unavailability of service. There should be little shortage of manpower if manpower is utilized properly.

Medical care stands at a critical point. One choice would be to adopt rash legislation that can only depreciate the quality of care for both the sick and the well. The better choice is to create a rational new medical-care delivery system that will make it genuinely possible to achieve the principle of quality medical care as a right. Matching the superb technology of present-day medicine with an effective delivery system can raise U.S. medical care to a level unparalleled in the world.

REPEATED SEGMENTS OF DNA

In cells of higher organisms a significant fraction of the genetic material appears in as many as a million identical or very similar copies. The origin and function of repetitive DNA remain unknown

by Roy J. Britten and David E. Kohne

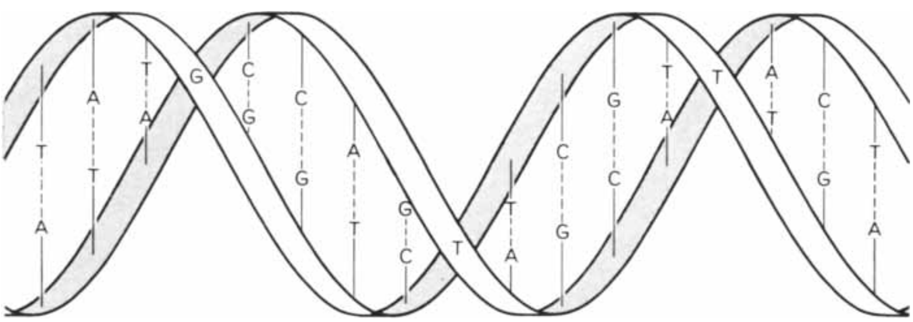
DNA was conclusively identified as the genetic material in 1944 and its structure was established in 1953. In the next few years it became clear how that structure is critical to DNA's replication, its transcription into RNA and its subsequent translation into particular chains of amino acids to form enzymes and other proteins. Everything that had been learned about DNA by the early 1960's emphasized the significance of the precise and unique sequence of nitrogenous bases that constitutes a gene and suggested that DNA consisted of chains of different genes. It was therefore a major surprise when it was discovered in 1964 that much of the DNA in the cells of the mouse consists of multiple copies of the same or very similar base sequences.

Repeated DNA has now been identified in all higher species that have been examined. It constitutes as little as 20 percent of all the DNA in the cell nuclei of some species and as much as 80 percent in others. The precision of repetition is often imperfect, so that members of a "family" of repeated DNA are usually closely related rather than identical. The number of related base sequences in a family ranges from 50 to two million. The wide distribution of repeated DNA, its persistence through millions of years of evolution and the fact that at least some of it is "expressed," or transcribed into RNA, all suggest that it is important to cell function and the survival of the organism. Yet it is still not known if the repeated segments are genes or parts of genes or if they carry out some role other than the specification of gene products. At this stage it seems likely that the most significant phenomenon may not be at the level of gene repetition; the repeated DNA may have an organizational or regulatory function. More insight into the evolutionary history and the present role of repeated DNA will surely lead to a new understanding of evolution and of the regulation of genetic functions in the living cell.

Before telling the story of the discovery of repeated DNA by our group in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, it will be well to briefly review the structure and behavior of DNA. Most DNA consists of sequences of only four nitrogenous bases: adenine (*A*), thymine (*T*), guanine (*G*) and cytosine (*C*). Together these bases form the genetic alphabet, and long ordered sequences of them contain in coded form much, if not all, of the information present in the genes. The DNA molecule in its native state (as it is found in the cell) is made up of two strands wound helically around each other. The bases face inward and each is specifically bonded to a complementary base on the other strand; *T* is always linked with *A* and *G* is always linked with *C*. These complementary bases have an affinity for each other such that, when they are paired, they contribute to the stability of the entire double-strand molecule.

In native DNA every base is paired with its complement and the molecule is quite stable. In isolated DNA the bonds between the bases can be broken by heating, and the two strands of the DNA can be completely separated from each other. This dissociation is usually accomplished simply by boiling the DNA solution for a few minutes. Left in solution, the single strands collide with complementary partners and, if the conditions are right, double-strand helixes are formed again. The requirements for such reassociation of DNA are surprisingly simple: the salt concentration must be fairly high, the temperature should be about 25 degrees Celsius below the dissociation temperature and enough time must be allowed for effective collisions to occur between complementary strands.

The extent of reassociation is the critical observation in most experiments with repeated DNA. Reassociation can be measured in a variety of ways, each depending on some easily detected difference between single-strand and double-strand DNA. Some time ago it was discovered that single-strand DNA absorbs more ultraviolet radiation than

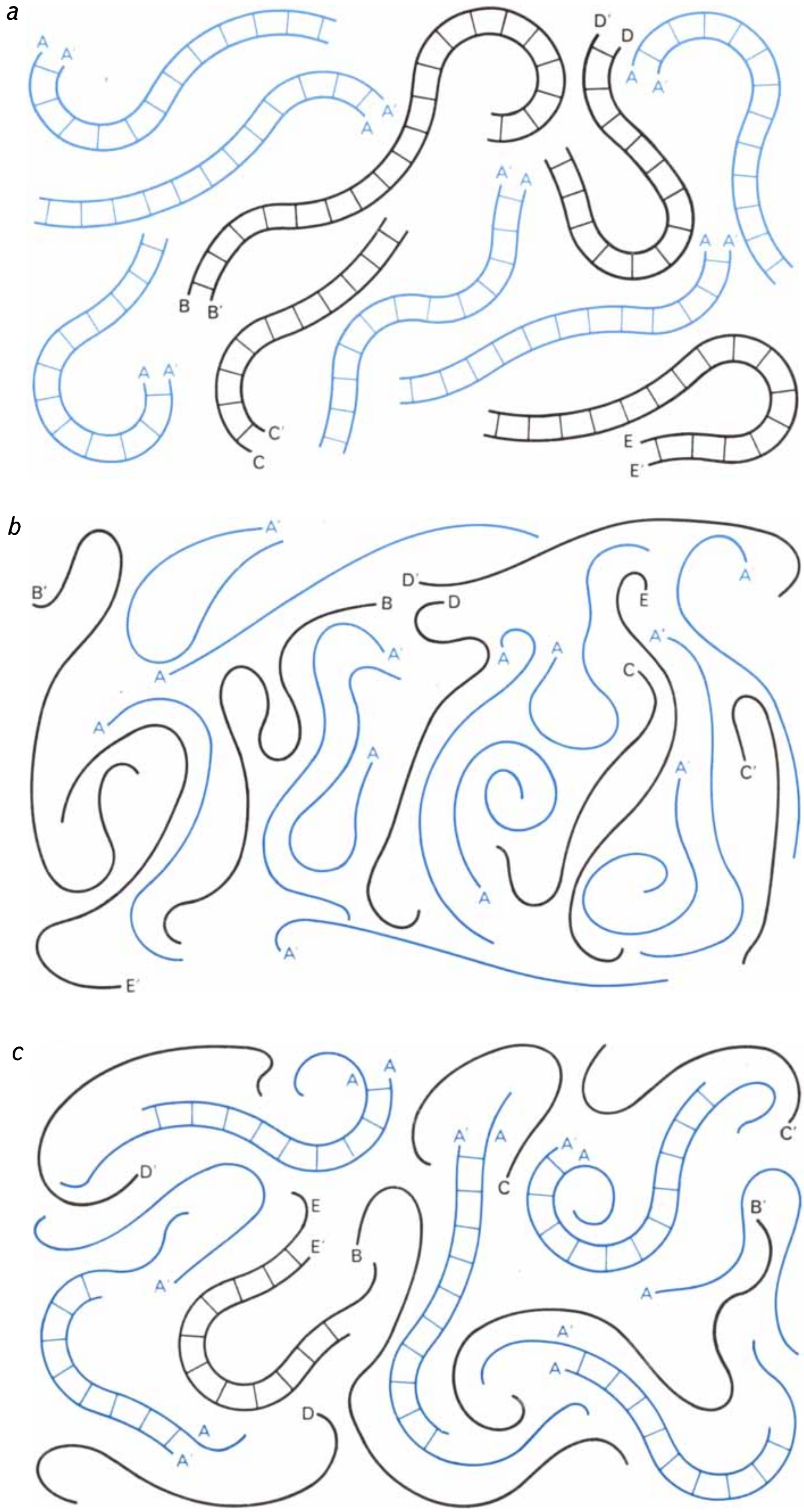


DNA in its native state is a double helix composed of two single strands. Each strand has a backbone of sugar and phosphate groups and a series of nitrogenous bases: adenine (*A*), thymine (*T*), guanine (*G*) and cytosine (*C*). The bases project inward and are linked by hydrogen bonds, which hold the two strands together like the rungs of a ladder; *A* always bonds with *T* and *G* bonds with *C*. The sequence of bases encodes genetic information.

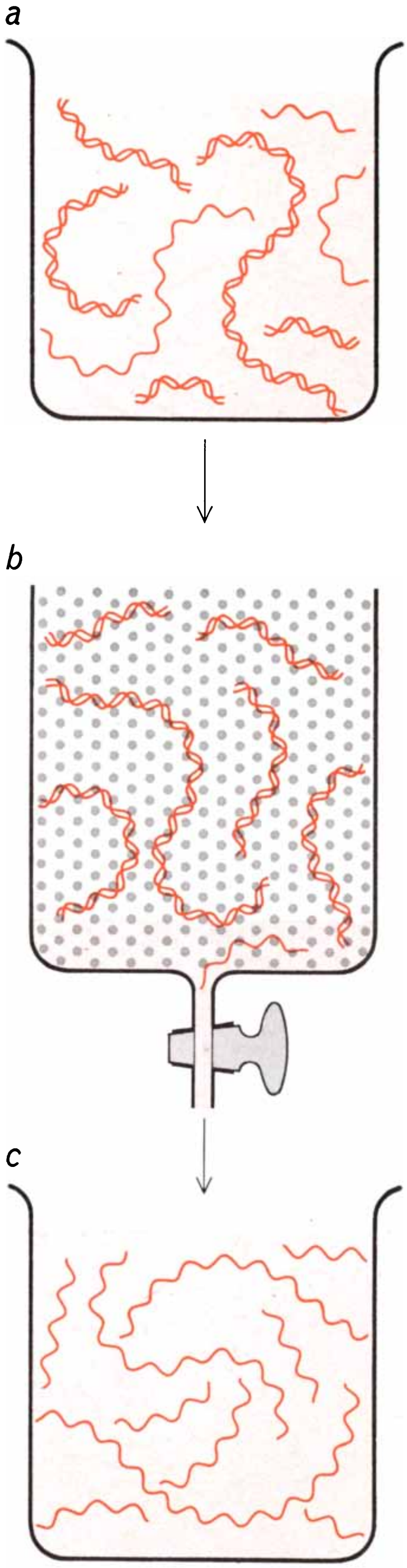
double-strand DNA does; with a spectrophotometer one can measure changes in ultraviolet absorption and thus in the amount of reassociation. In another method single-strand DNA labeled with radioactive atoms is incubated over other strands fixed in agar, and the quantity of radioactive DNA that is reassociated, and thereby bound to the agar, is measured. Our own preferred method for the study of repeated DNA utilizes hydroxyapatite, a crystalline form of calcium phosphate that was originally used for the fractionation of proteins. A number of years ago it was discovered that single-strand and double-strand DNA have different affinities for hydroxyapatite crystals. We have helped to bring this technique to the point where the solution of DNA used for reassociation can simply be passed through the hydroxyapatite. The single-strand DNA passes through the column of crystals; the double-strand DNA is absorbed on the hydroxyapatite and can be removed for assay. The solution and its temperature (about 60 degrees C.) are such that the amount of single-strand DNA that is absorbed is low but the double-strand DNA is efficiently bound. The temperature is only about 25 degrees C. below the dissociation temperature, which prevents the formation of strand pairs held together by very short or very imprecise complementary regions.

When DNA strands derived from different but related sources, such as two related animals, are reassociated, their bases will not be perfectly complementary. The best means now known for recognizing and measuring the extent of differences between similar DNA sequences is to form hybrid-strand pairs between the two DNA's and measure the stability of the resulting helixes. The presence of a few mismatched bases reduces the stability of an otherwise complementary strand pair and leads to its dissociation at a lower temperature. The best current estimate is that for every 1.5 percent of the base pairs that are mismatched the dissociation temperature is reduced one degree. In order to determine the stability of reassociated DNA one need only absorb hybrid-strand pairs on hydroxyapatite and wash the column free of single-strand DNA at 60 degrees. Then the temperature is raised in steps and the DNA that dissociates at each temperature is washed out and assayed.

In 1962 Ellis T. Bolton and Brian J. McCarthy of our biophysics group at the Carnegie Institution had devised the DNA-agar method for measuring the relatedness between different DNA's



REASSOCIATION of strands of DNA is the experimental procedure that gives information about repeated DNA. The schematic drawings show the process of dissociation and reassociation for a hypothetical genome, or gene complement, composed of six copies of a repeated DNA sequence (*color*) and four different (*black*) sequences (*a*). Heating the DNA above the dissociation temperature breaks the hydrogen bonds between complementary base pairs, thus separating the strands (*b*). After the temperature is lowered complementary regions of DNA strands that collide may match up, forming reassociated double strands (*c*). Collision of complementary regions is more likely in the case of repeated DNA than for single-copy DNA. Speed of reassociation is proportional to degree of repetition.



EXTENT OF REASSOCIATION is measured by separating double-strand DNA from single-strand DNA. A solution containing the two (*a*) is passed through a column of hydroxyapatite crystals (*b*). The double strands bind to the hydroxyapatite, whereas the single strands pass through the column (*c*). The double strands may then be collected by raising the column's temperature.

and RNA's and with it had measured the relations among various species of bacteria. With Bill H. Hoyer they undertook to apply the same method to the relations among vertebrate species. The first animal DNA they tried to reassociate was from mouse cells, and they succeeded. They went on to conduct a fascinating series of experiments on the relations between the genes of higher species and the expression of those genes in various tissues.

The trouble was that, according to what was then known about DNA, their experiments should not have worked. The cells of vertebrate animals contain much more DNA than bacteria do. As a result it had been expected that the concentration of each particular DNA sequence from vertebrate cells would be very small, and that after dissociation the complementary strands would rarely collide with each other. Yet the dissociated strands found their partners faster in the vertebrate DNA than they did in the bacterial DNA. Why? The question was set aside for future explanation, but as time passed it increasingly disturbed one of us (Britten). Had the reaction been accelerated by some unknown catalytic action of the agar or by the immobilization of the DNA? An experiment ruled out those possibilities: hybridization proceeded rapidly in free solution. By midsummer of 1964 only one explanation seemed possible and the basic hypothesis was proposed. Certain sequences in the DNA were reiterated again and again. Reiteration, or repetition, would make the concentration of some DNA base sequences much higher than had been expected and would thus account for the rapid reassociation.

On the basis of evidence that these related sequences were not identical with one another, the early hypothesis further suggested that some kind of multiplication process had occurred for selected segments of the DNA, forming large families of related sequences that became integrated into the genetic material and were then passed on to descendants by the usual hereditary mechanisms. It was further supposed that sequence changes, or mutations, altered various members of the families of repeated sequences, so that precise relationship was slowly lost among the member sequences. An essential part of the hypothesis was that new events of multiplication must have occurred at intervals throughout the course of evolution, producing new populations of repeated DNA segments. The evidence obtained since that time has supported this set of hypotheses.

The first direct evidence for repetition came out of an improbable piece of good fortune, again involving the mouse. Michael Waring arrived from the University of Cambridge as a postdoctoral fellow and chose to join in the search for actual pieces of repeated DNA. One of us (Britten) and Waring decided to extract DNA from mouse tissue because that tissue was convenient and available. We were quite unaware that mouse DNA has a singular family of repeated sequences. It is the most obvious one known even today; it makes up a tenth of the total mouse DNA and consists of about a million copies of a short sequence of some 300 base pairs. We had not expected anything so outlandish, but we immediately recognized the highly repetitive component. Because of its special qualities (it is lighter than most mouse DNA and forms a distinct "satellite" band when it is centrifuged in a cesium chloride density gradient), it could be purified in a few weeks and was shown to be an example of repetitive DNA. Soon afterward Ann McClaren and P. M. B. Walker of the University of Edinburgh, who were also working with mouse DNA, observed that 10 percent of it was bound to hydroxyapatite when it was expected to be single-strand and therefore not to bind. They did not imagine that reassociation could be as rapid as their results suggested and they identified their DNA as a stable fraction whose strands either had not separated or had folded back on themselves instantly. Walker's group at Edinburgh continued to investigate rapidly reassociating DNA in rodents. And since 1965 the authors of this article have collaborated on an extensive series of experiments to characterize the repeated sequences in the DNA of many different species.

Let us examine in more detail the paradox of the mouse-DNA reassociation, which led to the discovery of repetitive DNA. As we have noted, the reason animal DNA was expected to reassociate slowly is the large amount of DNA per animal cell [*see illustration on opposite page*]. If all the base sequences in the DNA of an animal were different from one another, then in a reassociation reaction each sequence would in effect be diluted by all the others. The dilution would lead to a reduced rate of reassociation, and so the rate of reassociation of the DNA from an animal with a large genome size, or DNA content per nucleus, should be less than the rate for DNA from one with a small genome.

This is exactly what we observe if we put aside the effects of the DNA present in multiple copies. In fact, the time required for the reassociation of unrepeated DNA to proceed halfway to completion is proportional to the genome size [*see illustration on next page*]. The reason is that complementary single strands must collide with each other before they can reassociate. Although most collisions are ineffective, occasionally complementary regions of the two strands are matched up in such a way that a short double-strand region results. If the neighboring regions are also complementary, then the double-strand region will grow into a stable helix; if they are not, the short region is likely to be unstable and therefore to dissociate. Under most practical conditions the rate of collisions controls the rate at which reassociation occurs. Reassociation between DNA strands therefore is normally, in the terminology of chemical kinetics, a second-order reaction. When its time course is plotted on a logarithmic scale, it takes the characteristic form of an S-shaped curve.

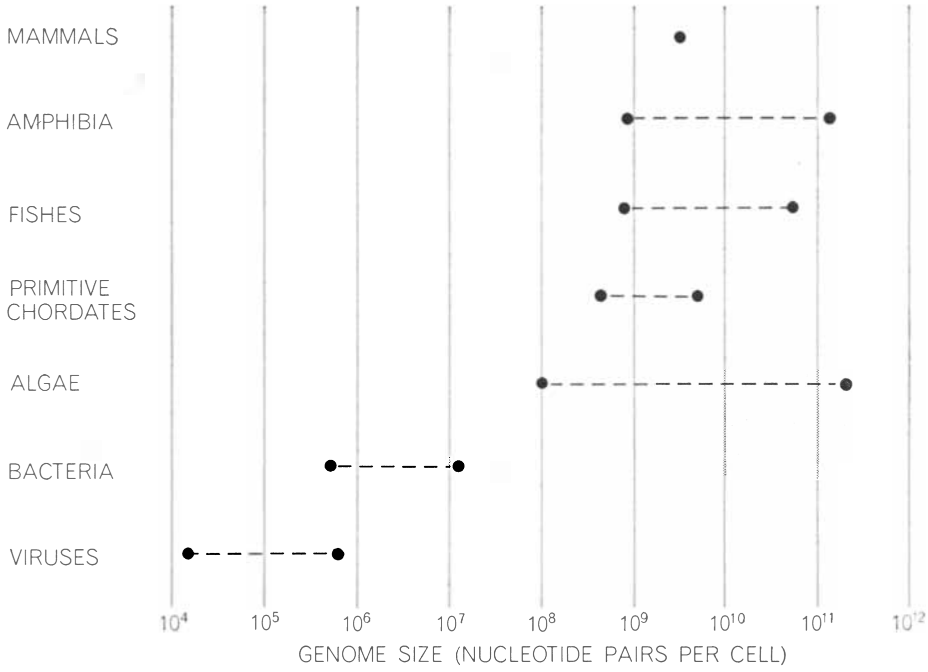
Measurement of the rate of reassociation is the best way to identify repetitive DNA. Because the rate of reassociation depends on a number of conditions, the DNA of a standard organism, the bacterium *Escherichia coli,* is taken as a reference. The length of the DNA of the *E. coli* chromosome has been well measured and its genome size is known. Virtually all the nucleotide sequences of its DNA occur only once, that is, it has little repetition. The time course of the reassociation of *E. coli* DNA [*see illustration on page 29*] reveals the S-shaped curve expected for a single-component reaction, and the precision of agreement with the predicted curve sets a low limit for the presence of repeated DNA. (The agreement also shows that such variables as fragment size have negligible effects and that the hydroxyapatite method adequately separates double-strand DNA from single-strand.)

The time required for half-reassociation is proportional to the DNA content per cell only if each sequence of bases occurs once in the cell's DNA. If a stretch of DNA sequence were to occur twice (if a gene were duplicated, for example), then the concentration of complementary fragments derived from the duplicate region would be twice as great as the concentration of the rest of the DNA. As a result these fragments would take only half as long to reassociate. If there were more copies, the period required for reassociation would be proportionately reduced. This simple rule apparently continues to hold even when as many as a million copies are present, as is the case for the most rapidly associating family in mouse DNA. With this rule we can evaluate the number of copies from measurements of the rate of reassociation.

The DNA that has been most thoroughly studied is the DNA of the calf (because calf thymus glands, which are rich in DNA, are readily available from meat-packers). When its reassociation curve is plotted in the same way as the *E. coli* curve, there are some obvious differences. The reaction starts much sooner and ends much later; it is evidently divided into two quite separate regions. The later region of the curve has been shown to be due to the reassociation of DNA present in single copies. In the earlier part of the curve the DNA on the average reassociates 100,000 times faster, indicating that for each of the segments reassociating in this early region there must be about 100,000 other segments in the genome that are similar enough to form complementary pairs of strands. More detailed measurements show there are two major families of repeated sequences whose reactions overlap. One is present in about a million copies and amounts to only a few percent of the DNA. The other repeated component, accounting for nearly 40 percent of the total DNA of the calf, is present in 66,000 copies, not all of them exactly alike.

The total quantity of DNA in the form of repetitive sequences is quite large: about 45 percent for calf DNA, according to the hydroxyapatite measurements. Actually this is a somewhat arbitrary figure. It depends on the degree of sequence relationship—the proportion of matching bases in each pair of strands—that is recognized in the particular measurement. We do not yet know how much of the DNA would have to be included if all degrees of sequence relationship greater than chance expectation were taken into account. In several species—Pacific salmon, wheat, onion and the salamander *Amphiuma*—more than 80 percent of the DNA shows repetition that is recognizable under the conditions in which calf shows only 45 percent repetition. Certainly the repeated sequences are not a minor part of the DNA. Why is there so much and what role does it play in the operations of the cell? Before considering the evidence bearing on these unsolved questions we will summarize what is known about the distribution of repeated DNA in various organisms, the frequency of repetition, the apparent evolutionary history of repeated DNA and the distribution of the material in the cell.

In the past few years the DNA of more than 60 plant and animal species has been examined. Significant quantities of repeated sequences have been found in the following groups: primates, other mammals, birds, amphibians, bony and cartilaginous fishes, amphioxus, echino-



GENOME SIZE, or the amount of DNA per cell, increases with increasing evolutionary complexity. For each group of organisms shown here the minimum and maximum genome size recorded in various species are plotted, expressed as number of nucleotide pairs per haploid cell (a germ cell in higher forms). Mammals all have about the same genome size.

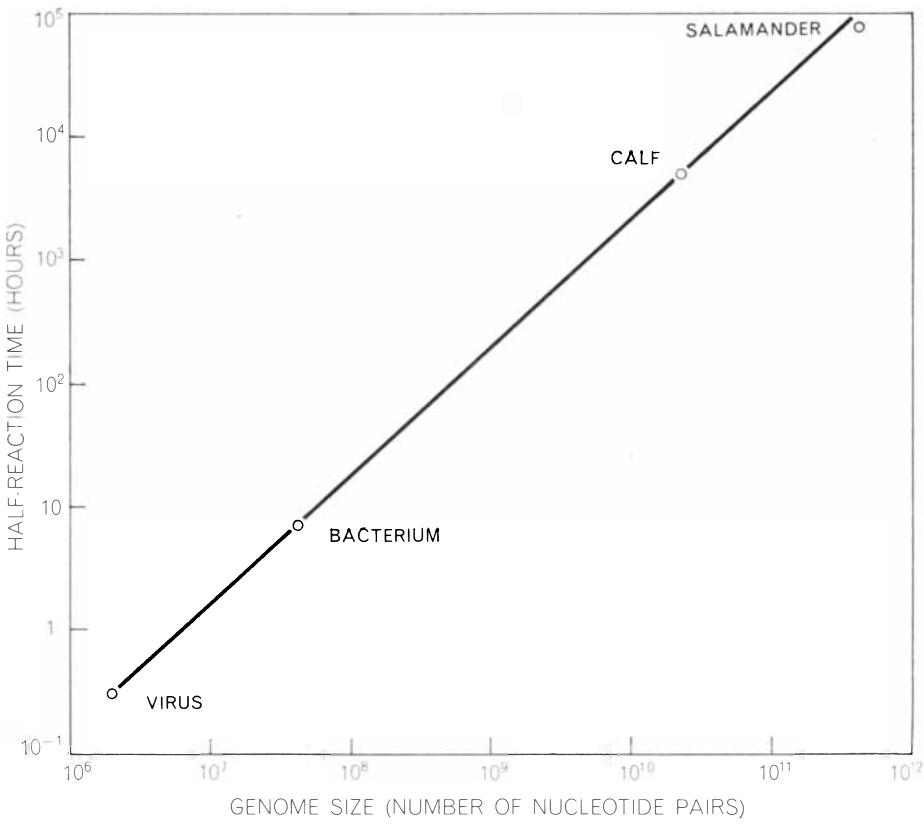
derms, brachiopods, insects, other arthropods, mollusks, coelenterates, sponges, protozoans and plants ranging from algae to wheat. Small quantities may be present in the nuclei of fungi, but here a clear separation from DNA outside the nucleus has not yet been made. Bacteria contain a number of copies of the genes that specify ribosomal RNA, but no other nuclear repeated DNA has been observed in the few species tested. (All species appear to have a few copies of certain special genes such as the genes for ribosomal or transfer RNA, and so one can say that repeated DNA probably occurs universally. The large quantities and high frequencies we are describing, however, appear to occur in species higher on the scale of complexity than fungi.)

The number of DNA segments from one cell that have similar base sequences is the repetition frequency for that set. One can regard the set of different repetition frequencies for each species as a spectrum [*see illustration on page 30*]. These spectra are somewhat tentative in detail, since measurements with adequate technique have just been undertaken; the overall patterns are nonetheless correct, and some of the spectra, such as the spectrum for calf DNA, have been fairly well measured. The repetition spectra show few common features. Calf cells have little or no DNA with frequencies between 10 and 10,000. Toad and snail cells have no families with more than 10,000 members, and their dominant components are in the broad frequency range that is not present in calf DNA. It is too early in the exploration to discern the regularities in frequency spectra that probably exist. For example, it appears that components in the range from 100,000 to a million copies may exist only in the DNA of mammals; each of the mammalian species examined so far has such highly repetitive components, which do not appear even in other vertebrates. Many more measurements are required to establish such generalizations.

It seems likely that repeated DNA originated in past events of DNA replication, each of which produced a family made up of identical copies of some preexisting DNA sequence. Then in the period of time since the original production of the copies a number of things must have happened. Segments were translocated and scattered into various parts of the genome; subunits were substituted and deleted. The traces of such events can be found in the present populations, and the result is that in most cases the members of a family of repeated sequences differ somewhat from one another.

Estimates of the degree of sequence difference can be made from the thermal stability of reassociated DNA, since the imperfectly complementary strand pairs have reduced stability compared with perfectly matched strands [*see top illustration on page 31*]. Typically when the entire population of repeated DNA in one organism is examined, a wide range of thermal stability is seen. Some sequences are quite closely related to others, even to the extent of being perfect copies, whereas other sequences differ so much that the strand pairs barely hold together under mild conditions. In the most divergent examples changes appear to have taken place in as many as half of the nucleotides. We believe all degrees of divergence are present, as would be expected if the processes of production and divergence had been active throughout the evolution of higher species.

When did the events that produced these enormous families occur? Some of them happened a very long time ago, perhaps several hundred million years ago. It is possible to date reasonably well the time in evolutionary history when there lived the last common ancestor of two related but now distinct modern species. This time may be considered, if enough fossils have been discovered and examined, to be the time of divergence of the ancestral lines of species that led to the present-day organisms. Any feature, molecular or morphological, that is now exhibited by both species probably originated before the time of divergence. We assume that any family of repetitive DNA held in common by two species probably originated before their ancestral lines diverged. (There are risks in this assumption where gene flow between species is possible, as it is in plants.) The relation between the fraction of the repeated DNA held in common between species and the time since their species lines diverged can be established [*see bottom illustration on page 31*]. Assuming, as seems reasonable, that in each species line there is production of new families of repeated DNA as preexisting families are slowly lost, the curve can be considered a "decay-of-relatedness curve," by analogy



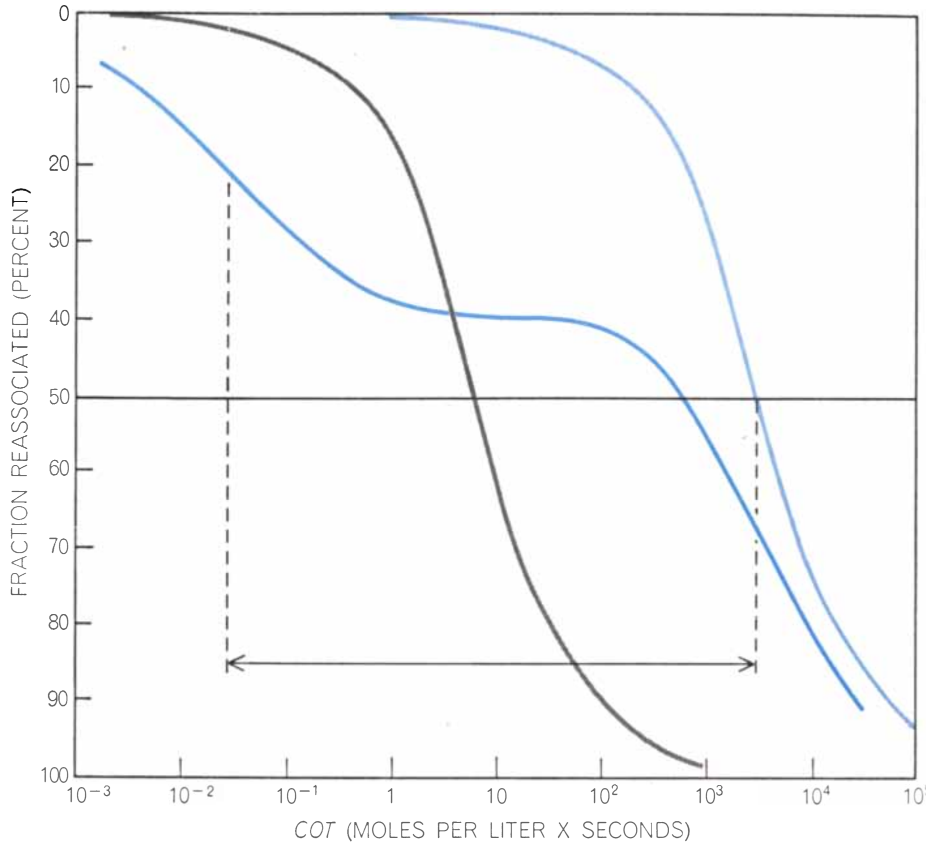
TIME FOR REASSOCIATION of single-copy DNA varies with the size of the genome and therefore increases with the complexity of the organism. Here the time for half-reassociation is plotted against genome size for a virus (T4) and a bacterium (*Escherichia coli*) and for the nonrepetitive DNA of the calf and a salamander, *Amphiuma*. The times shown are for a particular set of conditions; the time can be accelerated by increasing the concentrations of DNA and salt, but for large genomes it is difficult to measure a complete reaction.

with radioactive decay. For the vertebrates shown in the illustration the median age of the repeated families seems to be about 100 million years—the time in which half of the repeated DNA is replaced.

Some of the more abstract but nevertheless fascinating questions about repeated DNA sequences have to do with their organization in the cell. How long are the repeated elements? Do they occur together in the genome? Are they organized in special places in the DNA in keeping with some role in chromosome structure, or are they scattered throughout the DNA?

Several different classes of experiments yield information about the arrangement of the repeated DNA in the genome. One case—perhaps an atypical case—is the mouse satellite DNA, which has recently been studied in much detail by Walker and by William G. Flamm, now at the National Institute of Environmental Health Science, and by others. The sequences of this family are of fairly recent evolutionary origin, having appeared since the ancestral lines leading to the house (or laboratory) mouse and the rat diverged 10 or 20 million years ago. They have been shown to be arrayed in clusters containing as many as 100 copies, and according to recent measurements the clusters appear on many of the chromosomes of the mouse. This family is somewhat exceptional, since it is a very short repeated element present in very many copies and is found in only the one species.

Such detailed evidence is not yet available for any other family of repeated sequences, but there is evidence from a number of species that the repeated sequences are intimately scattered through the DNA. If DNA is prepared in fragments about 20,000 bases long, each fragment is almost certain to include a repeated sequence, and it usually includes more than one. The extent of scattering is known in a little more detail in calf DNA, where three-quarters of the fragments broken down to about 4,000 bases contain segments of repeated DNA.



TIME COURSE of reassociation is shown for bacterial and for calf DNA. The amount of reassociation is plotted against the *COT*, a coined word for the product of DNA concentration and time. The time course for bacterial (*E. coli*) DNA, almost all of which is single-copy DNA, plots as an S-shaped curve (*gray*). If calf DNA were also single-copy DNA, it would plot as a similar curve displaced to the right (*light color*). The actual curve for calf DNA (*dark color*) has a different shape, however. The shape of the curve indicates that the reaction takes place in two different stages, one early and one late; the midpoints of the two stages (*broken vertical lines*) are separated by a factor of 100,000. The early stage represents the reassociation of repeated DNA and the later stage that of single-copy DNA.

One approach to the difficult problem of the function of repeated DNA is to assay the extent to which it is expressed. All the genes of an organism's genome are present in all its cells, and yet many of the genes carry out no function in particular tissues or at particular times. Such genes are said to be unexpressed, whereas those that are active are said to be expressed. The function of many genes is to specify the synthesis of proteins, and the mechanism of these genes' expression is now quite well understood. The first step in the process is the transcription of the base sequence of the DNA into "messenger" RNA by the pairing of complementary RNA bases with the DNA as template. When the messenger RNA reaches the site of protein synthesis, its base sequence supplies information that is translated according to the genetic code to determine the amino acid sequence of the protein. Our interest here is only in the first stage, the synthesis of RNA on the DNA template, as an indication of gene expression. Clearly one can say that a gene is expressed if RNA complementary to one of its DNA strands is synthesized. Therefore a good test for genetic activity is to search for an RNA complementary to the DNA of the gene. In most cases this would be difficult, since preparations of the DNA of particular genes are not ordinarily available. In the case of repeated DNA taken as a whole, however, it is quite easy. The high frequency of repetition increases the rate of RNA-DNA hybridization just as it increases the rate of DNA reassociation. When proper precautions are taken, RNA that hybridizes rapidly with DNA can be assumed to be RNA that was synthesized on a repeated DNA sequence.

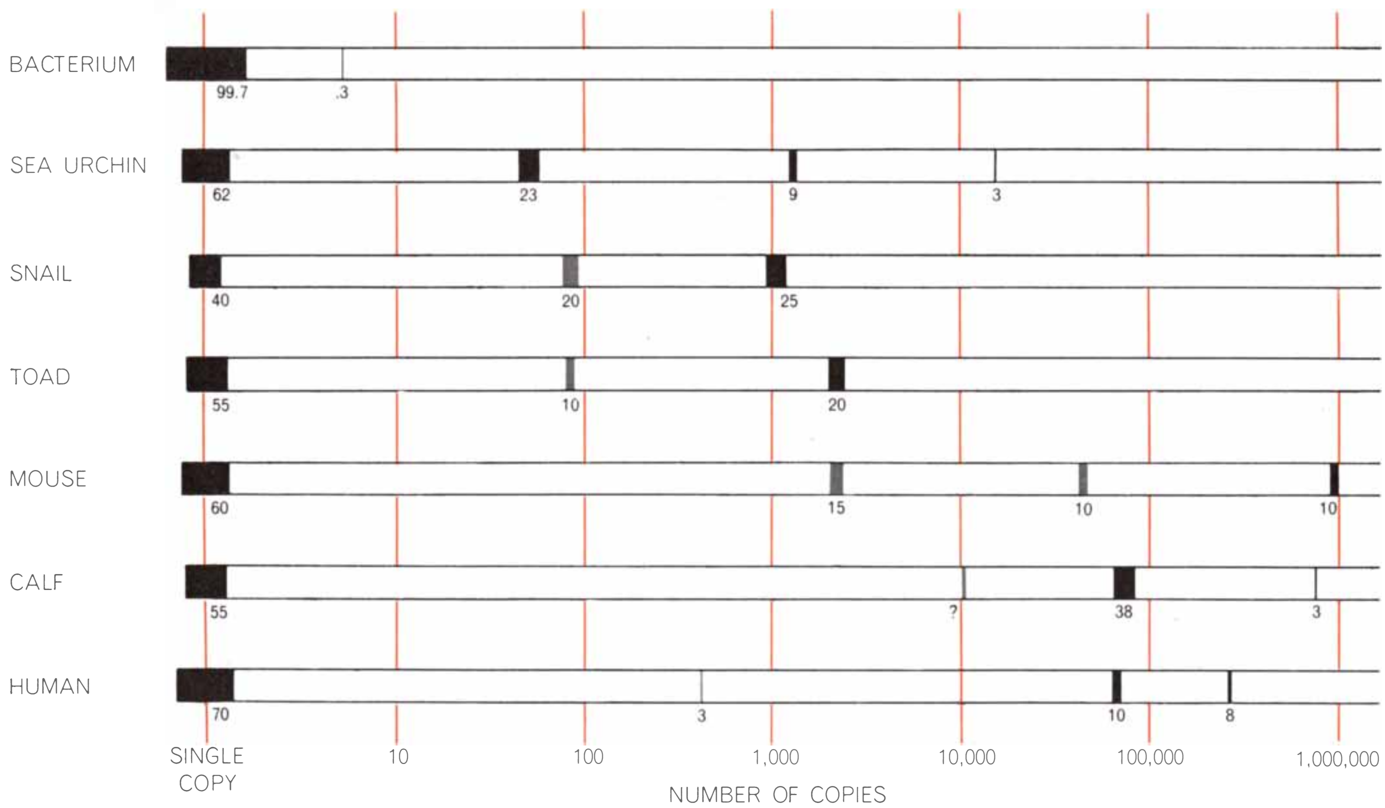
Hybridization experiments have been conducted in a number of laboratories in attempts to learn the mechanism of gene expression and its control. We now know that the limitations of the available techniques restricted the observations to rapidly hybridizing sequences—the sequences involving repeated DNA. The observations therefore made available a large body of measurements of the expression of repeated DNA sequences in a variety of cell types from a number of organisms. These measurements yield two principal results: first, repeated DNA sequences are expressed in every higher organism and cell type that has been examined; second, different families of repeated DNA are expressed in different tissues.

A particularly significant measurement of differences in patterns of expression can be made with a technique called competition. For this purpose RNA from one tissue is mixed at a high concentration with radioactively labeled RNA from a second tissue in the presence of DNA. To the extent that there are similarities between the RNA populations, the unlabeled RNA "occupies" the DNA and prevents the labeled RNA from hybridizing. In this way RNA populations from different tissues and different stages of embryonic development have been compared. In a number of instances the populations of RNA molecules are entirely dissimilar, indicating that the DNA sequences expressed are also dissimilar, that is, they are members of different families of repeated sequences. Why should a particular family of DNA sequences be expressed in an early embryo and not be expressed at a later stage of development? The answer to this question would probably go a long way toward revealing the role of repeated DNA in the molecular machinery of the cell.

The fact that repetitive DNA is expressed (transcribed into RNA) leaves no doubt in our minds about the significance of some of the repeated sequences. That brings us up against the problem of the hundreds of thousands and millions of copies present in the mammals. What role could such very large numbers of copies have? If these frequencies were observed even throughout the vertebrates, one might consider a structural or organizing role for the highly repetitive DNA, but it is unlikely that 1,000 times more copies would be required for such a purpose in the mouse than in, say, the toad. Mammalian chromosomes do not seem to be that much more complex. They have comparable amounts of DNA per cell; in fact, some amphibian cells contain a great deal more DNA than mammalian cells.

Taking the evidence all in all, the large size of some families of repeated DNA is probably best explained if the production of a family of repeated sequences is taken to be an analogue of a more familiar kind of mutation. Repeated sequences could be produced in large numbers "by accident," that is, by an event not directly related to their ultimate function. In the long run, of course, their fate would presumably be determined by natural selection, but for some time a large number of unexpressed copies might remain in the genome. In other words, we are led to the somewhat unorthodox view that a significant part of the DNA in the cell may not have a current genetic function.

We have called the appearance of a family of repeated sequences "saltatory replication" to imply a sudden event of multiplication. The evidence indicates that on an evolutionary time scale the appearance of a family is sudden, although we cannot tell whether the events occur within the lifetime of an organism or are spread over a few million years. Several steps are obviously required. First a segment of DNA must be multiplied; then the copies must be transmitted by heredity. The set of copies must become intimately associated with the chromosomes and ultimately must be linked directly into the principal DNA strands. If that much is accomplished in a small population within the species, this DNA must be transmitted throughout the species over a large number of succeeding generations, presumably by natural selection. Such a process would be inexplicable in neo-Darwinian terms unless some genetic advantage were associated with the family of repeated DNA sequences. We are unable

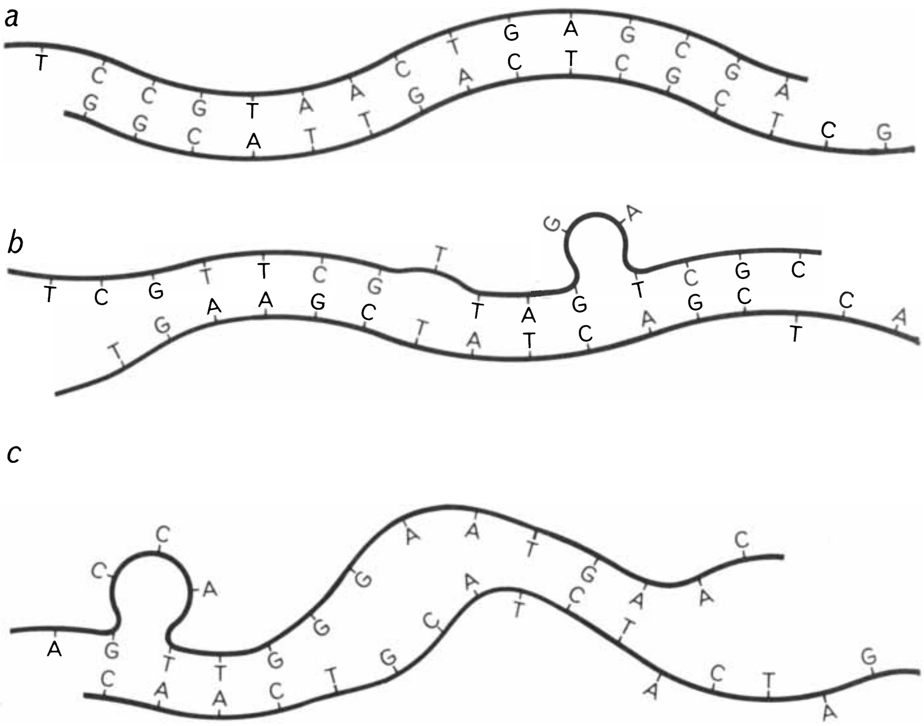


PATTERNS OF REPETITION of DNA sequences are shown in the form of spectra for a number of organisms. Each spectral band represents a repetitive class of DNA that has been identified to date. The width of the band indicates what percent (*given below the band*) of the total DNA is represented by that class. The position of the band indicates the frequency, or number of copies. (*Gray bands are those whose precise frequencies are not known.*) For example, the most repetitive mouse component amounts to 10 percent of its DNA and has about a million copies. Snail and toad data are from Eric H. Davidson of Rockefeller University.

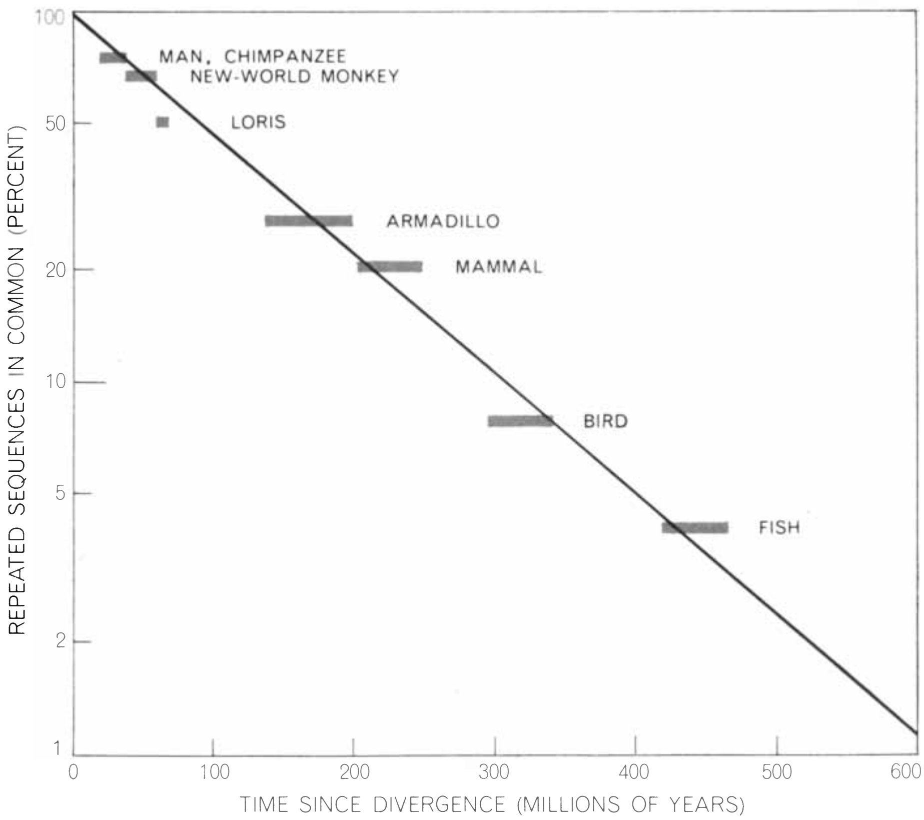
to specify what the advantage might be unless an actual function were already being carried out by the repetitive DNA at the earliest stages of the process.

The time period would be greatly compressed if the saltatory replication were due to a virus infection that swept through a large population. A model for such an event might be the behavior of bacteria that survive a viral infection because they have previously accepted the virus genome into an integrated, or lysogenic, state within their own chromosome and by so doing have achieved immunity to the virus. Cellular resistance to virus infection by this kind of mechanism has not been clearly demonstrated in animals. The transformation of animal cells by viruses, however, is well known, and in many cases it may be due to the integration of the viral genome with the host chromosomes. Even so, there is no reason to expect that an enormous number of copies would be involved. It is therefore merely possible—not likely—that an infection of some kind is responsible for the transmission of a family of repeated sequences to all the surviving members of a species.

Obviously we do not understand how a family of repeated DNA originates, but such families exist, and they must have originated somehow. What can be said of their subsequent history? We know that some of the sequences have become functional because RNA complementary to them is produced. We do not know when in their history the useful attributes were developed, how many of the members of a family of sequences are utilized or what function they carry out. It is clear, however, that the families of repeated sequences evolve and that the sequences change slowly. It is even possible to estimate the rate of change. Estimating the "decay of relatedness" is one approach, and more elegant methods are now available. Fairly good estimates can be made of the actual rate of base substitution in DNA by measuring the stability of strand pairs hybridized between chosen species. Such measurements have only been started and no broad generalizations can yet be drawn, but we should soon know whether or not natural selection operates to conserve the sequences of some of the members of a family while allowing others to change at a more rapid rate. We now know a little about the history of repetitive sequences and we possess techniques to learn a great deal more, but a comprehensive set of measurements is needed that will require much work at many laboratories.



STABILITY of reassociated DNA depends on how well the two strands are hydrogen-bonded, which depends in turn on the extent to which the two strands are composed of complementary base sequences. In native DNA or in two strands from identical copies of a repetitive DNA all the bases match and the strand pair is quite stable (*a*). If some bases do not match, the stability is reduced (*b*), and if many are mismatched, the stability is poor (*c*). The stability of DNA can be determined by measuring its dissociation temperature.



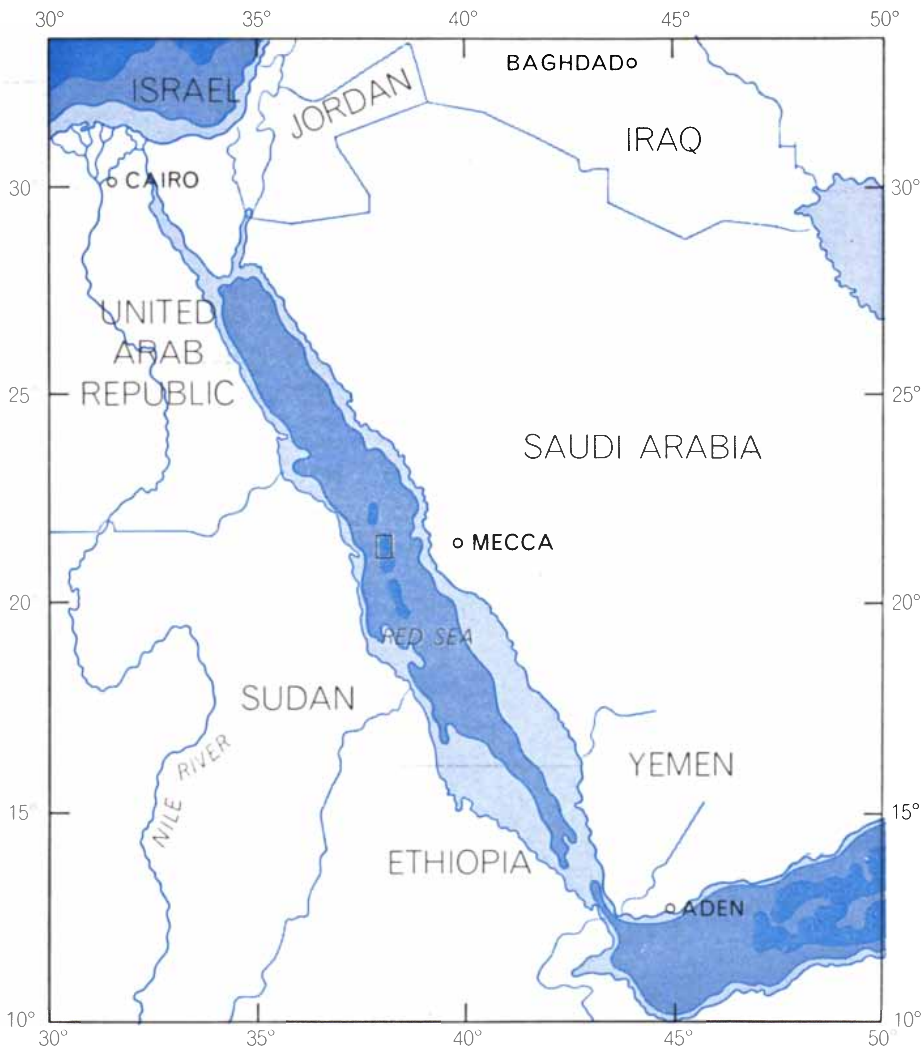
RELATIONSHIP between the similarity of repeated-DNA sequences and evolutionary history is shown, based on measurements made by Bill H. Hoyer, Brian J. McCarthy and Ellis T. Bolton of the Carnegie Institution. Vertical scale shows the fraction of repeated sequences held in common by the DNA of the rhesus monkey and that of other animals. The time of divergence of species lines leading to the rhesus and to other modern species is plotted on the horizontal scale. ("Mammal" refers to nonprimates other than armadillo.)

The Red Sea Hot Brines

Three pools of very salty hot water have accumulated at the bottom of the Red Sea. The sediments in these pools are rich in minerals deposited from the brines

by Egon T. Degens and David A. Ross

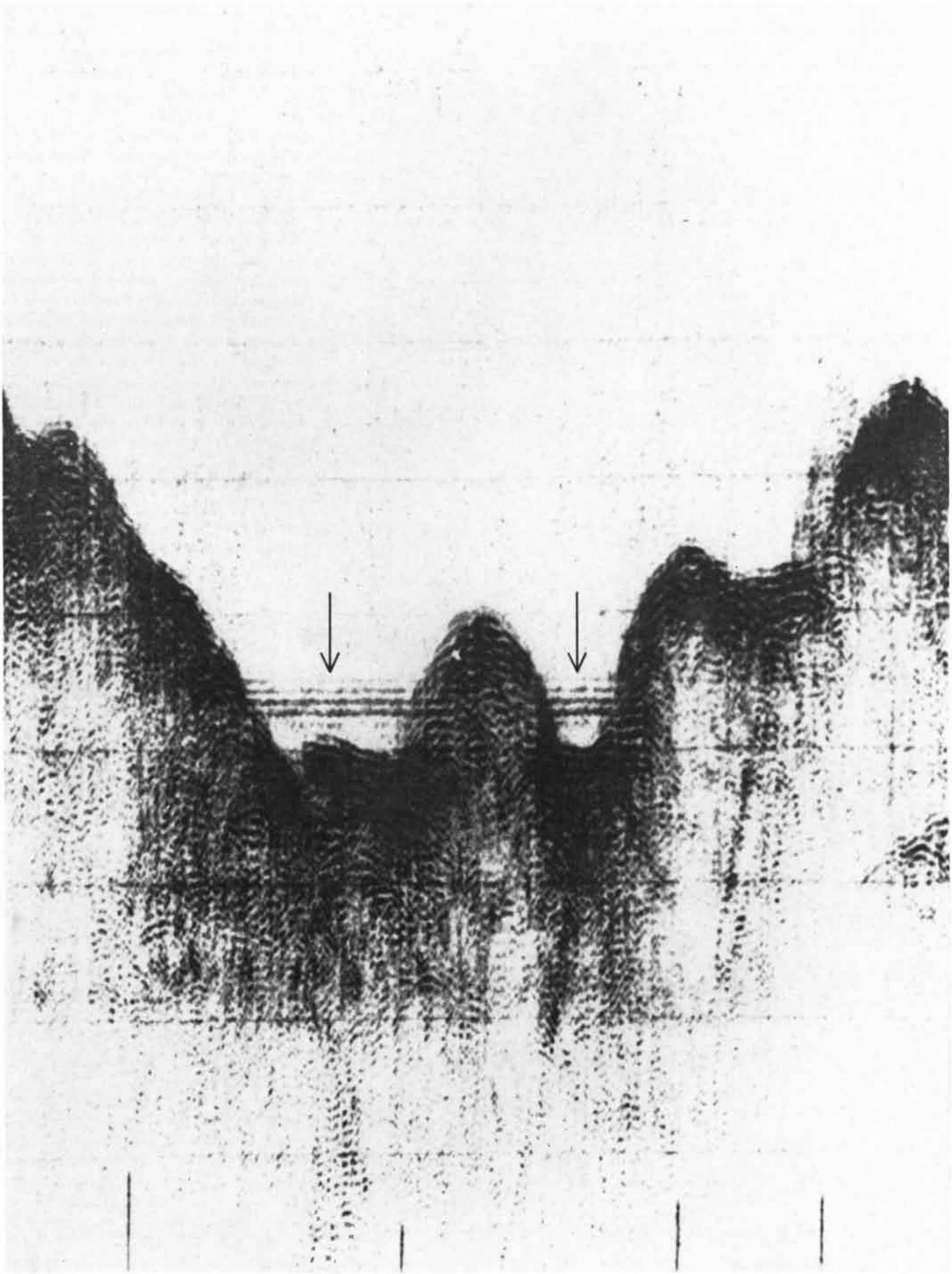
At the bottom of the Red Sea lies one of the world's most bizarre marine environments: three deep pockets filled with water that reaches a temperature of 133 degrees Fahrenheit and is nearly 10 times saltier than the sea above it. The existence of these hot brines had been suspected since the 1880's, but they were not studied in detail until 1966. In that year the research vessel *Chain* of the Woods Hole Oceanographic Institution was the spearhead of an investigation that before its completion involved some 70 workers from eight nations: physicists, chemists, geologists, hydrologists, biologists and geophysicists (including the authors of this article). It almost goes without saying that we are indebted to our colleagues for many of the findings presented in this account of the investigation.



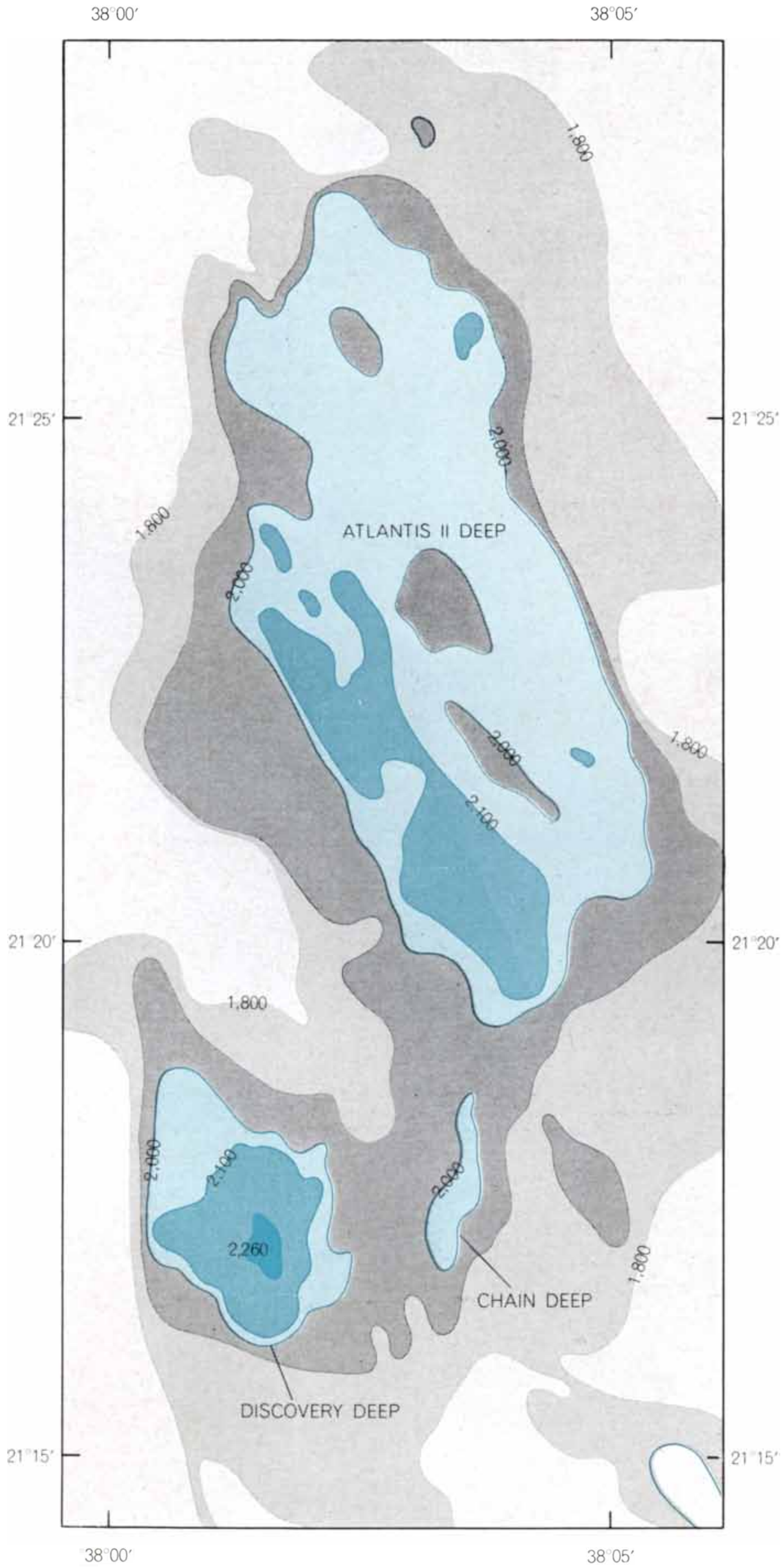
HOT BRINE POOLS lie close together near 21 degrees north latitude, on the crest of the mid-ocean ridge that divides the Red Sea into almost equal eastern and western halves.

A brine can be defined as anything saltier than ordinary seawater. In this sense the Red Sea itself is a gigantic pool of warm brine. Oceans on the average rarely contain more than 35 parts of dissolved salts in each 1,000 parts of water. Even the surface water of the Red Sea is nearly 10 percent saltier than that: its salinity is 38 parts per 1,000. Moreover, its surface temperature approaches 75 degrees F., compared with the ocean average of 55 degrees F. These abnormally warm and salty conditions are due mainly to two factors. First, the Red Sea is a tropical body of water: two-thirds of its 1,000-mile length lies south of the Tropic of Cancer. Second, the Red Sea has only one outlet (into the Indian Ocean), and there is only a limited exchange between the two bodies of water. The reason is that at its southern end the bottom of the Red Sea rises to a depth of only 400 feet below the surface. (The maximum depth of the sea is nearly 10,000 feet.) As a result the entire Red Sea is an evaporation pool. In the geologic past, when a lowering of the sea level isolated it from the Indian Ocean, the Red Sea came to be even saltier than it is today.

The fact that water in an area around 21 degrees north latitude is hotter and saltier than the water elsewhere in the Red Sea seems to have been first noted in the early 1880's, when workers aboard the Russian survey vessel *Vityaz* took water samples in this area at a depth of about 2,000 feet. Some years



FALSE ECHO, characteristic of a brine pool, is shown as groups of parallel horizontal lines (*arrows*) that appear at a depth of 2,000 meters in this seismic profile across the brine zone. The difference in density between seawater and brine produces the effect.



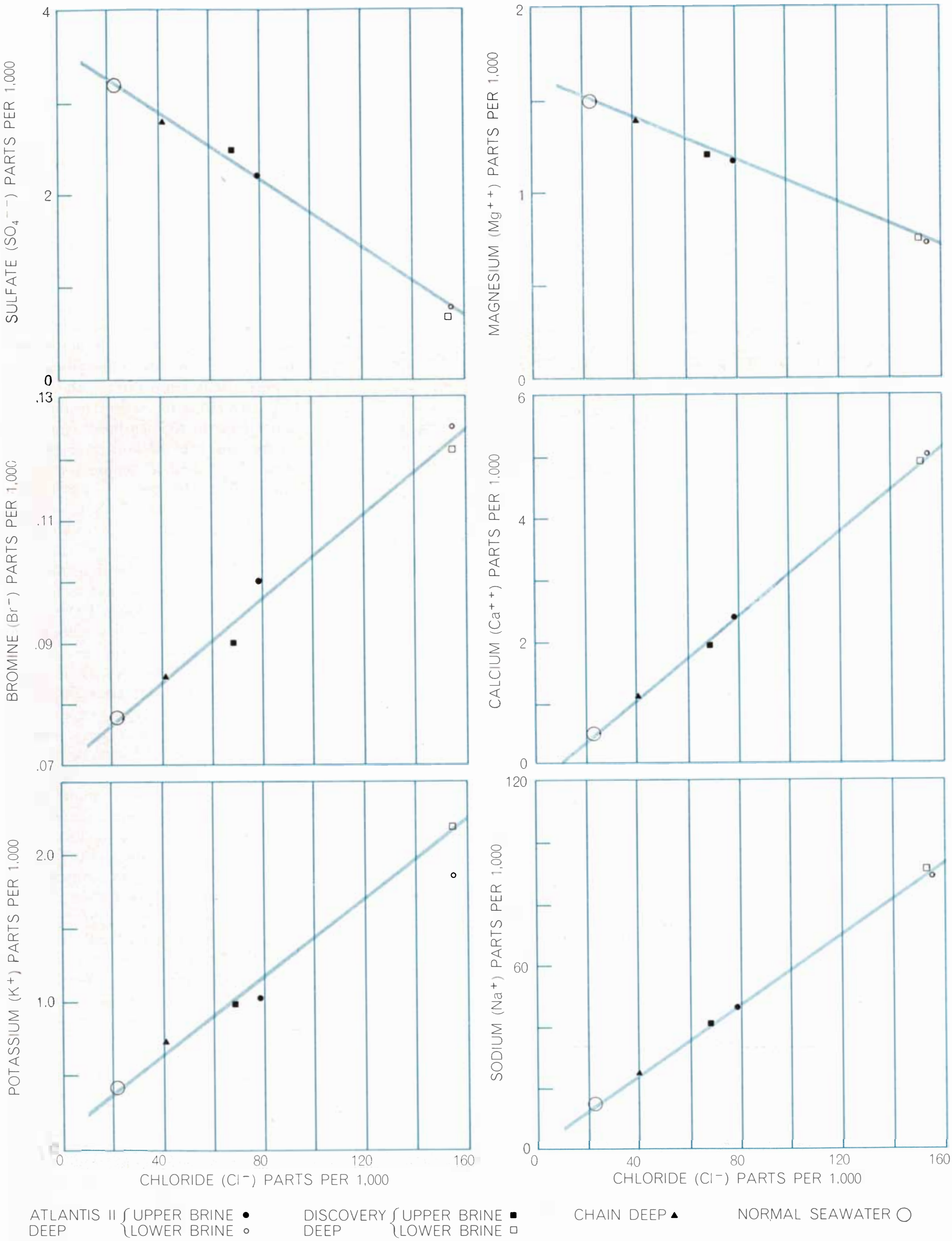
BRINE has accumulated below the 2,000-meter contour in three areas (*color*). The Chain Deep is the smallest of the three and the Discovery Deep is the deepest. Both evidently acquire new brine from the Atlantis II Deep when the brine there rises and overflows. Bottom contours have been simplified in this chart, and no details appear above 1,800 meters.

later the Austrian ship *Pola* (1897) and the German vessel *Valdivia* (1898) took samples in the same general location but at the greater depth of 6,500 feet and observed similar conditions. Subsequently the Swedish *Albatross* expedition of 1947 and 1948 and the Woods Hole Institution's *Atlantis* voyage of a decade later reported an increase above normal in water samples from the area of more than five degrees F. in temperature and of five parts per 1,000 in salinity.

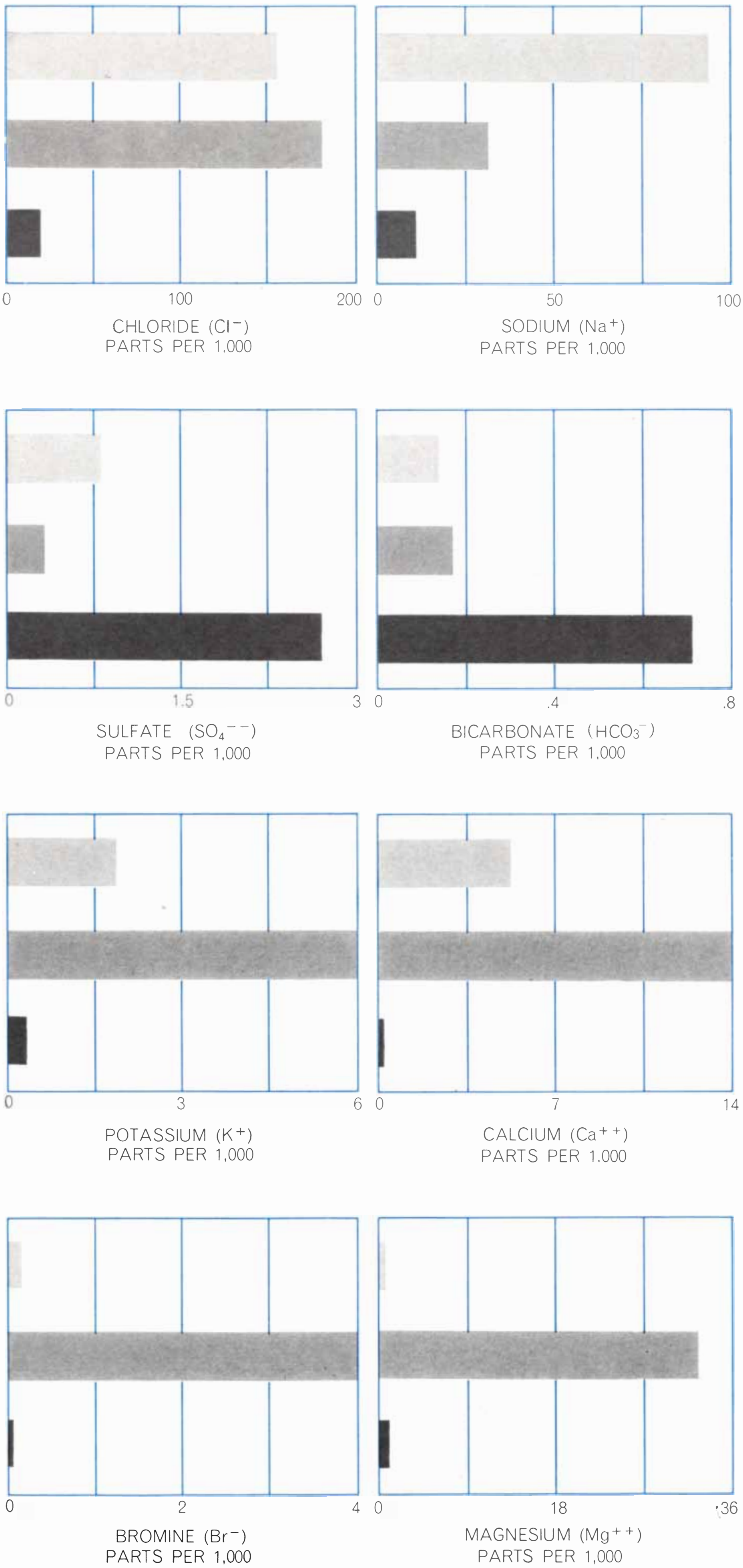
Before 1964 the usual explanation of these findings was that, since evaporation predominates over precipitation in the Red Sea, the saltier, denser surface water that forms by evaporation in coastal shallows drains continuously into the sea's central deeps, increasing the salinity of the deeper water. In that year, however, the British research vessel *Discovery* collected water samples with a temperature of 44 degrees Celsius (111 degrees F.) and a salinity of 256 parts per 1,000 from an area that has since been known as the Discovery Deep. It was virtually impossible that evaporation was the cause of such extreme temperature and salinity.

The Woods Hole vessel *Atlantis II* was four days behind schedule en route to the Indian Ocean when it passed through the Red Sea in the summer of 1965. Although time was short, no one aboard could resist the temptation of taking at least one water sample from the Discovery Deep. Moreover, the geologists aboard were eager to collect samples of the sediments at the bottom of the brine pool. The sampling procedure normally takes only two or three hours; what can be far more time-consuming is making sure that one is over the right spot.

We finally positioned ourselves over the Discovery Deep, but to our dismay before we could complete the lowering of our sampling devices the *Atlantis II* began drifting to the north. Our motion fortunately carried us across a hitherto undiscovered brine pool, which was promptly named the Atlantis II Deep. It was slightly shallower than the Discovery Deep but considerably hotter. Its water temperature was 56 degrees C. (133 degrees F.) and the sediment sample—a black ooze that had the physical appearance of tar—was too hot to touch. Later analysis showed that the sediment contained a mixture of metal compounds, principally oxides and sulfides of the metals iron, manganese, zinc and copper. After taking the samples we resumed our voyage, but we were determined to return to the brine area in the



SIX DISSOLVED SUBSTANCES are present in differing proportions in the Red Sea brines. When arrayed according to the chloride content of each brine, the differences assume linear relationships. As the quantity of chloride increases, the number of sulfate and magnesium ions in solution decreases; both are less abundant in the brines than they are in normal seawater (*the quantity shown at the extreme left in each graph*). The opposite is true of bromine, calcium, potassium and sodium. The bottom brine layer in the Atlantis II Deep is the saltiest of the five, but the bottom layer in the Discovery Deep is almost its equal in parts of salts per 1,000.



Chain the following year for a more detailed survey.

Aboard the *Chain* in 1966 we added to our knowledge of the brine pools. The Atlantis II Deep proved to be the largest of them, embracing about 30 square miles of bottom that is centered on the mid-ocean ridge that divides the Red Sea into almost equal eastern and western parts. It contains three distinct layers of brine. The top layer, lying a little below 2,000 meters, is a well-mixed, homogeneous brine 28 meters thick; its temperature is 44 degrees C. (111 degrees F.) and its salinity is 135 parts per 1,000. Below it lies a five-meter transition zone, characterized by a quick rise in temperature. The bottom layer, which at its deepest extends for 150 meters to the sea floor, is also homogeneous. It is the hottest and saltiest of all the brines: its temperature is 56 degrees C. (133 degrees F.) and its salinity 257 parts per 1,000 (only 13 parts per 1,000 less than the saltiest water known in nature, at the bottom of the Dead Sea). It is possible that still a third thin layer of brine may exist undetected near the bottom of the Atlantis II Deep.

The Discovery Deep is smaller but almost as complex in structure. Its area is nine square miles and its maximum depth is a little more than 2,200 meters. Its brines form two homogeneous layers. The top layer, which begins a little below 2,000 meters and extends to 2,027 meters, has a temperature of 36 degrees C. (97 degrees F.) and a salinity of 127 parts per 1,000. The bottom layer is the same temperature as the top layer of the Atlantis II Deep (44 degrees C.), but the bottom layer is much saltier. With a salinity of 256 parts per 1,000, it is only one part per 1,000 less saline than the bottom layer of the Atlantis II Deep. From the fact that two brines of the same temperature have different salinities we conclude that there is currently

ABUNDANCE of eight substances in three different waters is seen in the illustration at left. The three are the bottom brine in the Atlantis II Deep (*top bar*), the bottom brine in the Dead Sea (*middle bar*) and normal seawater (*bottom bar*). Evaporation, a process at work in the Dead Sea, sharply increases the concentration of calcium, bromine, potassium and magnesium in a brine but has a lesser effect on sodium. The Red Sea hot brine is far richer in sodium than brine from the Dead Sea but is comparatively depleted of the other four salts. Thus it is evidently not a product of evaporation.

no exchange of brines between the two deeps.

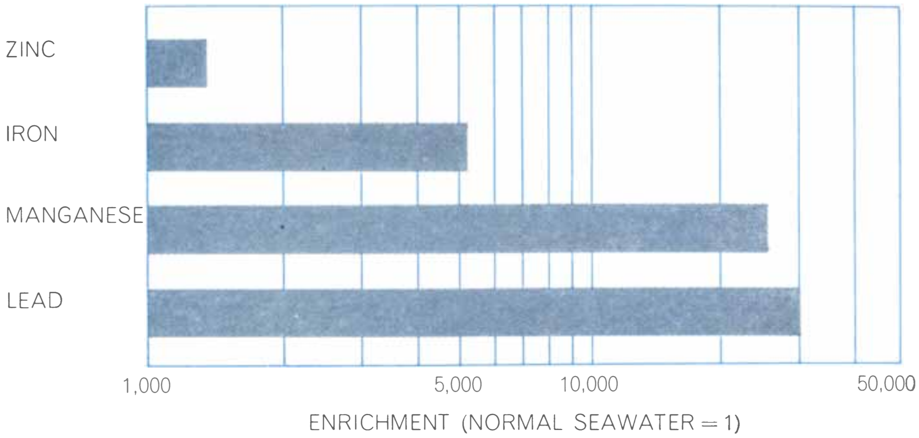
The hot brine area has a third deep that was discovered during our 1966 voyage and was accordingly named the Chain Deep. It is the smallest of the three deeps; its area is less than two square miles and like the Atlantis II Deep it is a little deeper than 2,000 meters. The smallness of the Chain Deep made it difficult to study, but we recorded a maximum temperature of 34 degrees C. (93 degrees F.) and a maximum salinity of 74 parts per 1,000. As with the Discovery Deep, this suggests to us that the Chain and the Atlantis II deeps are not now connected.

It is possible that the Red Sea harbors hot brine areas other than these three, although we explored the immediate vicinity without finding any others. Samples of bottom sediment that we collected about 150 miles north of the three deeps were much enriched in iron, however, suggesting that hot brine conditions may have existed there 100,000 years ago. In 1967 the research vessel *Oceanographer,* cruising some 400 miles to the north of the three deeps, recorded the presence of a sound-reflecting layer of water near the sea floor. Similar sound reflections are characteristic of the pools we studied, so that the *Oceanographer* observation may indicate another one.

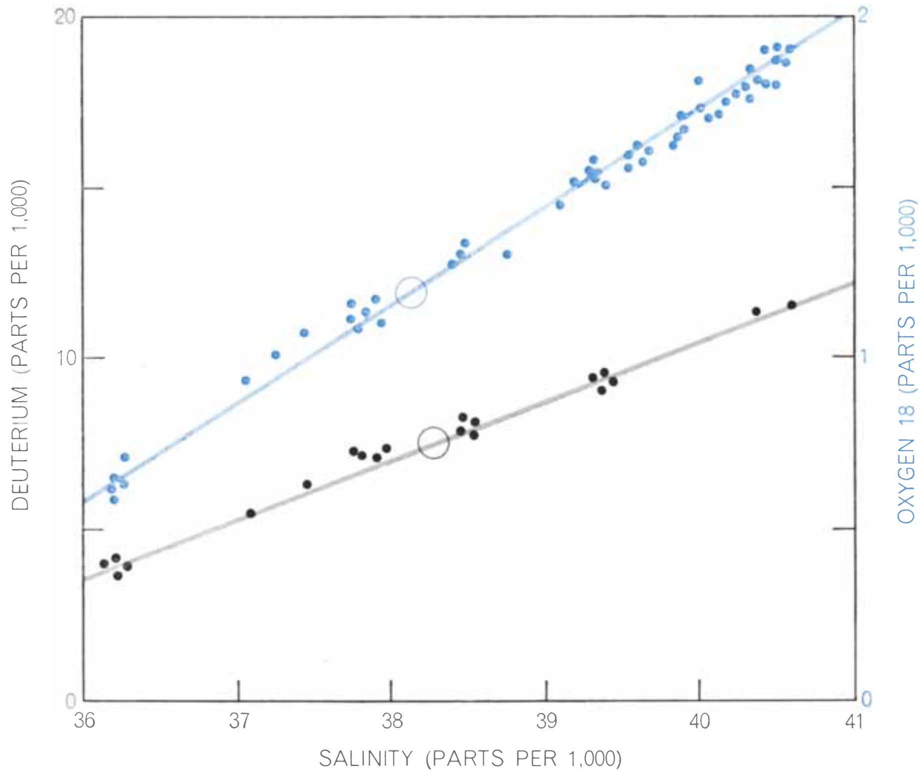
The term "salinity" is normally taken to mean that the proportion of the various elements in seawater remains the same regardless of the total salt content. This is not at all true of the hot brines. Compared with typical seawater the brines contain nine times the normal amount of sodium but somewhat less than the normal amount of magnesium. The concentration of elements in solution in each of the three deeps also varies considerably. When these values for the various brine layers are plotted against the increase in chloride concentration, some linear relationships become apparent [*see illustration on page* 35]. The best explanation of these relationships is that the less concentrated brines are the result of the mixing of normal Red Sea deep water (which has a salinity of about 40 parts per 1,000) in various proportions with the concentrated bottom brine in the Atlantis II Deep.

The most striking chemical feature of the brines is that they contain concentrations of various trace metals that are roughly 1,000 times greater than the concentrations found in normal seawater. At the same time the chlorine content of the brines shows only an eightfold increase. These concentrations are not uniform among the brines. The bottom Atlantis II brine, for example, contains no oxygen, so that the metals dissolved in it are not subject to oxidation but remain in a reduced state. As a result the metals stay in solution and the brine contains 5,000 times more iron, 25,000 times more manganese and 30,000 times more lead than normal seawater [*see illustration above*]. Oxygen is present, however, in the top brine of the Atlantis II Deep and the top and bottom brines of the Discovery Deep, with the result that they contain less metal in solution. Part of their iron and manganese has been oxidized, forming colloids that have settled to the sea floor. As these colloids sink they scavenge some of the other trace metals—copper, lead and zinc—from the brine, lowering their concentration too. Other reactions (which are also the result of oxidation-reduction processes) have led to the formation of iron silicates, of iron and manganese carbonates and of various sulfides of iron, zinc and copper.

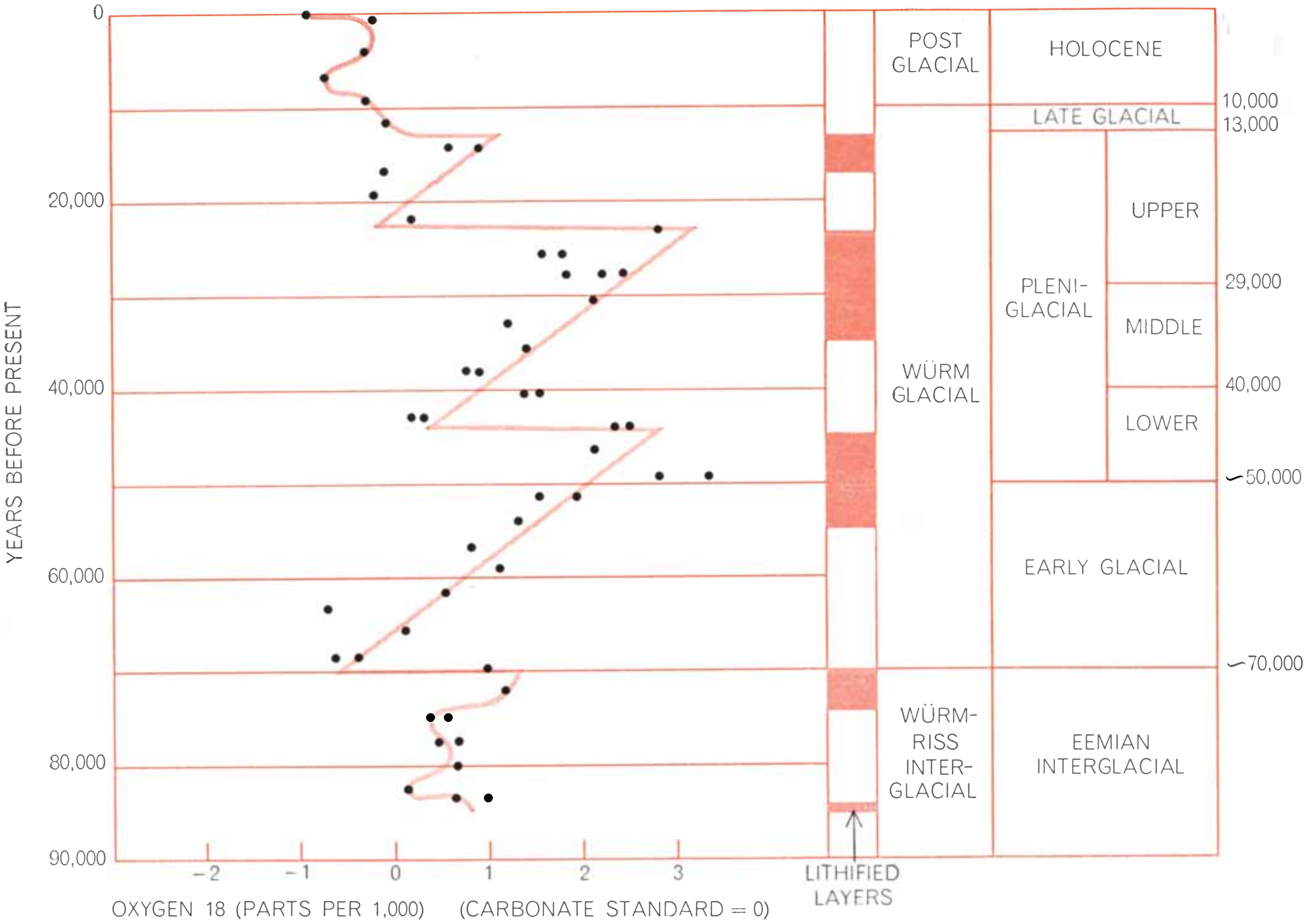
The chemical composition of the hot



METAL ENRICHMENT of the oxygen-depleted bottom brine in the Atlantis II Deep ranges from 1,500 times the amount of zinc in seawater to 30,000 times the amount of lead.



SOURCE of the Red Sea hot brines is suggested by the heavy isotope content of seawater that in general increases as salinity increases. Deuterium (*black dots*) and oxygen 18 (*colored dots*) in the brines equal the amounts in Red Sea water with a salinity of 38.2 parts per 1,000. Water with this average salinity is found only in the southern part of the Red Sea.



SALINITY CHANGES in the Red Sea over the past 70,000 years are reflected in changes in the amount of the isotope oxygen 18 incorporated in the fossils of foraminifera found at different depths in bottom sediments. Four slow rises to peak salinity are evident, followed by four abrupt declines. Stony layers of microfossils coincide with periods of high salinity. The cycles appear to be controlled by a glacial mechanism. The isotope values shown represent deviation with respect to ocean-water standard in parts per 1,000.

brines destroys once and for all the theory that they owe their origin to evaporation. Evaporation is a process that increases the concentration of highly soluble elements such as potassium, calcium, magnesium and bromine. The degree to which evaporation will increase the sodium content of a brine, however, remains comparatively small. One of the world's finest examples of a brine formed by evaporation is the water of the Dead Sea. When one compares the proportion of these and other elements in normal seawater, in the hot brines and in Dead Sea water, the differences are striking [*see illustration on page 36*]. Magnesium is seven times more plentiful in the Dead Sea than it is in normal seawater or the hot brines; bromine is eight times more plentiful. Dead Sea water contains more than twice the amount of calcium and potassium found in the hot brines. With respect to sodium, however, the hot brines outweigh Dead Sea water three to one. The brines simply cannot be evaporation products.

This chemical analysis is no help in the search for an alternative origin of the brines. For this we must turn to the brines' content of two heavy isotopes of oxygen and hydrogen: oxygen 18 and deuterium (hydrogen 2). As a rule evaporation systematically increases the amount of these isotopes in a body of water because the water vapor tends to carry off the lighter isotopes and leave the heavier ones behind. Water vapor, however, is the source of all the earth's precipitation. The result is that fresh water is poor in oxygen 18 and deuterium, whereas seawater is relatively rich in them. Moreover, the saltier the water is, the richer it usually is in these heavy isotopes.

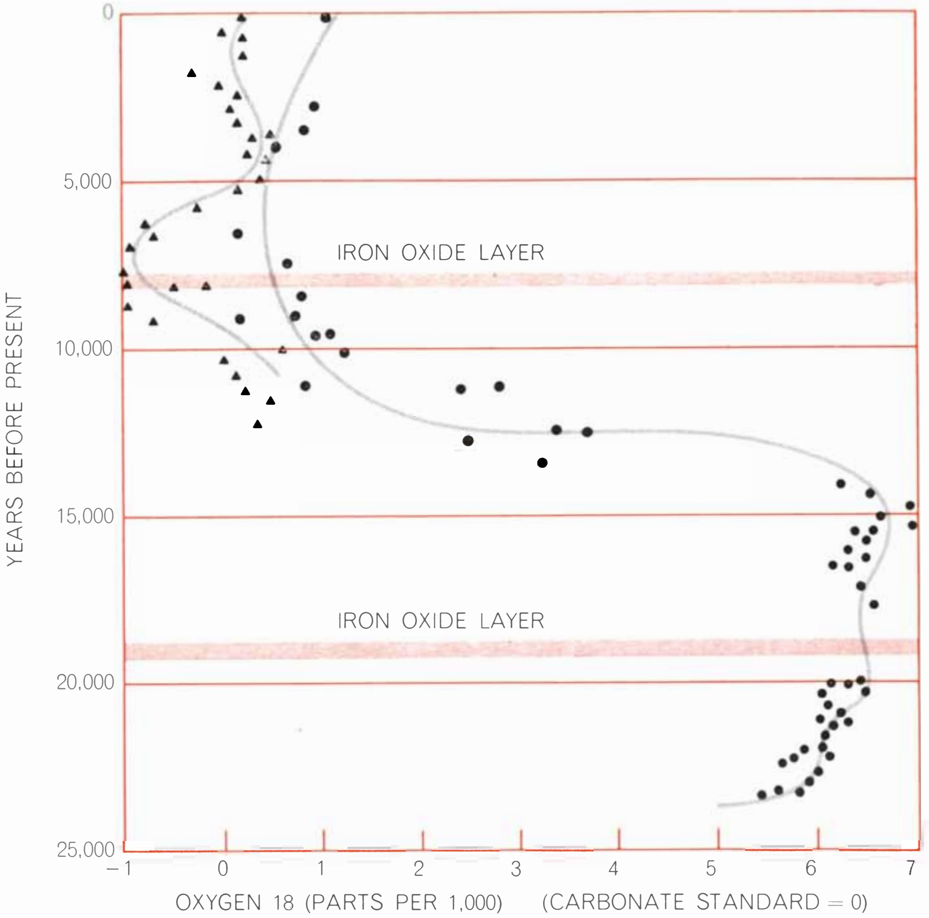
When the isotope content of the brines is compared with the isotope content of other Red Sea waters with various salinities, the result is surprising. Although the brines are almost 10 times saltier than the saltiest normal Red Sea water, their isotope enrichment is not as great as that of many parts of the Red Sea. Indeed, it is equal to the enrichment of water with a salinity of 38.2 parts per 1,000, a level that is relatively low for the Red Sea [*see bottom illustration on preceding page*]. This fact is informative. For one thing, it rules out fresh water as a possible source of the brines. There is no need to speculate that water-bearing rock strata are leading rainfall from the African or the Arabian mainland out to the middle of the Red Sea. Nor can the brines come from "juvenile water": the previously uncirculated water that is brought to the surface by volcanic magmas. Juvenile waters exhibit different isotope relations. Only one other possibility exists: the brines must be derived from the Red Sea itself. The source cannot, however, simply be the seawater that overlies the deeps. What, then, is it? Fortunately the isotope content of the brines offers a clue to their point of origin, and their phenomenal content of salts and metals suggests what route they have traveled.

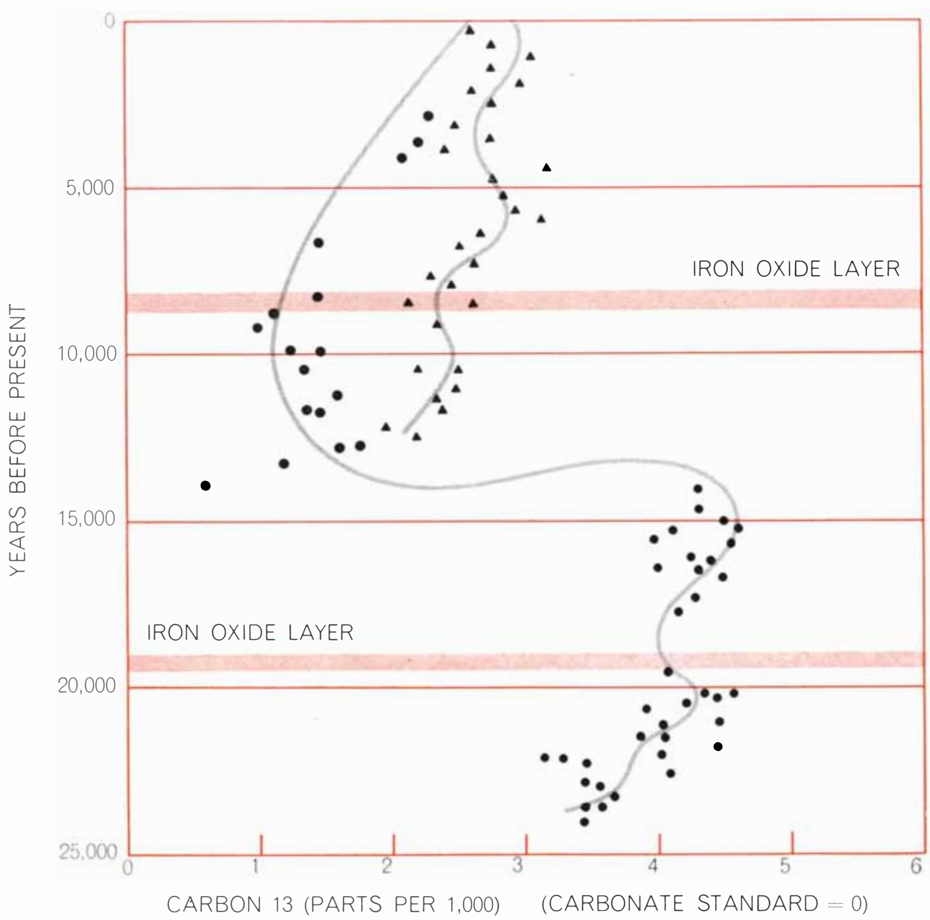
The only part of the Red Sea that matches the brines in isotope content is an area near its southern end, several hundred miles distant from the brine pools. If seawater from this area is the source of the brines, it must travel downward and northward through the rocks below the sea floor for as much as 600 miles before reaching its destination [*see illustration on page 41*]. In doing so it could easily acquire its content of salts and metals by leaching them out of the rock formations through which it percolates. What evidence do we have that the water actually travels this long route? The isotopes of the brine enable us to define the conditions of its journey, but in a somewhat negative way.

The original isotope content of water that passes through a rock formation can be altered by two circumstances. One is exposure to extreme temperature; the other is storage in the rock for prolonged periods. In either case atoms and molecules are exchanged between the water and the rock, causing shifts in the water's content of oxygen 18 and deuterium. If we are correct in assuming that distant Red Sea water is the source of the brines, the unaltered isotope content of the water tells us two things about its journey. First, in its percolation through the basement rock the water has remained below the temperature that encourages atomic and molecular exchange. Second, the time required for the journey has been at most a few thousand years.

A more positive kind of evidence is found in the record of past history that is written in the sediments of the Red Sea floor. Marine deposits more colorful than the spectrum of blacks, blues, reds, yellows and whites in the cores taken from the Atlantis II Deep would be hard to find. The color, texture and mineral composition of these sediments and their alternating layers of two contrasting classes of materials illuminate the origin and evolution of the brines. One class consists of materials that have entered the deep from the outside: quartz, feldspar and clay, for example, that are brought to the sea in runoff from the land, and the calcareous debris of dead marine organisms. The other class is generated entirely within the brines themselves. It consists of various metal compounds: sulfides, sulfates, carbonates, silicates and oxides, principally of iron, manganese, zinc and copper.

Cores from the sea floor outside the brine deeps also reflect the past. The remains of marine life contained in the cores, such as the tiny skeletons of foraminifera and the shells of pteropods, are of particular importance. The oxygen-18 content of the calcium carbonate

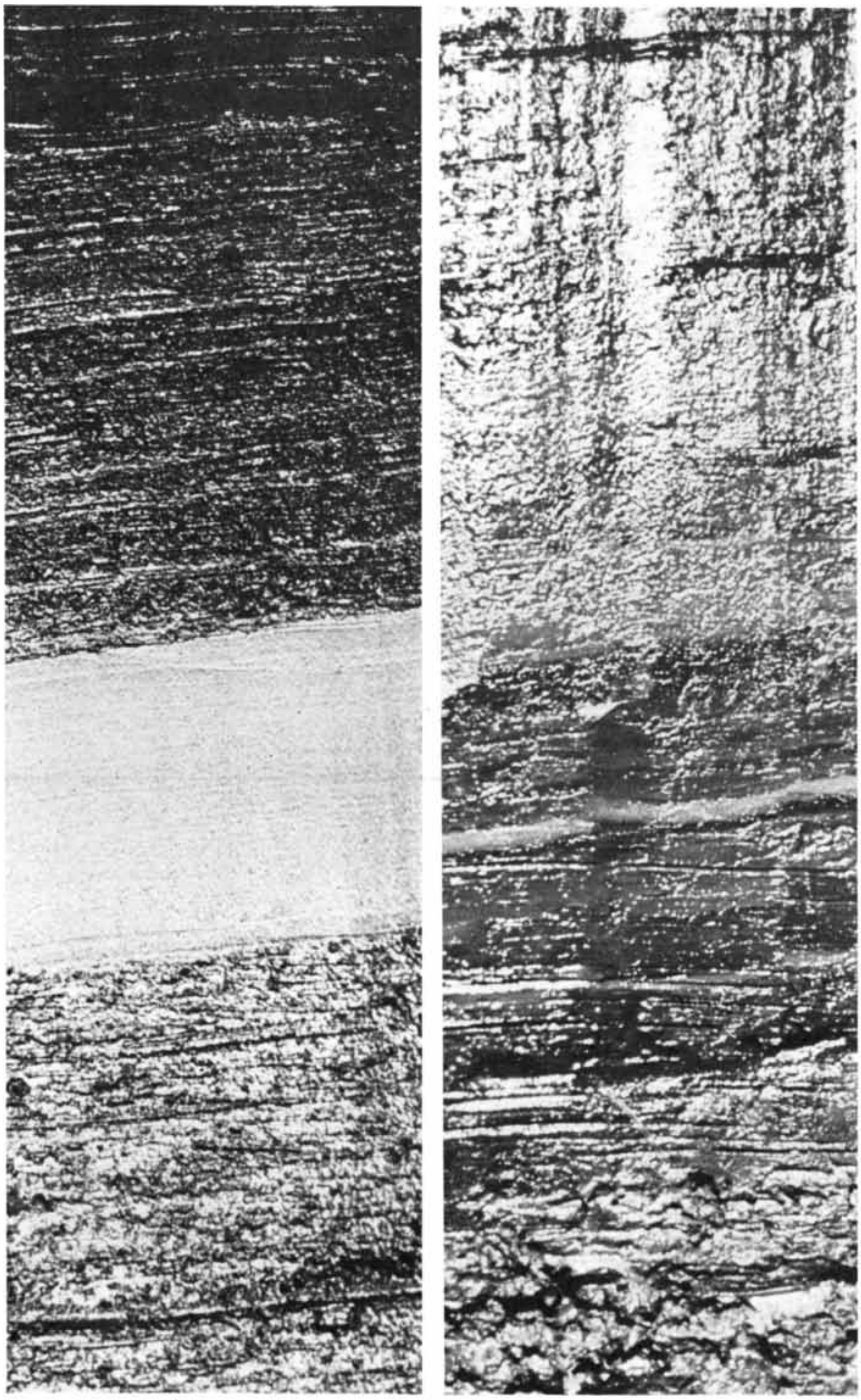




TWO BRINE OVERFLOWS, 8,000 and 19,000 years ago, are indicated by layers of iron oxide (*color*) in Red Sea bottom cores. Both came some 5,000 years after an abrupt decline in salinity, shown by the amount of oxygen 18 (*top graph*) and carbon 13 (*bottom*) in pteropods (*dots*) and foraminifera (*triangles*). Values are deviations from a carbonate standard.

that forms these fossils reflects the temperature and salinity of the water the animals lived in, so that the fossils preserve a record of changes in the Red Sea's temperature and salinity over the past 100,000 years.

Combining all these sources of information, it appears that during the past 70,000 years there have been four periods when the Red Sea has been saltier than usual [*see illustration on page 38*]. These cycles of salinity seem to have been controlled by the advance and retreat of the great continental glaciers.



BOTTOM CORES from the Atlantis II Deep show the interbedding of different materials that is characteristic of the brine-pool sediments. The pale band at the middle of the left core is composed of detritus from sources outside the pool. The darker areas above and below are sulfides of iron that have precipitated from the brine. The core at right shows a thick layer of detritus above a series of fine bands. These are layers of iron oxides and iron carbonates precipitated from the brine, alternating with additional layers of detritus.

A little more than 70,000 years ago, approximately at the end of the Würm-Riss interglacial period, there was a minor increase in salinity. Thereafter two peaks of extreme salinity occurred, followed by a lesser increase. Each period was characterized by a long interval of gradually rising salinity followed by an abrupt decline. Stony layers of pteropod shells filled and encrusted with the mineral aragonite are found in the sea-bottom cores; these layers were formed each time the Red Sea began to approach peak salinity. The subsequent quick declines in salinity, we believe, mark the times when the connection between the Red Sea and the Indian Ocean, which had been partly or completely cut off during periods of rising salinity, was reestablished and a free exchange of waters between the two could resume.

What seems to have happened on these four occasions was that so much water was stored in the glaciers that the level of the oceans was depressed below the shallows at the southern end of the Red Sea. Cut off from the Indian Ocean, the sea began to dry up. If it did so at today's rate of evaporation, it would have been some 500 feet lower before a century had passed. At this rate the part of the sea floor that is presumably the feeder zone for the brines would soon have been high and dry, and the flow of seawater to the brine area would have stopped. When the glacial control mechanism next allowed the ocean level to rise, water would again have covered the sea floor near the shallows, and the flow to the brine zone would have resumed. A few thousand years would have been required to empty or refill the "pipeline" between the feeder zone and the brine area.

Evidence that the water supply to the brines has been turned off and on in the past strengthens the argument that the source of the brines lies in this part of the Red Sea. The evidence is contained in two sea-bottom cores. One is from a small depression some three miles south of the Chain Deep; the other is from the summit of an elevation within the Atlantis II Deep that reaches up some 200 feet into water of normal salinity. Each of the cores shows two layers of iron oxide, deposited about 8,000 and 19,000 years ago respectively. To judge from the small amount of material from external sources associated with them, the layers formed quickly. They could not have formed at all, of course, unless the areas where they were deposited had been submerged in brine at the time.

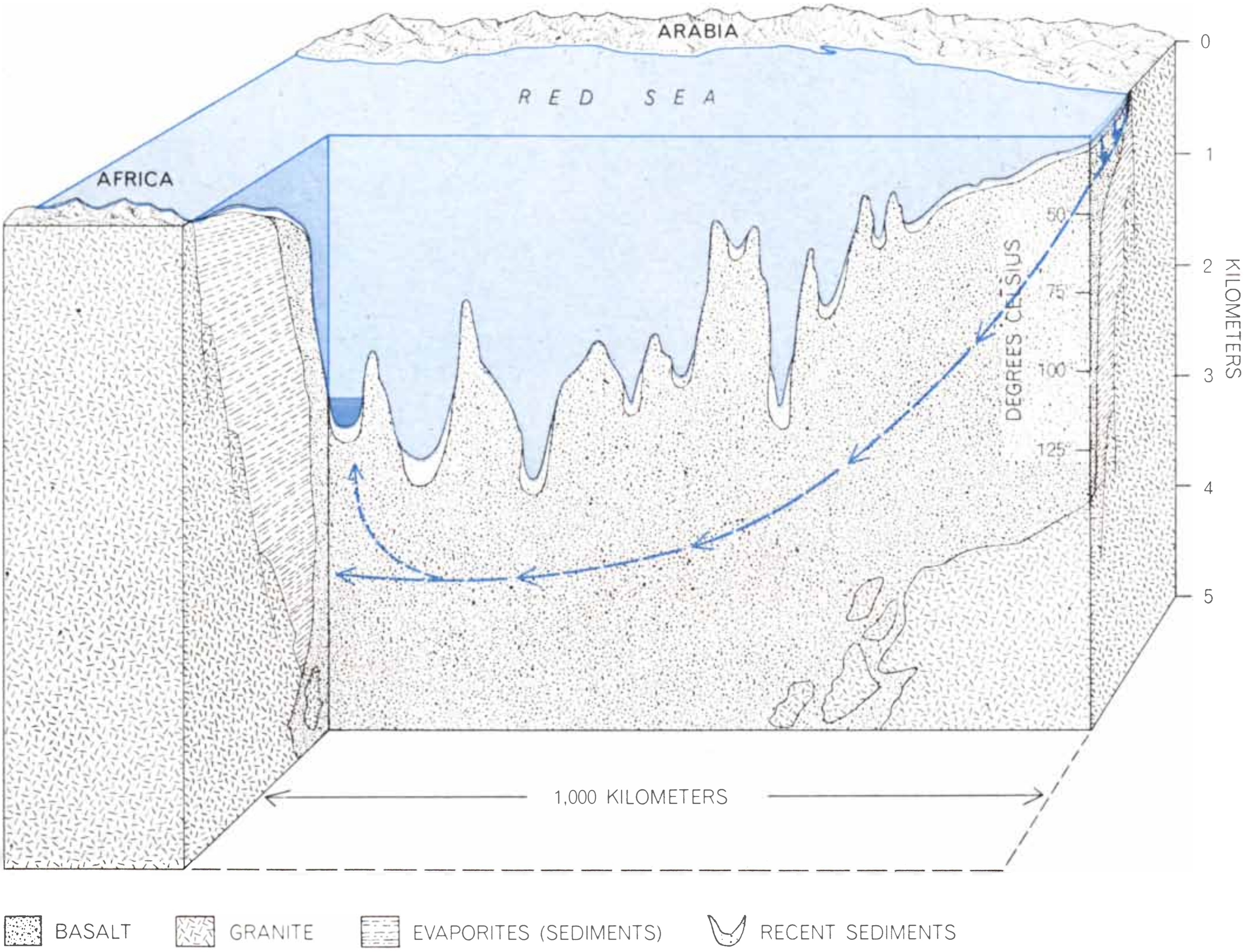
Their existence means that at least twice in the past 25,000 years the brine in the Atlantis II Deep has overflowed, raising the boundary between it and the normal Red Sea water some 200 to 250 feet.

Each of the overflows of brine took place approximately 5,000 years after a period of high Red Sea salinity had ended abruptly and water exchange with the Indian Ocean had resumed. We suggest that each overflow reflects the arrival of a renewed supply of water from the feeder zone near the southern end of the Red Sea.

Some of the history of the brine zone following the last overflow 8,000 years ago is evident in the alternation of external material and brine-derived material in the cores from the Atlantis II Deep. As we read the evidence, the level of the brine has continued to rise periodically. The rises have only been high enough, however, to surmount certain obstacles on the sea floor and overflow into the Chain and Discovery deeps, recharging the brines in them. Variations in core layers reflect the timing and the magnitude of the overflows.

In the perspective of geophysics the existence today of a zone of hot brines on top of a mid-ocean ridge is only the last link in a long chain of events. Molten crustal material has been welling up along the Red Sea ridge for at least the past 20 million years, as the land masses of Africa and Arabia have been spreading apart and creating rifts in the crust. In the earliest stage of the rifting deep subterranean fissures were opened to the passage of water. The rifting and the rise of molten magma provided not only the heat but also the gases, such as carbon dioxide, needed to transform the former Red Sea water into chemically active solutions. As the solutions migrated they dissolved salts from sedimentary rock formations and leached heavy metals out of crustal basalts. These acquisitions transformed the solutions into metalliferous brines. Once the brines had begun to ascend and cool, they probably released most of their metals (in the form of sulfides and carbonates), forming veins in the basement rock of such ores as galena (a sulfide of lead), sphalerite (a sulfide of zinc) and siderite (a carbonate of iron).

The hot brine that emerges to feed the Atlantis II Deep is only one of many metalliferous brines that may be assumed to be percolating through the basement rock under the Red Sea today. It is probably discharged through vents in the sea floor that resemble the fumaroles and hot springs common in volcanic areas ashore. What minerals the

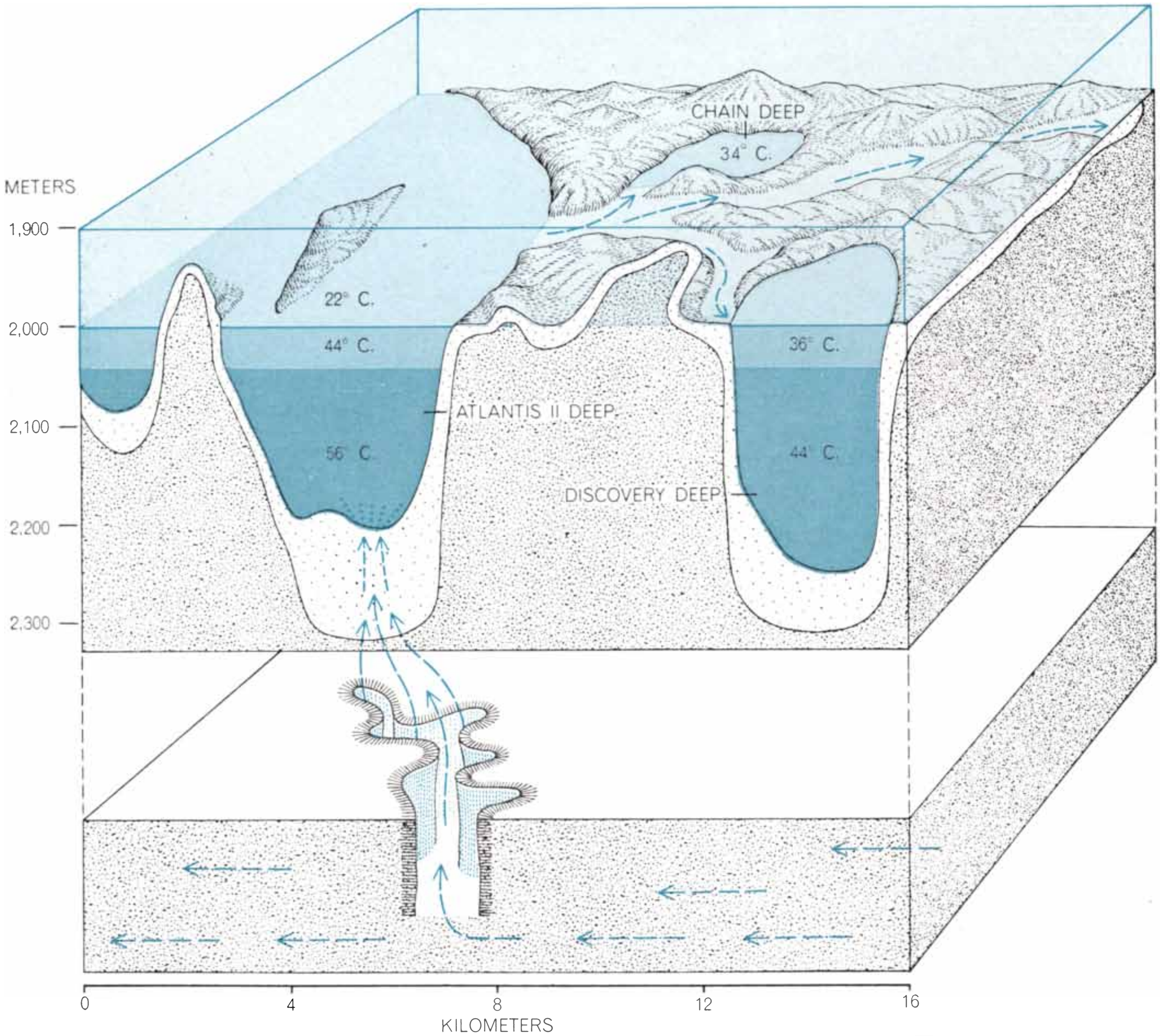


SLOW PERCOLATION of Red Sea water downward and northward through the rocks below the sea floor is shown schematically. The flow probably begins in the area where the sea floor rises to within a few hundred feet of the surface at the southern end of the Red Sea. As the water percolates underground it leaches salts out of the sedimentary rocks it passes through and also picks up metals from basaltic rock of the mid-ocean ridge. The temperature of the brine rises because at a depth of two kilometers the basement rock is hot enough to boil water. Eventually (*left, upward arrow*) some of the brine rises into the pocket that forms the Atlantis II Deep.

brine stream delivers to the Atlantis II Deep are at least partly determined by the velocity of the discharge. At high velocities, for example, the brine would have little time to cool off, and the elements giving rise to such minerals as sphalerite and siderite, instead of being deposited as veins of ore in the basement rock, would remain in solution and would only be precipitated later in the brine pools. The velocity of discharge has apparently never been sufficiently high to carry enough dissolved lead into the Atlantis II Deep for the deposition of galena. This mineral precipitates at quite a high temperature, and no trace of it has been found in any of the deeps.

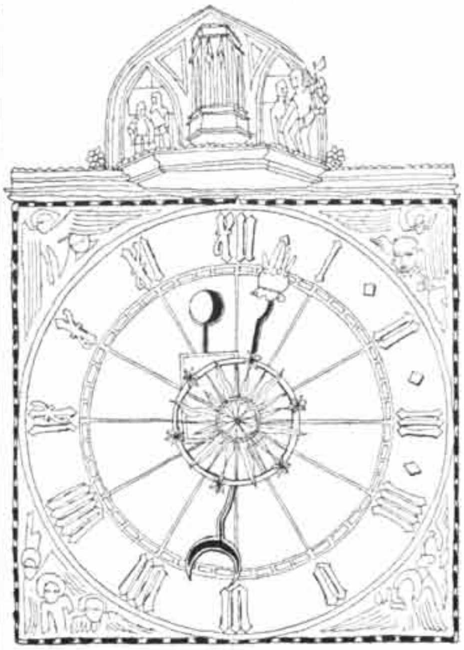
What is the age of the hot brine zone? An estimate is possible. The rate of sedimentation in the Atlantis II Deep appears to be about two inches per century. Only the upper 30 feet or so of the sediments has been studied in detail. There is an indication, however, that the sediments may be more than 300 feet thick in places, which would suggest a history of nearly 200,000 years of sedimentation. One can only speculate on the value of the metals that have accumulated in the hot brine deeps. The gold, silver, copper and zinc in the upper 30 feet of sediments alone should be worth something more than $2 billion where they lie. The value of the ore veins that may exist farther below the deeps cannot even be guessed.

Who owns the hot brine zone? The question is a difficult one. If it is decided according to the "law of median lines," the area belongs to the nearest coastal state, which is the Sudan Republic. At least one group of would-be exploiters has applied to the Sudanese government for mining rights in the zone. Other groups, however, just as rightly point to the fact that the zone is in international waters. Where the legal maneuvering will conclude no one knows, but it is distinctly possible that in the end lawyers will profit more from the hot brines than oceanographers will.



SEA-BOTTOM TOPOGRAPHY in the area of the three deeps is seen near the top of this exploded cross section of the basement underlying the mid-ocean ridge. The view is from the west; north is at left. The long axis of the block measures 16 kilometers but depth indications below 2,300 meters are arbitrary. Top arrows show how overflow of the Atlantis II Deep can periodically replenish the two other pools. The winding "canyon" visible in the lower block represents zones in the basement rock where the percolating brine, cooling as it rises toward the floor of the Atlantis II Deep, has probably deposited rich veins of various metallic ores in the rock below.

SCIENCE AND



Keeper of the Conscience

In his recent message to Congress on the environment President Nixon listed 37 steps "we can take now and that can move us dramatically forward toward what has become an urgent common goal of all Americans: the rescue of our natural habitat as a place both habitable [by] and hospitable to man." The 37 steps consist of 23 major legislative proposals and 14 new administrative actions or executive orders designed to achieve progress in four major areas: control of water pollution, control of air pollution, management of solid wastes and provision of more recreational areas and open space. One of the administrative actions was to create a three-man Council on Environmental Quality to "be the keeper of our environmental conscience, and a goal to our ingenuity."

Water pollution, Nixon observed, has three principal sources: municipal, industrial and agricultural. Control of the first, he said, will cost about $10 billion over the next five years, half of which will be provided by the Federal Government. (Senator Edmund S. Muskie estimates, however, that $25 billion is needed to do the job.) To curb industrial pollution, Nixon promised stricter standards, federally enforced, including fines of up to $10,000 a day. He also proposed that the Federal Government extend its control to include "all navigable waters, both inter- and intrastate [and] all interstate ground waters." Nixon described the third source of water pollution, agricultural wastes, as "the most troublesome to control" and said he was asking the Council on Environmental Quality to give it special attention.

As for air pollution ("our most serious environmental problem") the President said he would ask for Federal regulations to "provide a minimum standard of air quality for all areas of the nation." Noting that motor vehicles account for half of the pollution, he also announced new Federal standards to reduce vehicle emissions, including limits on nitrogen oxides in 1973 and on particulate emissions two years later. Nixon urged legislation to correct "two key deficiencies in the present law." One new law would require testing the emissions of production vehicles throughout the model year in place of testing (now on a voluntary basis) special prototype vehicles. A second new step would be the setting of standards for motor fuels (presumably involving a limitation on the use of tetraethyl lead). Beyond that, Nixon declared that "prudence dictates ... the goal of producing an unconventionally powered, virtually pollution-free automobile within five years."

To control solid wastes that "litter the landscape," Nixon said the Government would help to devise "techniques for recycling materials and [encourage the] use of packaging and other materials which will degrade after use." He proposed also that the price of an automobile "should include not only the cost of producing it but also the cost of disposing of it."

Finally, the President spoke of creating more public parks, recreation areas and open space. Toward this end he listed many specific measures, from releasing federally owned real estate for public use to conversion of agricultural lands not needed for crops into parks. In conclusion Nixon paid his respects to "the often embattled but always determined 'conservation' movement" of the turn of the century, adding that today "we have to go beyond conservation to embrace restoration."

No More Toxins

To correct "a slipup" in staff work, President Nixon has now included bacterial toxins under the unilateral ban he placed on biological weapons last November. Toxins are poisonous substances made by microorganisms. Their exclusion from the November ban had been widely criticized by biologists and others. Department of Defense spokesmen had argued that toxins had been exempted because their effects were not communicable from one individual to another and therefore could not trigger uncontrollable epidemics. This argument has now been officially rejected.

The November renunciation of biological warfare was unilateral and unequivocal. The President announced that the U.S. stockpile of biological weapons would be destroyed and that only research on defensive measures would be continued. The ban still does not apply, however, to incapacitating gases and chemical defoliants, which many experts regard as being covered by the 1925 Geneva Protocol outlawing the use of chemical weapons. The British government has recently sided with the U.S. in concluding that such gases and defoliants are exempt.

Long Slide

Federal appropriations for research and development have been declining for some years, and it is evident from President Nixon's budget proposals for fiscal 1971 that the trend will continue. The President proposed obligations of $15.8 billion in 1971 compared with $16.4 billion in 1970. Even though the budget provides increases for the conduct of research and for the support of research and development in colleges and universities (the former up from $5.5 billion to $5.8 billion and the latter rising $114 million to a total of $1.5 billion), a number of factors appear likely to combine to make investigators relying on Federal funds feel a pinch.

First, even assuming that Congress approves all the increases, which would be unusual, their effect is likely to be overtaken by the effect of inflation. Another consideration is that significant cutbacks will be made by three agencies that have been heavily involved in the support of the physical sciences: the Department of Defense, the National Aeronautics and Space Administration and the Atomic Energy Commission. The cutbacks reflect in part the completion or phasing-down of certain weapons systems and the Apollo lunar-landing program and in part the Administration's decision to increase emphasis on research and development relating to problems of the environment, education, housing, transportation and crime.

Not clear in its effect is the "Mansfield amendment," sponsored by Senator Mike Mansfield of Montana and applied by Congress to the Defense Department's appropriation for the current fiscal year. The amendment specifies that the department should spend money only on research that can be shown to be directly relevant to defense. The Administration also appears to be cutting back on the support of students in fields of science and technology.

Advances in Segregation

In the past few years much attention has been given to the fact that the central cities of the U.S. are coming to have a racial composition strikingly unlike that of their surrounding suburbs. The 1968 report of the President's National Advisory Commission on Civil Disorders, for example, stated that if present trends continue, there will be "a white society principally located in suburbs, in smaller central cities and in the peripheral parts of large cities and a Negro society largely concentrated within large cities." A detailed examination of this hypothesis by a sociologist at the University of Michigan reveals that in spite of an accelerating growth of the Negro suburban population in recent years, urban-suburban differences in the proportion of blacks in the population are still increasing. Moreover, patterns of residential segregation by race within suburbs are emerging that are similar to those found within central cities.

In a review of the Census Bureau's monthly Current Population Survey that appeared recently in *American Journal of Sociology,* the Michigan investigator, Reynolds Farley, finds that in general the growth of the black population in the nation's central cities, a trend that developed in the World War II era, has continued, although the growth rate in the 1960's is somewhat lower than it was in the 1950's. In addition, during the 1960's the white population of the central cities, with the exception of a few Western cities, has continued to decrease.

In the suburban rings of the northern and western U.S., however, the black population has increased quite rapidly since 1960—not only more rapidly than it did during the 1950's but also more rapidly than the white population did during the later period. This has produced a slight change in the racial composition of these suburban rings. Within southern suburban rings the white population has increased at a higher rate than the black, but the black population has grown more rapidly during the 1960's than it did during the 1950's.

In spite of this evidence of the suburbanization of blacks, Farley concludes that the data generally support the view of the Commission on Civil Disorders, in the sense that the proportion of the population that is black is rising more rapidly in the central cities than in their suburban rings. Nonetheless, he cautions, "two facts should not be overlooked."

First, blacks are at present a minority in most central cities, and with a few exceptions will continue to be so for the foreseeable future. According to Farley, "the black population is simply not growing rapidly enough, nor are there sufficient numbers of rural Negroes to radically change the racial composition of most central cities even if whites continue to move away."

Second, some suburban black communities, in both the North and the South, have grown much more rapidly between 1966 and 1968 than they did between 1960 and 1966. This growth is not evenly distributed throughout the suburbs but appears rather to be concentrated in three types of area: older suburbs that are experiencing population succession, new developments designed for Negro occupancy and some impoverished suburban enclaves.

An interesting aspect of this recent migration to the suburbs is that it is apparently selective of younger, more affluent black families. According to Farley, "it is likely that the census of 1970 will reveal that the socioeconomic status of suburban blacks exceeds that of central city blacks." This finding would represent a reversal of the past situation, in which blacks who lived in the suburbs were, unlike whites, typically lower in socioeconomic status than their counterparts who lived in central cities.

In general, Farley finds, "the suburbanization of blacks does not herald a basic change in the patterns of racial segregation within metropolitan areas. Cities and their suburban rings are becoming more dissimilar in racial composition, and the out-migration of some blacks from the city will not alter this process." What the data do indicate, he concludes, is that "Negroes, similar to European ethnic groups, are becoming more decentralized throughout the metropolitan area after they have been in the city for some time and improved their economic status." Unlike the European immigrant groups, however, the residential decentralization of blacks is apparently not being accompanied by a reduction in residential segregation. Instead "the residential segregation patterns of central cities are reappearing within the suburbs."

Three Masks Make a Circuit

The Bell Telephone Laboratories, which pioneered the technology for making integrated circuits containing scores or hundreds of transistors on a single chip of silicon, has announced a much simplified process capable of producing integrated circuits with a density exceeding 500,000 transistors per square inch. Thus a typical chip a tenth of an inch square can contain more than 5,000 transistors. Using the conventional integrated circuit technology, which produces bipolar transistors, the upper limit of density is about 100,000 transistors per square inch. A more recent metal-oxide-semiconductor (MOS) technology can produce upward of 500,000 transistors per square inch, but it is more complex and costly than the new Bell Laboratories process.

The new technique resembles the others in that it uses precise photographic masks to define the microscopic areas that are exposed by etching and then modified in various ways to create the finished transistor. In the bipolar technology from five to seven masking and etching steps are needed. The MOS technology requires at least four such steps. Because it uses only three masking steps the new process has been given the name Tri-Mask. The first mask defines areas where the transistor's emitter and collector regions are to be formed by diffusing an n-type dopant into a p-type base. (The letters n and p stand for "negative" and "positive.") The second mask defines the location of tiny holes for making contact with the emitter, collector and base of each transistor. Finally, metal is evaporated over the entire surface of the chip and a third mask defines the areas where it is etched away, leaving a network of conducting pathways. The resulting Tri-Mask transistors are comparable to conventional bipolar transistors in that they have switching thresholds that are low, sharp and stable.

Sweet Smells

The search for more specific insecticides than the ones now in general use has focused on the pheromones, or sex attractants, secreted by the females of many species. If the attractant of a

The only thing standing between you and a Renault 16 is a little information.

It has been written that the ride you experience in the Renault 16 "can be compared only to that of the Mercedes, Rolls, or Citroën."*

Colin Chapman chose the engine of the Renault 16 for his Lotus Europa.

And the quietness of the Renault 16 (which goes for a mere $2,395†) comes only in cars costing thousands more.*

Someone is sleeping in Detroit.

Road Test is an impartial magazine. At the time of this writing, it did not even take advertising. After exhaustive tests on the Renault 16, Road Test wound up suggesting that "all the automotive designers in Detroit be ordered to spend two weeks behind the wheel of this car in the hopes that their dormant imaginations might be sparked to life." Thank you, Road Test.

A textbook for Britain.

Stirling Moss has written: "There is no doubt that the Renault 16 is the most intelligently engineered automobile I have ever encountered and I think that each British motor-car manufacturer would do well to purchase one just to see how it is put together."

The Renault 16 happily consents to offering a course in Renault 16.

Where we made our points.

Needless to say, our car has impressed a lot of people. We'd like to tell you why.

Before our car was a car, it was a project. It was designed and built from scratch. Like the factory that makes it. So we didn't build a new car around old parts.

For better traction and superior road handling, the Renault 16 has front wheel drive with engine weight over the drive wheels.

Its engine gets a miserly 30 miles per gallon. But it does an honorable 93 mph, top speed.

Its unique 4-wheel independent suspension system has already put the 16's ride in a league with the Rolls Royce's.

The seats in the 16 were designed by a doctor and will challenge the comfort of any easy chair. They too have been compared with the Rolls'.

Even more points.

Disc brakes resist fade. Our front wheel disc brakes will stop you in a straight line instead of the next lane.

Seven different seating arrangements give the Renault 16 perhaps the most versatile interior you can drive. It can be a plush sedan, a roomy wagon, or anything in between.

It's got a sealed cooling system that doesn't overheat and virtually eliminates adding antifreeze.

And finally, the sound of a Renault 16 running is very close to silence.

Extracurricular reading.

If any information still stands between you and a Renault 16, you can have Road Test's full report on it by sending in the coupon below.

But if you've read this far, we suspect you're at least ready for a test drive.

Renault, Inc., Box 1970, Port Washington, N.Y. 11050

Gentlemen: Please send me my free copy of Road Test magazine. (OFFER EXPIRES AUGUST 1, 1970)

NAME

STREET

CITY STATE ZIP

RENAULT 16

Dept. No. 3

AVAILABLE FOR TEST DRIVING AT ANY RENAULT DEALER.

*ROAD TEST MAGAZINE. †SUGGESTED RETAIL PRICE, P.O.E. TAXES, FREIGHT, OPTIONS (SUCH AS AUTOMATIC TRANSMISSION, ELECTRIC SUN ROOF, WHITEWALLS, RADIO, ETC.) AND DEALER DELIVERY CHARGES ADDITIONAL.

species can be identified and synthesized, the males can be lured to traps and the reproductive effectiveness of the species can be impaired. During the past decade about 200 species of insects have been found to have sex attractants. The number for which the attractant or an analogue has been identified and synthesized is far smaller but recently has been increased by four: the fall armyworm, which attacks corn; the pink bollworm, a cotton pest; the cabbage looper, and the European corn borer.

The work on the fall armyworm was done by A. A. Sekul and Alton Sparks of the U.S. Department of Agriculture; on the pink bollworm, by William A. Jones and Martin Jacobson of the department, and on the cabbage looper by Robert S. Berger of Auburn University. These attractants were tested in the field by the Department of Agriculture and are now being marketed commercially. Whether or not they will control pests over a large geographical area is uncertain. The Department of Agriculture has found that the attractants are valuable in ascertaining where a particular pest is and in providing an indication of the pest's numbers, but that control of the insects usually requires the application of a pesticide. Since the application is localized, the use of the pesticide is minimized.

The sex attractant of the European corn borer has been identified and synthesized by Jerome A. Klun and Tom A. Brindley of the Department of Agriculture. The attractant turned out to be identical in structure with the sex attractant of two apple pests, the red-banded leaf roller and the oblique-banded leaf roller. The department plans to make large-scale field tests of the synthetic attractant as an inhibitor of mating by male borer moths.

Java Man's Jeopardy

The thighbone of Java man, the famous human fossil discovered by Eugène Dubois in 1892, has an abnormal bony growth near its upper end. The bone is at least 700,000 years old, so that its abnormality represents the oldest-known disease of man. Thanks to a recent discovery in Spain, the disease can now be diagnosed as a form of fluorine poisoning.

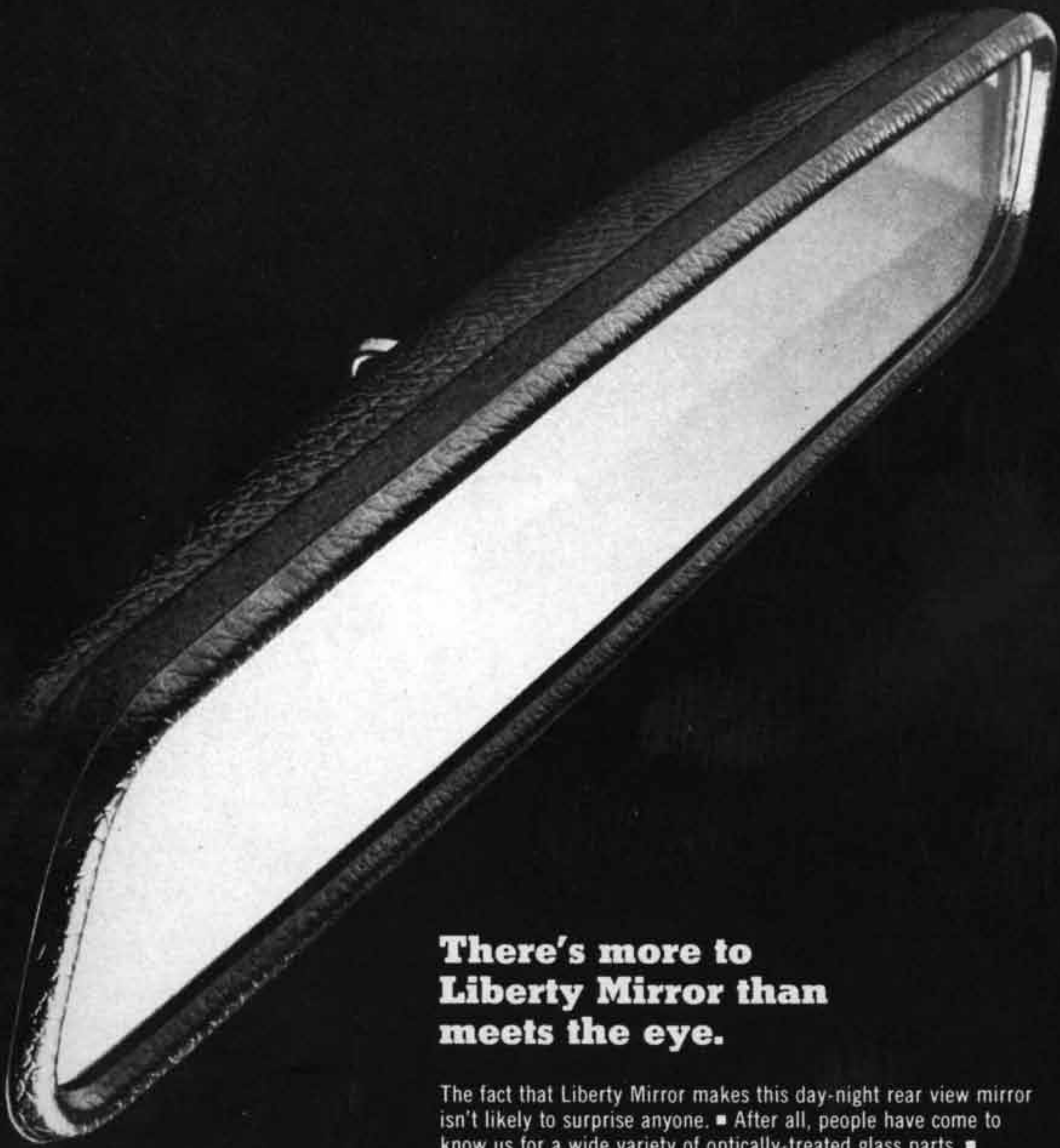
Writing in *American Journal of Physical Anthropology,* M. Soriano of the University of Barcelona reports that an autopsy he performed on a patient more than a decade ago revealed the presence of a bony growth on the femur that was strikingly like the growth on the Java femur; the patient, an alcoholic, had died of cirrhosis of the liver. At the time Soriano could not find out why the growth had formed, but he did notice that similar growths were developing in other patients under his care. He was finally able to show that the abnormalities were caused by the ingestion of large amounts of sodium fluoride, which had been fraudulently added (to control fermentation) to the bulk wine the patients had been drinking. Searching for other instances of fluorine-caused bone disease, Soriano found that sheep grazing in areas of Iceland contaminated with fluorine because of volcanic activity also develop abnormal bone growths.

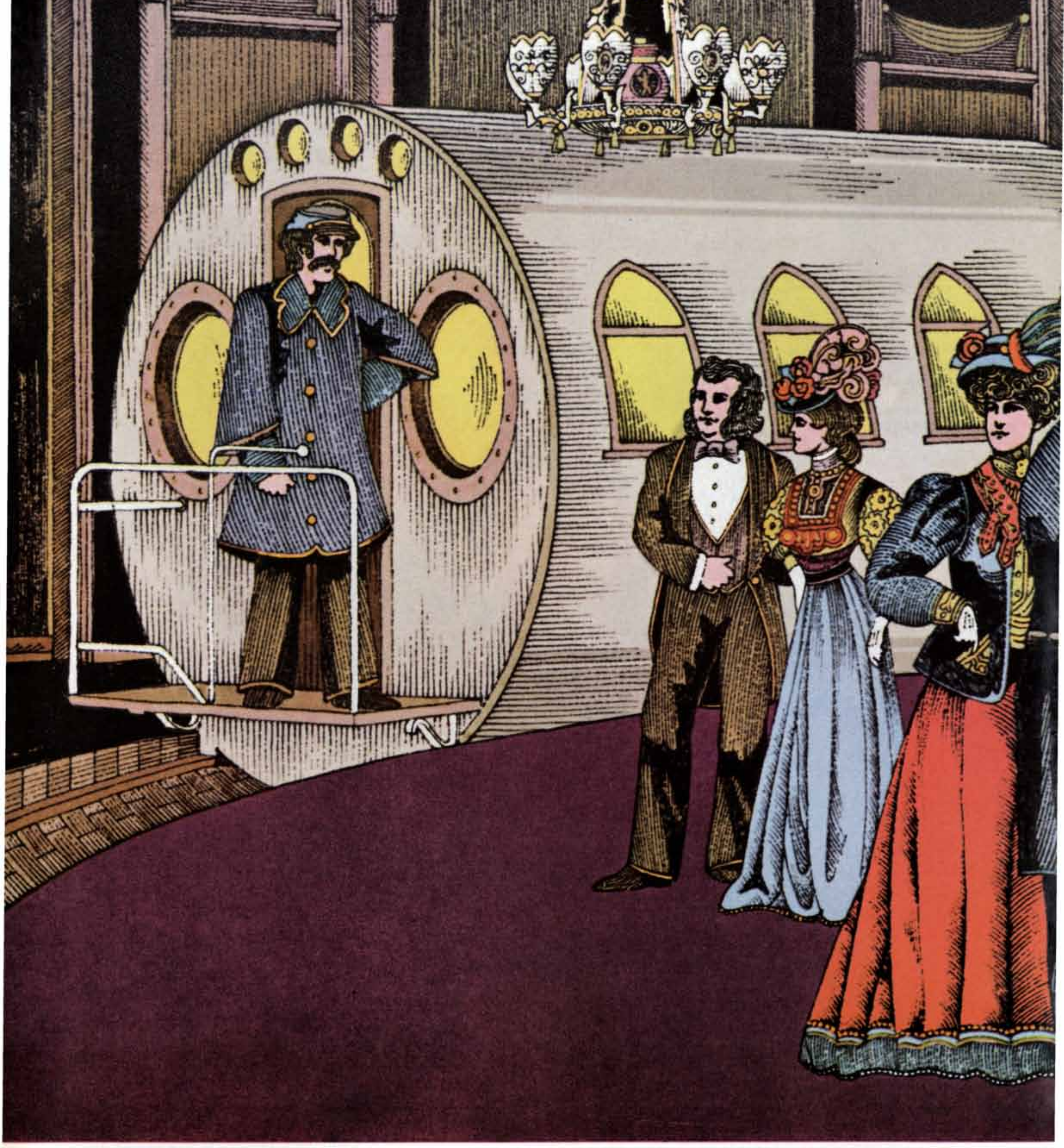
Java man's remains were found in association with thick beds of volcanic ash. Soriano suggests that the fruits and other plant materials eaten by Java man would have contained enough volcanic fluorine to produce the disease.

Contradiction in Terms

One might suppose that few people with color blindness would knowingly choose a career in painting. A recent survey of students at the Glasgow School of Art indicates that, on the contrary, the proportion of color-blindness to normal color vision among student painters was the same as that among the Scottish population in general. Six men and one woman out of 223 students proved to have defective color vision. All but one knew of the handicap; all were certain it had no significant effect on their work.

R. W. Pickford of the University of Glasgow and his colleague Donald I. A. MacLeod screened first- and second-year students at the School of Art, using the 1964 edition of the Ishihara numeral-discrimination test. An anomaloscope was then used to assess the type and the extent of the deficiency; the six men were unable to make the normal distinction between red and green and the woman was abnormally insensitive to red. All the students brought Pickford examples of their work; all had used green pigments in their paintings but it was not uncommon for their greens to be criticized by others as "raw." One man thought that the gray shadows in one of his paintings were actually green. Another thought that the green sky in a painting of his was gray. Reporting the results of his survey in *Journal of the Biosocial Sciences,* Pickford notes that the seven color-blind painters showed surprising powers of adaptation. Partly as a result of consciously realizing their deficiency, he concludes, they had learned to avoid colors that could give rise to difficulties.



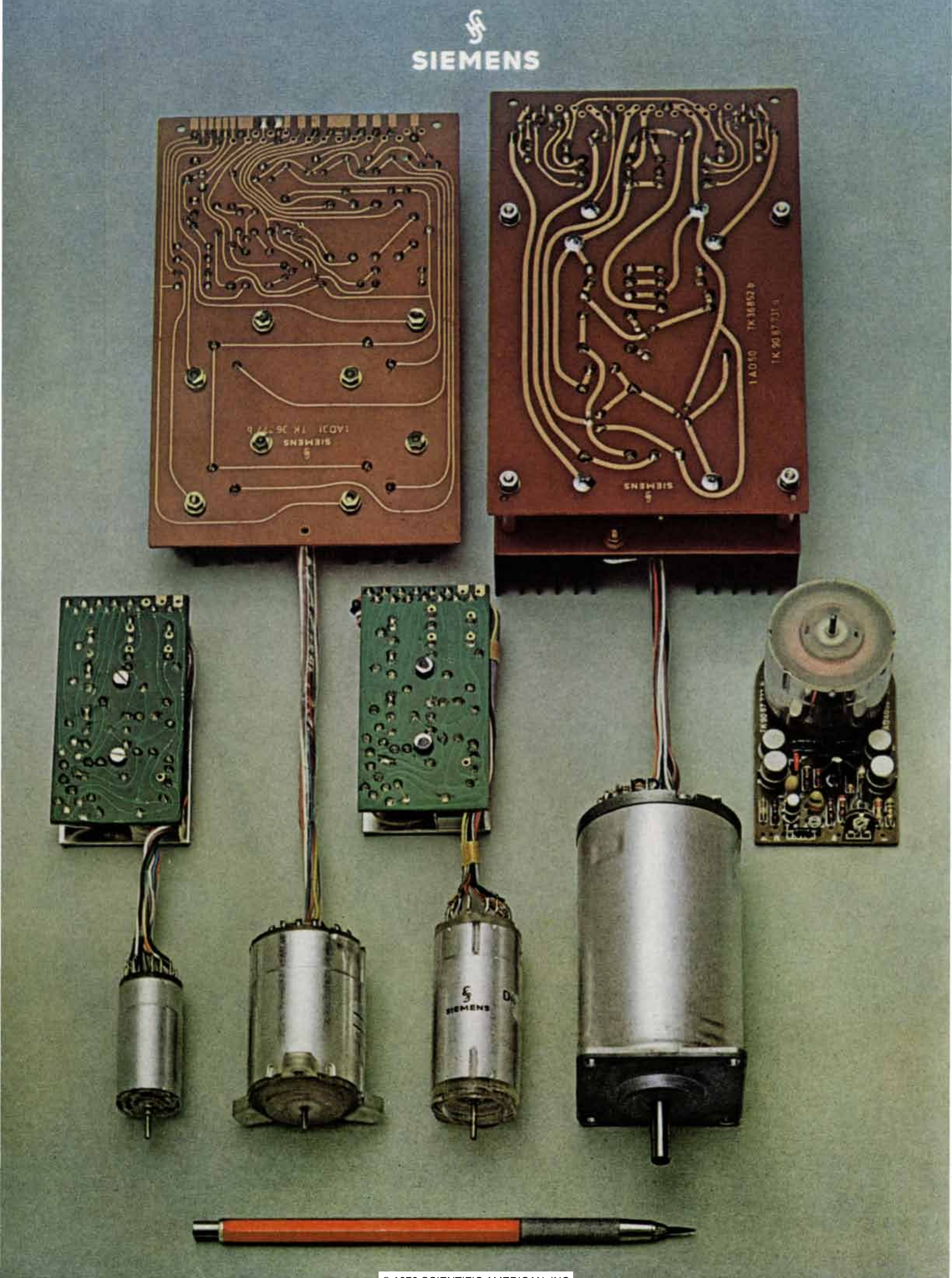


The Sub Rosa Subway or GOLDFISH & BRAHMS beneath the GREAT WHITE WAY

Back in 1870 New Yorkers woke one morning to the whoosh of America's first subway. Built in secret to spite a corrupt political machine, it ran for 312 feet under the very center of Broadway.

The station was a model of Victorianism—frescoed walls, fountain, goldfish tank, even a grand piano. About the only thing the Alfred E. Beach Pneumatic Subway didn't have was a chance to succeed. Advanced though it was, the giant fan which propelled it also had the disconcerting habit of sucking in people's hats and parcels through the sidewalk air intake, then spewing them out mangled when the


PNEUMATIC
1870
TRANSIT


SIEMENS

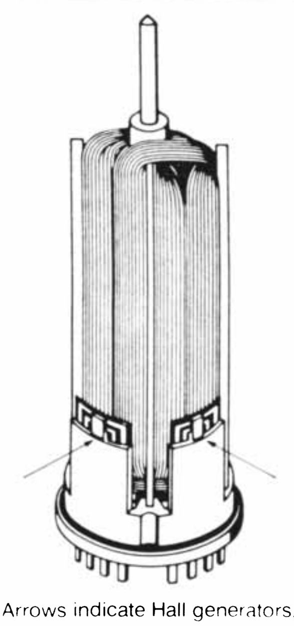
Siemens

Solid-state makes these dc motors run six times longer without maintenance. We bring Qualitätsware to America.

Solid-state technology is turning up in some surprising places.

Siemens developed a line of direct-current motors without brushes or commutators. Instead of these electro-mechanical devices, the new "brushless" dc motors use solid control circuits.

By eliminating brush-commutator switching, the operating life of a Siemens brushless dc motor is increased to a predicted 10,000 hours without maintenance. (Even the most perfectly balanced conventional dc motor usually requires brush replacement within 1,500 hours.) The Siemens solid-state dc motor is the first brushless type to be accepted in mass quantity by industry. More than 200,000 units have been sold around the world for hundreds of applications. This overwhelming acceptance is due not only to the greater reliability of the Siemens dc motor but also to its improved performance. For the first time, the speed of a dc motor is not dependent on or affected by variations in voltage input.



Arrows indicate Hall generators.

The secret of the Siemens dc motor's success is an ingeniously simple device called the Hall generator. Only one tenth of an inch square, two of these generators are located 90 degrees apart on the stator winding. During the rotation of the permanent magnet cylindrical rotor, they generate sinusoidal currents that permit precise stator winding switching by utilizing a separate control circuit. (Shown on top of each motor at left.)

A special feedback circuit is also used to precisely control the speed of the motor.

Siemens solid-state dc motors make dc motors practical for some previously impractical applications. For example, leased equipment, such as in devices for data processing systems, are ideal applications for this versatile motor. Such equipment can now benefit from accuracy of dc motors without the need for frequent costly brush replacement. Available in a range of sizes up to 7 oz./in, Siemens solid-state dc motors and gear motors are being widely used in tape recorders, medical instruments, missile guidance systems and other precision applications that require direct-current motors with long life, reliability and accuracy.

Siemens Corporation, 186 Wood Avenue S., Iselin, New Jersey 08830.

Or contact your Siemens representative anywhere in the world.

Siemens, a worldwide company that sold 2.84 billion dollars worth of quality products last year.

CHEMISTRY BY COMPUTER

Computed quantum-mechanical models of the electronic structure of atoms and molecules can provide a reliable and comprehensive alternative to the traditional experimental approach to chemistry

by Arnold C. Wahl

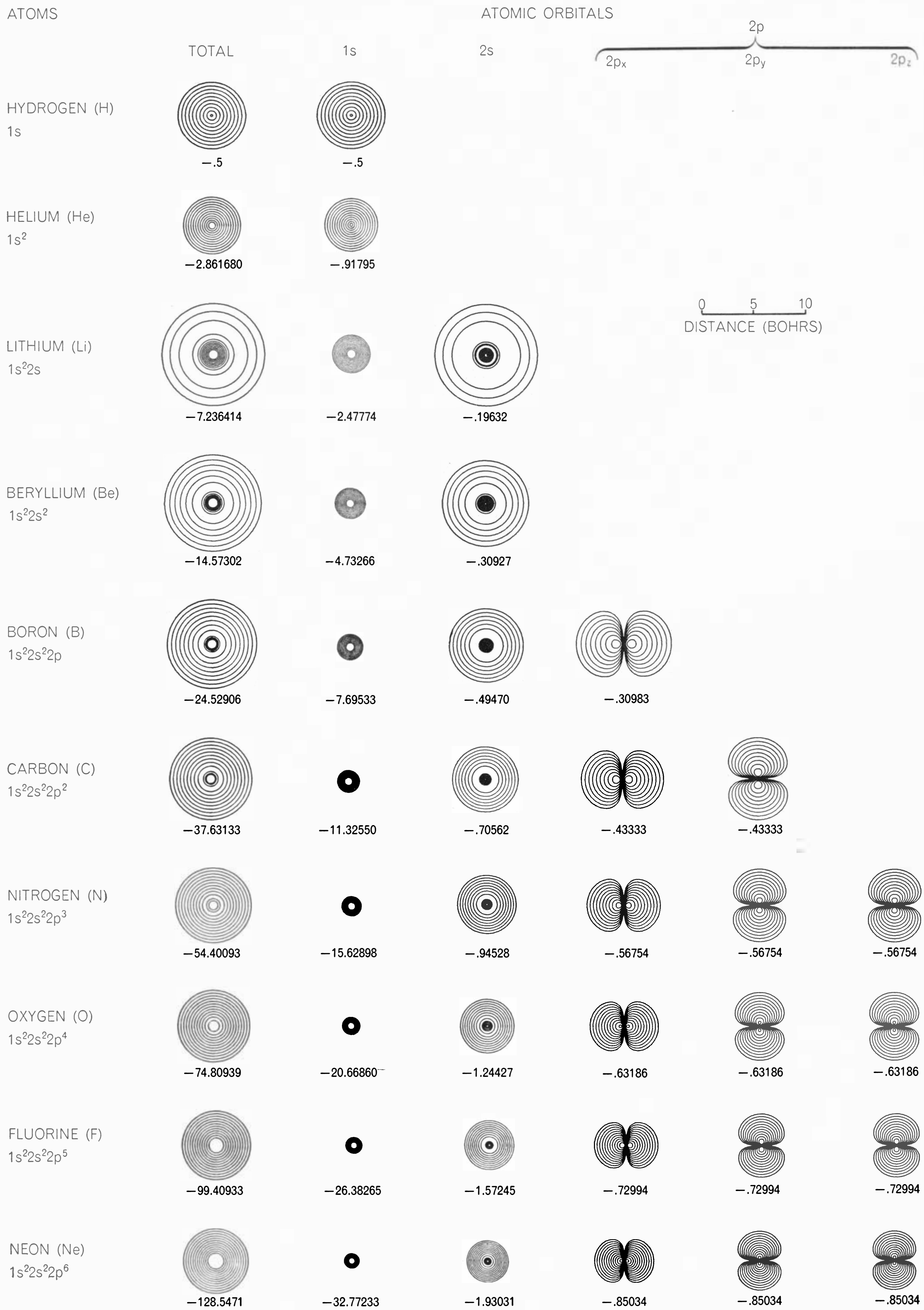
Traditionally chemistry has been a predominantly experimental discipline, consisting for the most part of direct measurements of the properties of matter and laboratory analyses of the reactions by which chemical substances are transformed into other chemical substances. The great contribution of modern quantum theory to chemistry has been to enrich the language of the chemist and to emphasize and explain the atomic and molecular basis of chemical phenomena. Assuming that one starts with a fundamentally sound theoretical model of the structure of the individual atoms or molecules, and of the nature of the forces between them, the laws of basic electrostatics, classical physics, quantum mechanics and statistical mechanics in principle provide a means for computing the macroscopic outcome of a chemical experiment—without ever performing the experiment! This possibility is particularly intriguing when the answers one could theoretically obtain in this way might not be accessible experimentally, as for example with highly corrosive substances or substances that exist either for a very short time or only at very high temperatures.

Since the introduction of the fundamental wave equation of quantum mechanics by Erwin Schrödinger in 1926, much of the work of quantum chemists has been focused on its solution for specific chemical systems; in other words, on the problem of constructing adequate mathematical models of atomic and molecular structure in order to obtain reliable nonexperimental information about chemical processes and to unify existing information. The major difficulty encountered in this effort arises from the intractable multidimensional differential equations that the Schrödinger equation demands as the only proper way of describing such a complex system of subatomic particles.

One of the most useful approaches to this problem has been the "electron orbital" picture of atoms and molecules. The orbital picture for atoms was a direct outgrowth of Schrödinger's solution of his wave equation for the hydrogen atom; during the period from 1927 to 1932 this picture was extended to many-electron atoms by William and Douglas R. Hartree, Vladimir Alexandrovitch Fock and James C. Slater and to molecules by Robert S. Mulliken, Felix Hund and J. E. Leonard-Jones. The essence of this theory is that the electrons of a given atom or molecule occupy a set of distinct orbitals. Each orbital is characterized by a set of "quantum numbers," denoting various properties of the electrons in that orbital (for instance their spin, angular momentum and the probability of finding the electrons in various regions of space). One can build up an orbital picture that represents the approximate structure of the entire atom or molecule as a product of these individual orbitals.

Until recently the quantitative accuracy of this orbital model for molecules was rather poor, and it found its greatest use as a conceptual and interpretive tool. The advent of large electronic computers, however, has made it possible to perform the vast amount of algebra and arithmetic required to determine molecular orbitals and to make some necessary improvements beyond the orbital picture, providing in many cases reliable

FIRST 10 ATOMS in the periodic table of the elements are depicted on the opposite page in the form of sets of computer-generated diagrams showing the spatial distribution of the atoms' electrons in terms of contour lines of equal charge density. Each atom is represented by one diagram showing its total electron density and one or more diagrams showing the electron density of its constituent "orbitals." Under the name and symbol of each atom at left is the orbital configuration of that atom's complement of electrons; for example, in the orbital picture the configuration of the eight electrons in the oxygen atom is designated $1s^2 2s^2 2p^4$, which means that two electrons occupy the oxygen atom's 1*s*, or lowest-energy, orbital, two electrons occupy the 2*s*, or next-higher, orbital, and four electrons occupy the 2*p* orbitals (for which three different orientations, corresponding to alignment of the orbital's long axis along the *x*, *y* or *z* directions respectively, are possible). The electron densities of the orbitals were computed directly from each atom's orbital "wave function," a complex mathematical expression that is obtained by approximately solving the Schrödinger wave equation for the atom. This orbital picture yields a good approximation of the electronic structure of atoms and molecules. (The 2*p* orbitals must be spherically averaged when added to the total electron density, since the electrons can occupy different combinations of the 2*p* orbitals with equal probability.) The total and orbital energies are given below the respective diagrams in hartrees (an atomic unit of energy equal to 27.7 electron volts). The unit of charge density is one electron per cubic bohr, where one bohr (the atomic unit of distance) equals 5.29×10^{-9} centimeter; thus all diagrams are at a scale that represents a magnification of about a half-billion diameters. The highest contour value plotted corresponds to a density of one electron per cubic bohr and the value of the succeeding contours decreases by a factor of two down to 4.9×10^{-4} electron per cubic bohr. All plots are in a plane passing through the nucleus of the atom. This illustration and the ones on pages 58, 60 and 62 are based on a series of wall charts prepared by the author and his colleagues and published by McGraw-Hill, Inc.


ATOMS
ATOMIC ORBITALS
TOTAL
1s
2s
2p
2px
2py
2pz
HYDROGEN (H)
1s
−.5
−.5
HELIUM (He)
1s2
−2.861680
−.91795
0 5 10
DISTANCE (BOHRS)
LITHIUM (Li)
1s22s
−7.236414
−2.47774
−.19632
BERYLLIUM (Be)
1s22s2
−14.57302
−4.73266
−.30927
BORON (B)
1s22s22p
−24.52906
−7.69533
−.49470
−.30983
CARBON (C)
1s22s22p2
−37.63133
−11.32550
−.70562
−.43333
−.43333
NITROGEN (N)
1s22s22p3
−54.40093
−15.62898
−.94528
−.56754
−.56754
−.56754
OXYGEN (O)
1s22s22p4
−74.80939
−20.66860
−1.24427
−.63186
−.63186
−.63186
FLUORINE (F)
1s22s22p5
−99.40933
−26.38265
−1.57245
−.72994
−.72994
−.72994
NEON (Ne)
1s22s22p6
−128.5471
−32.77233
−1.93031
−.85034
−.85034
−.85034

and comprehensive chemical information independently of experiment. To give some idea of the computational power modern computers have made available to quantum chemists, a calculation of the orbital picture of a simple diatomic, or two-atom, molecule that 20 years ago would have required about 15 man-years of labor consumes only about 20 seconds on the most capable computer available today.

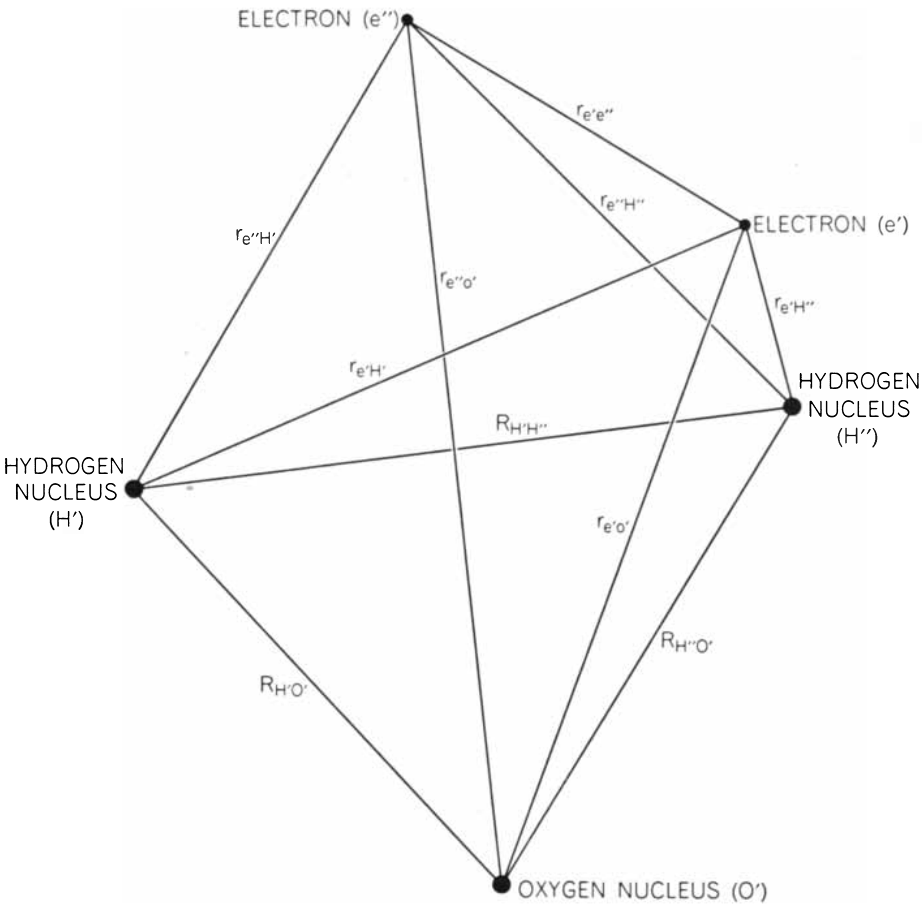
So far the chemistry amenable to such computer modeling is concerned only with small systems, but they are by no means chemically uninteresting systems. What is more, the success achieved in these limited cases portends an increasingly important role for "computational chemistry" in the future. Potentially this new approach presents the chemist with an opportunity to view in unprecedented detail and with arbitrary magnification or time scale the various stages of such chemical processes as the formation, excitation, ionization, vibration or collision of molecules. What is perhaps most exciting about this new tool is that it is not merely an information-retrieval or information-extrapolation system but rather a true information-creation system; through an inductive mathematical process beginning with the Schrödinger equation it creates information in usable form where there was none before. Thus its greatest value will be as an independent check on the answers provided by experimental chemistry, as an independent means of predicting answers currently inaccessible to experimental chemistry and as a conceptual framework for empirical information.

The Theoretical Approach

In formulating his wave equation Schrödinger cast in rigorous mathematical form the earlier body of quantum-mechanical knowledge. His equation, which can be written in a variety of forms, in general gives the total energy of any system of particles in terms of that system's characteristic "wave function." When the Schrödinger equation is solved for a particular system, it turns out that the wave function obtained must satisfy a set of distinct conditions. These imply that the energy of the system is itself "quantized"; in other words, the system can exist only in certain definite energy states. Another implication of the Schrödinger equation is that the positions of the individual particles that constitute the system cannot be located exactly in space; all that can be obtained is a mathematical expression giving the probability of finding any particle in various regions of space. Thus one way of looking at the structure of a quantum-mechanical system such as an atom or a molecule is as though it were an electron "cloud" of varying density surrounding a central nucleus (or group of nuclei). The exact shape and value of the charge density of the cloud are the quantities that are specified directly by the characteristic wave function of the system.

For example, in the case of the simplest atom, namely the hydrogen atom, which is made up of one nucleus (a single proton) and one electron, the solution of the Schrödinger equation yields a series of exact wave functions corresponding to the various allowed energy states of the atom. These are known as hydrogenic orbitals. As soon, however, as one goes to the slightly more complicated system of the helium atom, which has two electrons instead of one, an exact solution of the Schrödinger equation is impossible. Instead one must resort to special approximation procedures that approach the exact result very closely.

Beyond three- or four-electron systems, even these approximate solutions of the Schrödinger equation call for awesome amounts of computation, since the exact total wave function of such systems is a function of all 3*N* dimensions of the *N* electrons. Hence some more generalized simplifying approximation must be made in order to solve the Schrödinger equation for the larger systems. The most successful approximation of this type is the orbital model, in which the 3*N*-dimensional wave function is expressed in a similar-looking but actually much simpler form: as the product of *N* three-dimensional wave functions, each of which describes the orbital for a single electron. This method of computing approximate atomic structures by means of their atomic orbitals was perfected largely through the efforts of Hartree and Fock; the resulting total wave functions are sometimes called Hartree-Fock



MAGNITUDE OF THE PROBLEM involved in performing the computations necessary to extend the orbital model to molecules is suggested by this schematic illustration of a water molecule. In order to solve the Schrödinger equation for such a quantum-mechanical system one must take into account (among other things) the potential energy represented by the interactions between all the particles in the system; in the water molecule these interactions include three nucleus-nucleus repulsions, 30 electron-nucleus attractions and 45 electron-electron repulsions. Typical interparticle distances over which such interactions must be calculated and averaged within the electron clouds are indicated for five of the total of 13 particles in the system (*all three nuclei but only two of the 10 electrons are shown*).

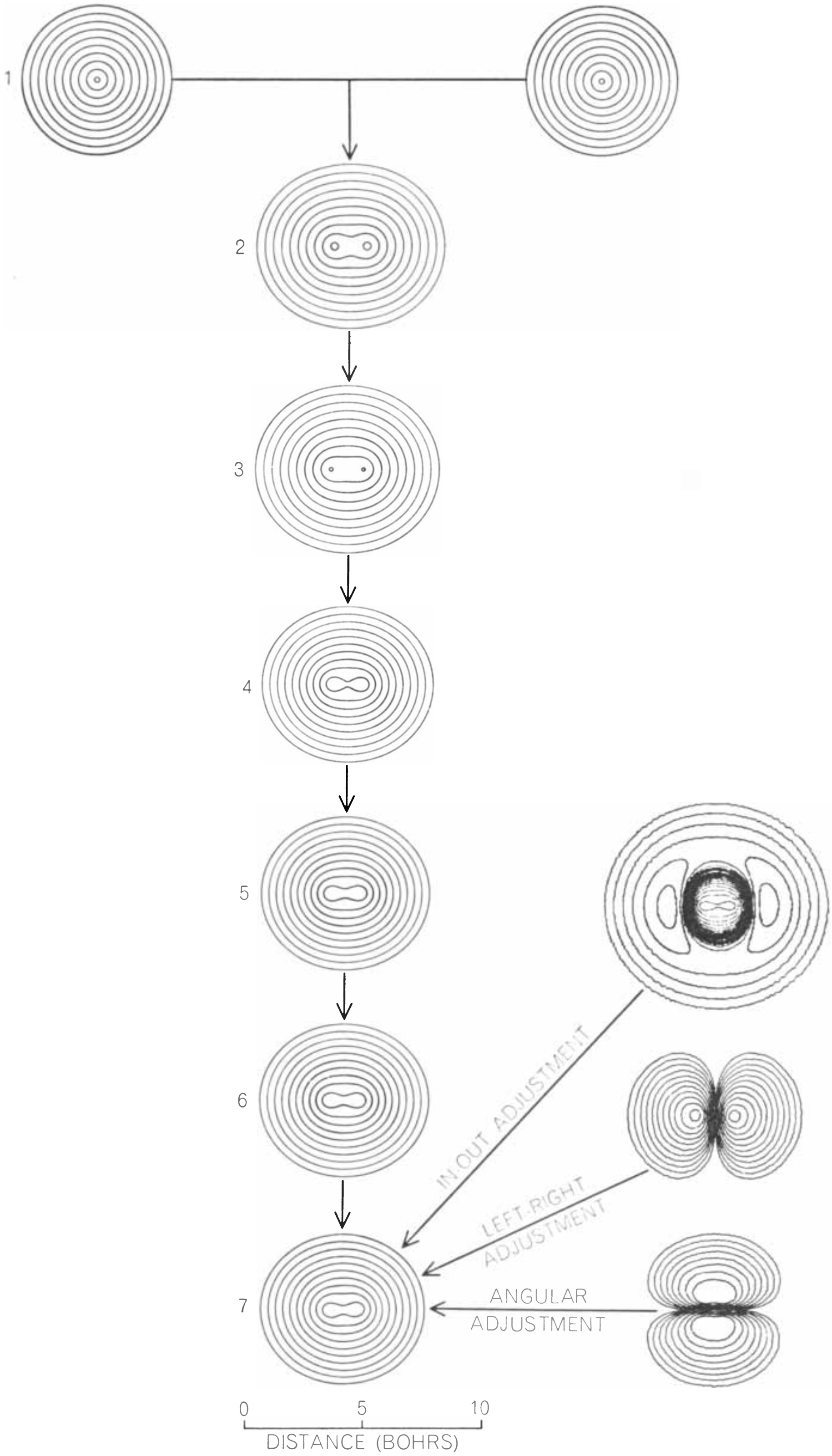
atomic orbitals. Hartree-Fock atomic orbital pictures of the first 10 atoms of the periodic table are shown in the illustration on page 55 in terms of contour lines of equal electron density.

The Hartree-Fock atomic orbital model provides a comprehensive framework for discussing the internal structure of individual atoms and in fact can be viewed as the quantum-mechanical basis and analogue of the periodic table. In particular this model has been conceptually invaluable in sorting out the incredible intricacies of atomic spectra, in effect answering the question of what is really happening when the energy states of an atom change. In addition the orbital model yields many useful chemical properties of atoms, such as their size and their approximate ionization potential (the amount of energy required to strip an atom of its electrons). Nonetheless, inherent defects in the orbital model for atoms prevent the accurate prediction of such properties as the affinity of an atom for an extra electron, the energy differences between atomic states and the total atomic energies.

The Molecular Orbital Model

The extension of the orbital model to molecules was a formidable computational task, primarily because the mathematics involved in the evaluation of the interactions among electrons in the molecule is much more difficult than in the case of the atom. (The spherical symmetry of the atom is a great advantage here.) The first step in simplifying the Schrödinger equation for molecules was in effect to separate out the motion of the nuclei, that is, to consider the nuclei to be at rest and to solve the Schrödinger equation for each electron moving with respect to this fixed framework. The motion of the nuclei can then be studied as if it were taking place on a potential-energy surface determined by the total electronic energy of the system. Max Born and J. Robert Oppenheimer were able to show quite early that this is usually a valid approximation, owing to the fact that the comparatively massive nuclei move much more slowly than the lighter electrons; as a result the electronic wave function can adjust itself instantaneously to the position of the nuclei at any given time.

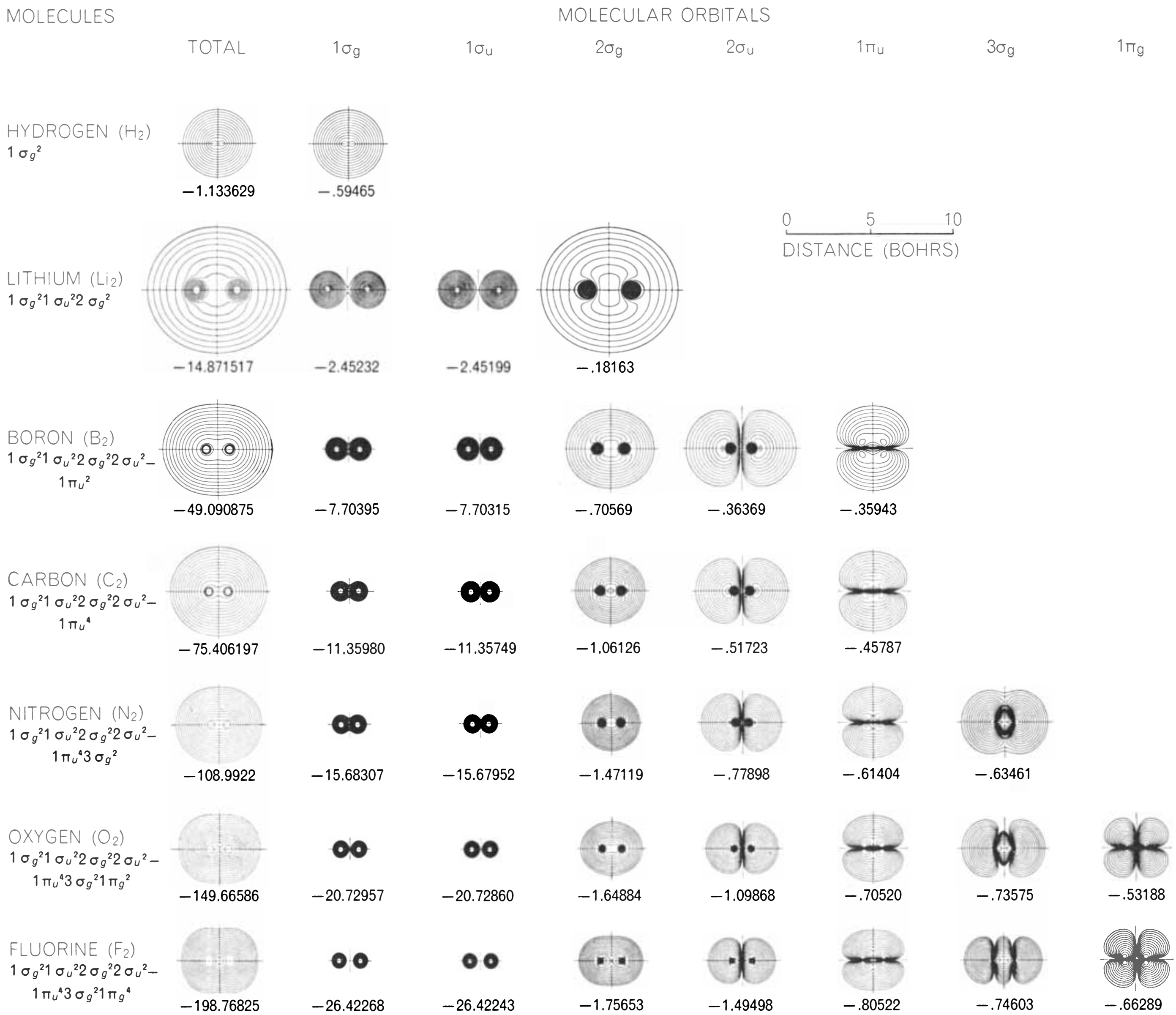
How does one actually go about developing a mathematical model of a simple diatomic molecule, say the hydrogen molecule (H_2)? It is helpful to visualize the job in stages [*see illustration at right*]. First we may compute precisely



TYPICAL PROCEDURE followed in developing a mathematical model of a simple diatomic molecule can be visualized in stages. First the charge density for two isolated hydrogen atoms is computed (*1*). Then the two hydrogen atoms are brought together as if they were classical (non-quantum-mechanical) spherical clouds of electronic charge (*2*). Next quantum mechanics is invoked and electron exchange is allowed to take place between the two atoms (*3*). This now produces a valid molecular orbital wave function, but it is not yet the best possible one. The shape of the molecular orbital is therefore changed in a variety of ways (*4, 5, 6*) until the energy associated with it reaches a minimum, ultimately giving one of the best approximate solutions of the Schrödinger equation for the molecule (*6*). Further adjustments must be added to the best molecular orbital picture in order to allow the electrons to avoid each other more effectively in an in-out, left-right and angular sense (*lower right*); the resulting "electron-correlated" picture (*7*) is not visibly altered, but the predicted binding energy and the description of the bonding process are greatly improved.

the charge density for two isolated hydrogen atoms, displaying the result in the form of an atomic orbital picture composed of contour lines of equal electron density. We then bring the two hydrogen atoms together as if they were classical (non-quantum-mechanical) spherical clouds of electronic charge. This would be a valid picture if it were not for the fact that according to the laws of quantum mechanics electrons are indistinguishable and therefore cannot be rigidly assigned to one hydrogen atom or the other; rather they must be allowed to "exchange," or mix freely, between the two atoms.

Next we invoke quantum mechanics and allow electron exchange to take place. This now produces a valid molecular orbital wave function, but it is not yet the best possible one. In order to obtain the best possible molecular orbital wave function (the Hartree-Fock function) we must vary the form of the molecular orbital picture until the energy associated with it reaches a minimum. A convenient way of doing this in forming the molecular orbital is to include in addition to the simple 1*s*, or lowest-energy, hydrogenic function higher functions such as the 2*s*, 2*p*, 3*d* and 4*f* functions. When allowed to combine with the 1*s* wave function, these additions can change the shape of the molecular orbital in a variety of ways and ultimately give the best solution of the Schrödinger equation for the molecule. We have displayed such best molecular orbitals in terms of contour diagrams of electronic charge density for a variety of diatomic molecules [*see illustrations below and on page 60*].



SEVEN COVALENT DIATOMIC MOLECULES (that is, molecules that share their outermost pairs of electrons) are represented here by contour diagrams of their total and orbital electron densities; the molecules shown are those that result from combining in homonuclear pairs seven of the first 10 atoms in the periodic table. The electronic configurations of the molecules (that is, the number of electrons in each of a given molecule's set of orbitals) are given at left under the names and symbols of the respective molecules. The subscript letters *g* and *u* indicate whether a molecule's "inversion symmetry" (its symmetry across a central plane) is either even (in German *gerade*) or odd (*ungerade*). As in the case of the atomic orbitals on page 55, orbital energy is given below each diagram in hartrees, and charge density is plotted in electrons per cubic bohr. The diatomic molecules of helium (He_2), beryllium (Be_2) and neon (Ne_2), which are members of this homonuclear series, are not bound in their ground, or lowest-energy, state and hence are not displayed here. In this illustration and the one on page 60 three additional, low-value contour lines have been plotted.

Creativity in corporate finance

is raising $100,000,000 at

4⅝%

when the prime rate is 7½%

Long-range growth programs require new capital. Unfortunately, corporations cannot always predict what interest rates will be at the time they need the money. For the Burroughs Corporation, it was a matter of raising capital for growth and expansion plans in a tight money market.

That's why, after discussing various financing alternatives, the Burroughs Corporation asked Kidder, Peabody to manage a public financing.

Through our domestic and international operations, we were able to explore what type of financing would satisfy both buyer and seller.

We examined–jointly with the financial officers of the company –various financing alternatives: equity, preferred stock plus equity, straight debt, convertible debt, Euro-dollar financings and domestic financings. Plus combinations thereof. We examined current money markets, current securities markets, and made judgments of what future markets might be. A domestic convertible bond financing was chosen as offering the best end result.

A specially selected investment banking group was created to underwrite the proposed offer. The playback between the worldwide Kidder, Peabody sales force and the underwriters was vitally important. It continued for 17 days.

On May 14, to the surprise of many investors, Kidder, Peabody decided on *"a 4⅝% coupon, and convertible at 20% over the market for Burroughs common."* This was the lowest interest coupon and one of the highest premiums to date in 1969. The DJII was in a downtrend and the prime interest rate was at a 30-year high of 7½%. Would the financing sell? The issue sold.

Naturally, Burrough's reputation and prospects had a strong bearing on what could be done. But certainly the know-how and expertise of the underwriter was a major factor. After all, in 1969 alone, Kidder, Peabody managed over 150 different public and private corporate financings which raised over $2 billion, in addition to being a major underwriter of another 325 corporate financings.

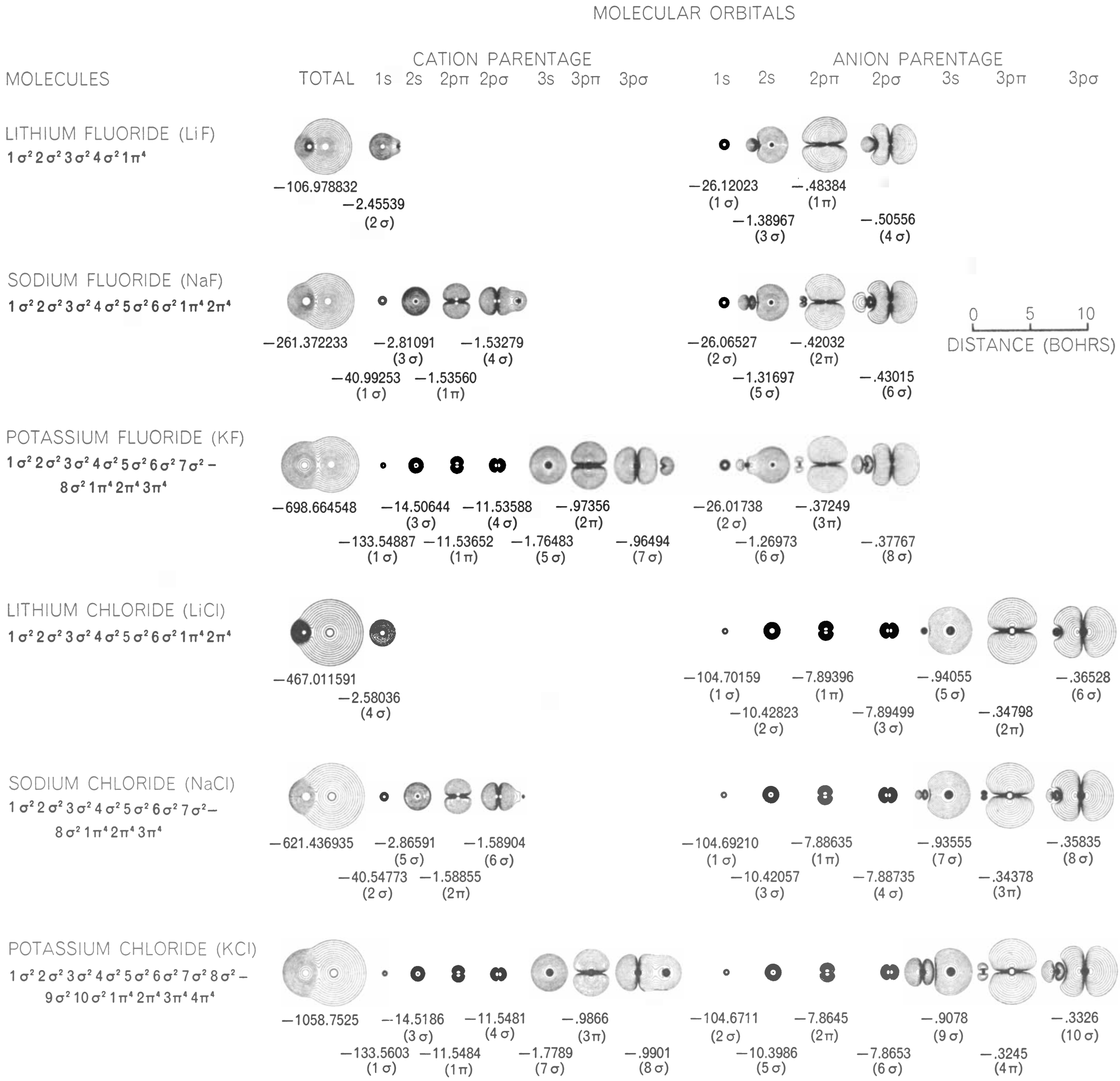
To creatively raise capital in today's tight money market, contact Raymond J. Raff, Vice President, Corporate Finance Department. All you have to do is show a little interest.

Kidder, Peabody & Co. INCORPORATED
Founded 1865
Members New York and American Stock Exchanges
20 EXCHANGE PLACE • NEW YORK, N.Y. 10005

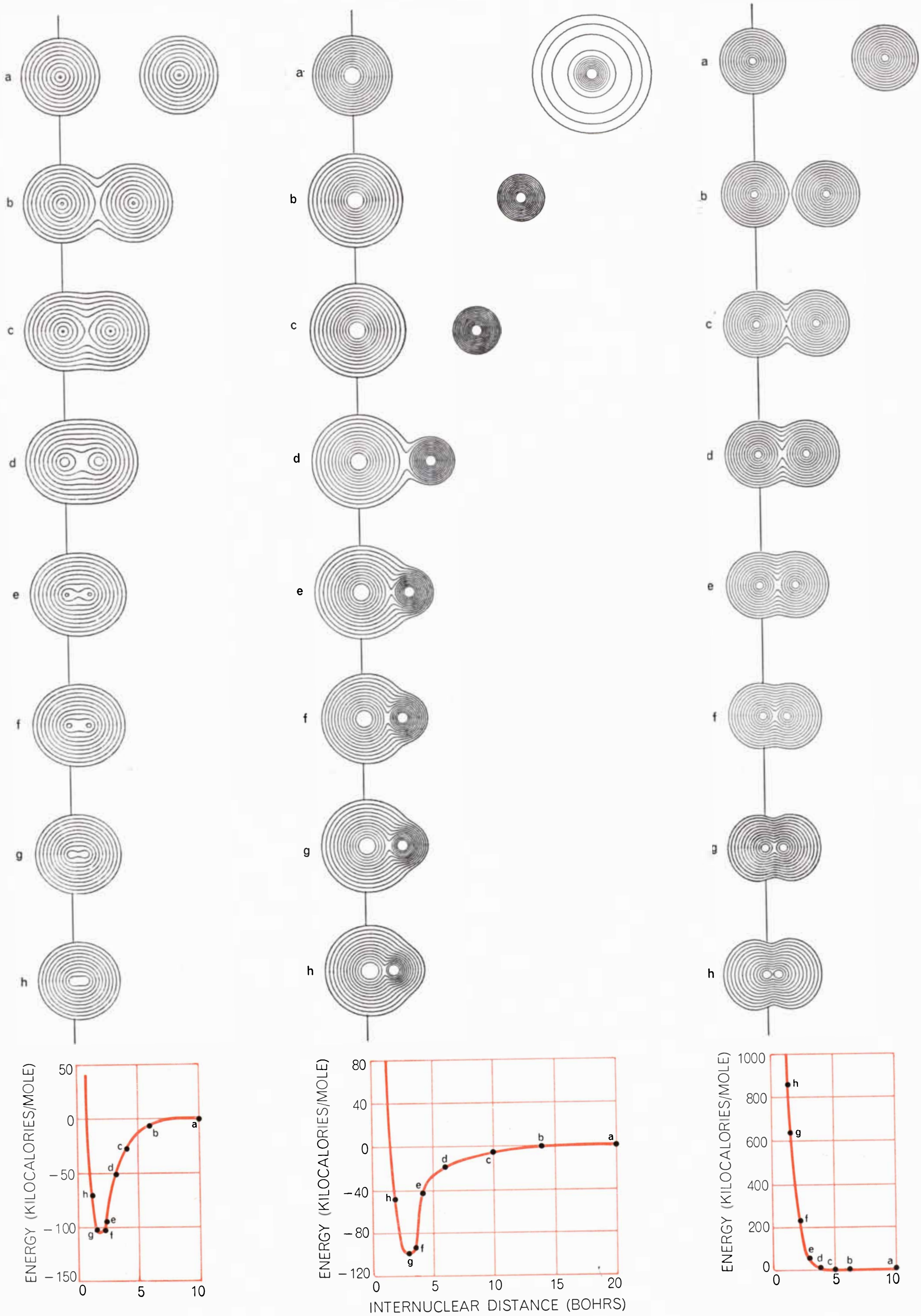
BOSTON, PHILADELPHIA, CHICAGO, SAN FRANCISCO, LOS ANGELES, ATLANTA, DALLAS,
Albany, Altoona, Amarillo, Baltimore, Detroit, Harrisburg, Houston, Lowell, Milwaukee, Minneapolis, New Bedford, Newark, Portland, Providence, Reading, Seattle, Spokane, Springfield, White Plains, Wilkes-Barre, Worcester.
Affiliated companies in: London, Paris, Geneva, Hong Kong, Madrid, Mexico City, Beirut.

The molecular orbital model has proved to be a great aid to the chemist in talking and thinking about chemical bonding and molecular energy states. It also yields by computation many molecular properties. Among these are molecular charge density, bond lengths and angles (which determine the size and shape of the molecule), ionization potentials, magnetic moments and vibrational frequencies.

One of the main inadequacies of the orbital model is its inability to quantitatively predict chemical-bond strengths and energy differences between various states of a molecule and its ions. This defect results from the fact that the error in the orbital approximation is a sensitive function of both the number of electrons in a given chemical system and the way they are distributed in space. Thus when a molecule forms from two atoms, the error in the orbital approximation of the molecule is larger than the error in the orbital approximation of the two separated atoms. Moreover, when a molecule or an atom gains or loses an electron, or changes its electronic state, the error of the orbital approximation also changes. This error, which arises from the fact that in the orbital picture electrons can only avoid one another on the average and are not able to correlate these motions instantaneously (as the Schrödinger equation demands), is accordingly called the correlation error.



SIX IONIC DIATOMIC MOLECULES (that is, molecules formed by the attraction between positively charged ions, called cations, and negatively charged ions, called anions) are shown in these contour diagrams of electron density. The ionic systems displayed are known as alkali halides. The molecular orbital structures are arranged according to their separated ion parentage; the set arising from the cation is at left and the set arising from the anion is at right. Again total and orbital energies are given in hartrees, and charge densities are plotted in electrons per cubic bohr. The names, symbols and electronic configurations of the molecules are indicated at left; in this case, however, the corresponding molecular orbitals are identified in parentheses directly under each orbital energy.


a
b
c
d
e
f
g
h
ENERGY (KILOCALORIES/MOLE)
50
0
−50
−100
−150
0
5
10
80
40
0
−40
−80
−120
0
5
10
15
20
INTERNUCLEAR DISTANCE (BOHRS)
1000
800
600
400
200
0
0
5
10

Significant progress has been made by quantum chemists in modifying the orbital picture to allow electron correlation. This is customarily done either by abandoning the orbital picture completely (a great conceptual sacrifice) and allowing the wave function to depend on the distances between all electrons or by extending the orbital picture so that it enables the electrons to spend a fraction of their time in a variety of different orbital configurations instead of just one; this enables the electrons to avoid one another more effectively. When these correlation terms are added to the best molecular orbital picture so as to allow the electrons to avoid one another in an in-out, left-right and angular sense, the charge density is not significantly affected, but the binding energy and the description of the bonding process are greatly improved. Some effective correlating orbitals are displayed in the illustration on page 57.

Computing Molecular Properties

The orbital picture enables us to look at a chemical process such as molecular excitation (the promotion of electrons into higher energy states) or ionization (the removal of electrons from a molecule) in terms of changes in the electronic charge distribution [*see illustration on next page*]. In order to have the energy-level spacing or the ionization potentials correct, however, one must go beyond the molecular orbital model and include electron correlation. The correlated orbital model generally gives an error of several electron volts in both ionization and excitation energies. This error is sometimes tolerable, but often a much higher precision is needed to be of genuine aid to the experimentalist in interpreting atomic or molecular spectra.

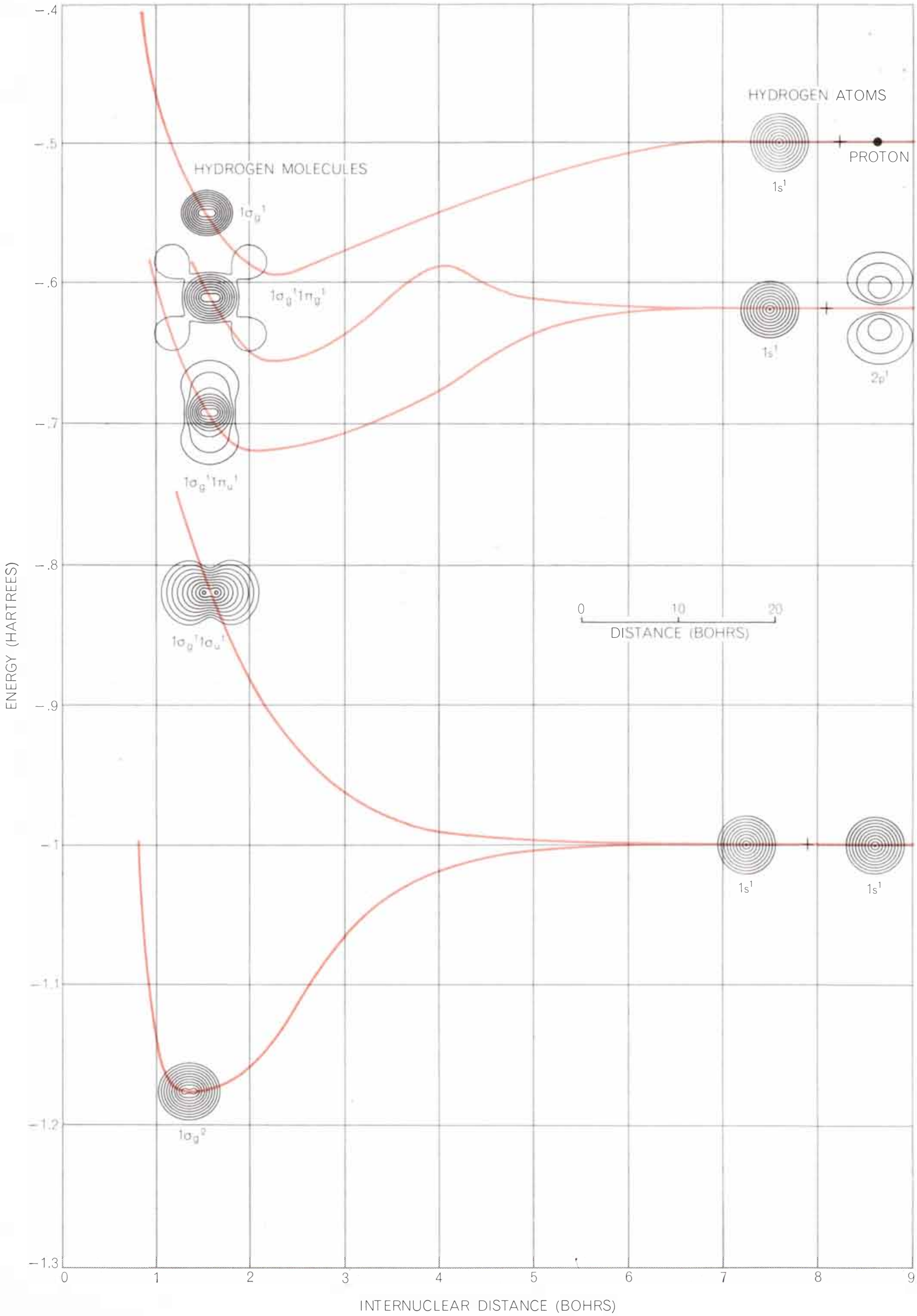
Molecular properties associated with the vibration of molecules are customarily studied mathematically by solving the Schrödinger equation to obtain the value of the molecular energy for various fixed positions of the nuclei in the molecule. This procedure determines a "potential well," or energy curve, in which the nuclei are considered to vibrate [*see illustration on page 68*]. This approach is quite good in most cases when the change of molecular energy can be computed accurately. Since the molecular orbital model gives the change in molecular energy with nuclear position fairly well near the equilibrium nuclear positions of the molecules, the vibrational frequency can be determined within about 10 percent; for higher precision one must go beyond the orbital picture. (A molecule can absorb or emit even smaller quanta of energy through changes in its rotation.)

An important class of molecular properties that can be studied by means of the orbital approach involves only the individual coordinates of each electron; accordingly such properties are known as "one electron" properties. These properties are evaluated by summing over all space the contribution of all electrons to the total electronic charge distribution. A typical example is the electric-dipole moment of a diatomic molecule, which is a measure of the imbalance between the electronic and the nuclear charge distribution. Other one-electron properties are evaluated in a similar manner and are obtainable from the orbital picture, usually to within a precision better than 20 percent. For molecular properties that depend on the simultaneous position of two electrons or on a fine detail of the wave function, such as its behavior at the nucleus, correlation effects are important and must be included.

The concept of the chemical bond has been indispensable in discussing the mechanism by which elements and compounds are held together. Theoretically this concept states simply that a given chemical compound is stable if its energy is lower than that of the competing reactions; thus a chemical bond is said to exist between two atoms if there exists an equilibrium internuclear separation such that any deviation from it leads to a higher energy for the system. Quantum chemists, however, have sought for many years to produce a more tangible characterization of the chemical bond, preferably in terms of the electronic charge distribution in the molecule itself. One way to analyze the chemical bond is to study the difference in electronic charge density and its associated energy between a molecule and its constituent atoms. Most workers agree that the chemical bond can be associated with an overall contraction of the charge cloud, leading to an increase in charge density between the nuclei [*see top illustration on page 69*]. Nonetheless, there is still some ambiguity as to how exactly this change in charge density is associated with the various energy variations. Another way of looking at the chemical bond is in terms of the force exerted on the nuclei by the charge cloud. This approach has been applied recently to a variety of molecules. Accurate computer chemistry provides an unprecedented opportunity to probe the details of chemical bonding.

As our theoretical models are further refined and as our mathematical apparatus and computers increase in efficiency over the next few years we expect to be able to observe an entire simple chemical reaction on the computer. Thus when we write $2H_2 + O_2 \rightleftharpoons 2H_2O$, we should like to see a continuous process in terms of accurate electronic charge densities [*see bottom illustration on page 69*]. We would then be able to explore fully the changes in the energy and electron distribution as the hydrogen and oxygen molecules approach each other from different angles and pass through a series of intermediate steps to yield the stable water molecule. It is perhaps in this respect of being able to explore slowly and visually a complicated chemical process

FORMATION OF DIATOMIC MOLECULES can be visualized by arranging sequences of computer-generated electron-density diagrams depicting pairs of atoms at successively closer internuclear distances. The three examples on the opposite page show two isolated hydrogen atoms coming together to form the covalent-bonded H_2 system (*left*), a neutral lithium atom and a neutral fluorine atom joining to form the ionic-bonded LiF system (*center*) and two helium atoms being forced together to form the unstable He_2 system (*right*). Below each sequence of diagrams is a corresponding graph giving the changes that take place in the total energy of the system during the successive stages of molecular formation. In the H_2 sequence the initial delocalization of the electrons is evidenced by the disappearance of the innermost contour (stage *d*). This is followed by an overall contraction of the electron-density cloud as the formation process continues with a gradual buildup of charge density between and around the two nuclei. The equilibrium, or minimum-potential-energy, configuration of the molecule is reached at stage *g*, which corresponds to the bottom of a "potential well" in the energy graph below. In the LiF sequence a drastic change in charge density takes place at an internuclear distance of 13.9 bohrs (stage *b*) when the system changes from a neutral one to a more stable ionic one. The comparatively undistorted Li^+ ion and F^- ion then come together to the equilibrium LiF separation (stage *g*). In the He_2 sequence the two helium atoms repel each other, in contrast to the stable H_2 system in which the two atoms attract each other. The electronic charge density in the He_2 system is pushed out from between the two nuclei because as noble-gas atoms their outermost electron shells are filled and the type of electron-sharing that was possible between the unfilled shells of the hydrogen atoms cannot take place.



HYDROGEN ATOMS
PROTON
HYDROGEN MOLECULES
$1\sigma_g{}^1$
$1s^1$
$1\sigma_g{}^1 1\pi_g{}^1$
$1s^1$
$2p^1$
$1\sigma_g{}^1 1\pi_u{}^1$
$1\sigma_g{}^1 1\sigma_u{}^1$
0
10
20
DISTANCE (BOHRS)
$1s^1$
$1s^1$
$1\sigma_g{}^2$
ENERGY (HARTREES)
−.4
−.5
−.6
−.7
−.8
−.9
−1
−1.1
−1.2
−1.3
0
1
2
3
4
5
6
7
8
9
INTERNUCLEAR DISTANCE (BOHRS)

in terms of both its quantitative features and its conceptual features that such computer "experiments" offer their most informative potential. Such computer studies of chemical reactions, which are now in their early stages, also promise by extensive interplay with parallel experimental results to characterize and define such often vague concepts as the transition state of a molecule. In addition fine details of the nature of the chemical-reaction surface (that is, the energy changes associated with the approach of reacting atoms from all possible directions) are accessible to the computer experiment, whereas the conventional physical experiment often sees these effects only as the average over time or space of a continuous chemical process, a result that cannot usually be translated unambiguously into a detailed reaction surface.

On to Bulk Properties

As I have mentioned, one of the most compelling reasons for being able to evaluate the properties and interactions between individual atoms and molecules is that highly sophisticated statistical theories have been developed that allow the calculation of the equation of state and transport properties of a macroscopic system from the characteristic atomic and molecular wave functions. Such theories are now quite accurate for dilute gases and are becoming increasingly precise for dense gases, liquids and solids. We know, for example, that for a

EXCITATION AND IONIZATION of a hydrogen molecule are viewed according to the orbital model as changes in the density and shape of the molecule's electron cloud. When such a molecule is excited to a higher energy state by absorbing energy from outside in discrete quanta (*corresponding to the vertical distance between the colored energy curves*), its charge cloud typically becomes more extended and more complicated. (When the molecule emits energy, the reverse changes occur.) When enough energy is absorbed, the molecule's outer electron is ejected, creating a positive molecular ion of hydrogen (*top left*). The curves indicate how the total energy of the system changes as the two hydrogen atoms (*right*) come together in various ways. The electronic configurations next to the diagrams indicate the atomic or molecular orbital that is in each case the dominant contributor to the total wave function. At higher excited states of the molecule the area enclosed by the highest-value, innermost contour first becomes smaller and then disappears as charge density is removed from this region.

Although the cathode ray tube terminal has become commonplace in computer systems, the problem of getting hard copies of the readouts has persisted.

Until now, available devices have been too costly. Or too bulky. Or immovable. Or too slow, tying up equipment for too long.

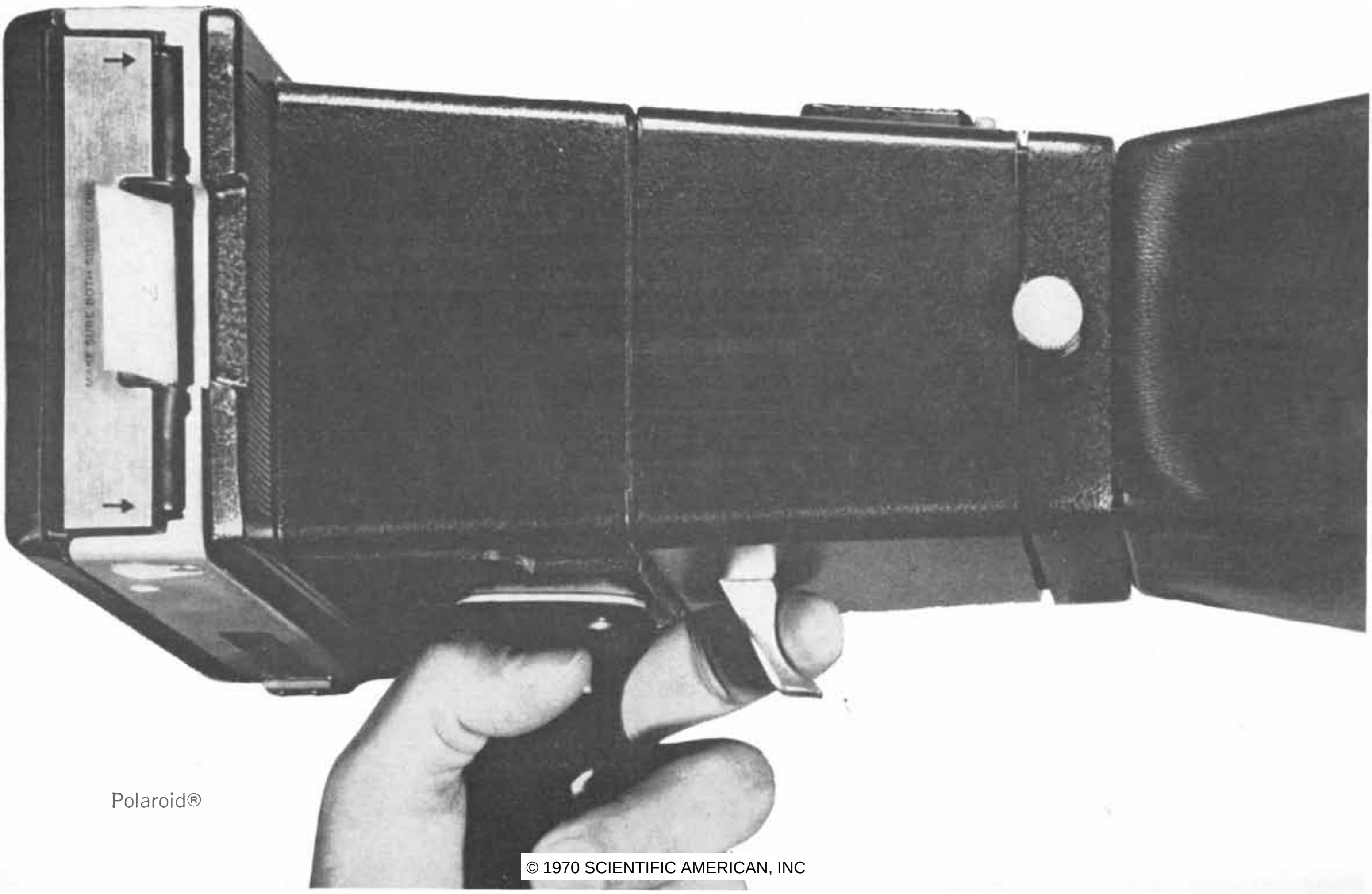
But that's all over. Polaroid's new CU-5 Hard Copy Land Camera has arrived.

You don't have to be a photographer to use it. The hood positions the camera for sharp focus, frames the image, and blocks out ambient light. All you do is hold the camera against the display, pull the trigger, and you have a shot in a split second.

And with Polaroid instant photography, in just seconds more you have the copy in your hand.

It's light in weight and hand held, so using it

The trouble-shooter: Now Polaroid solves problems for computers.

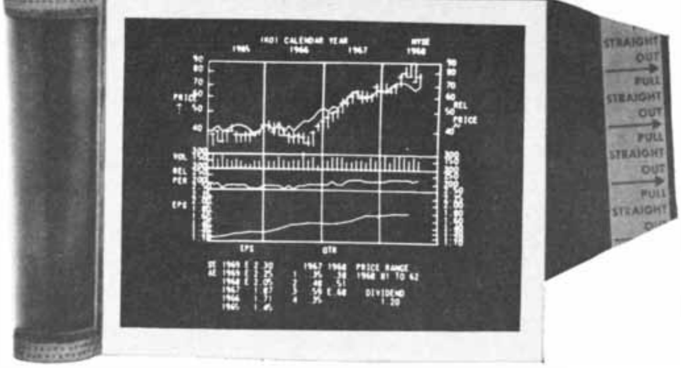


Polaroid®

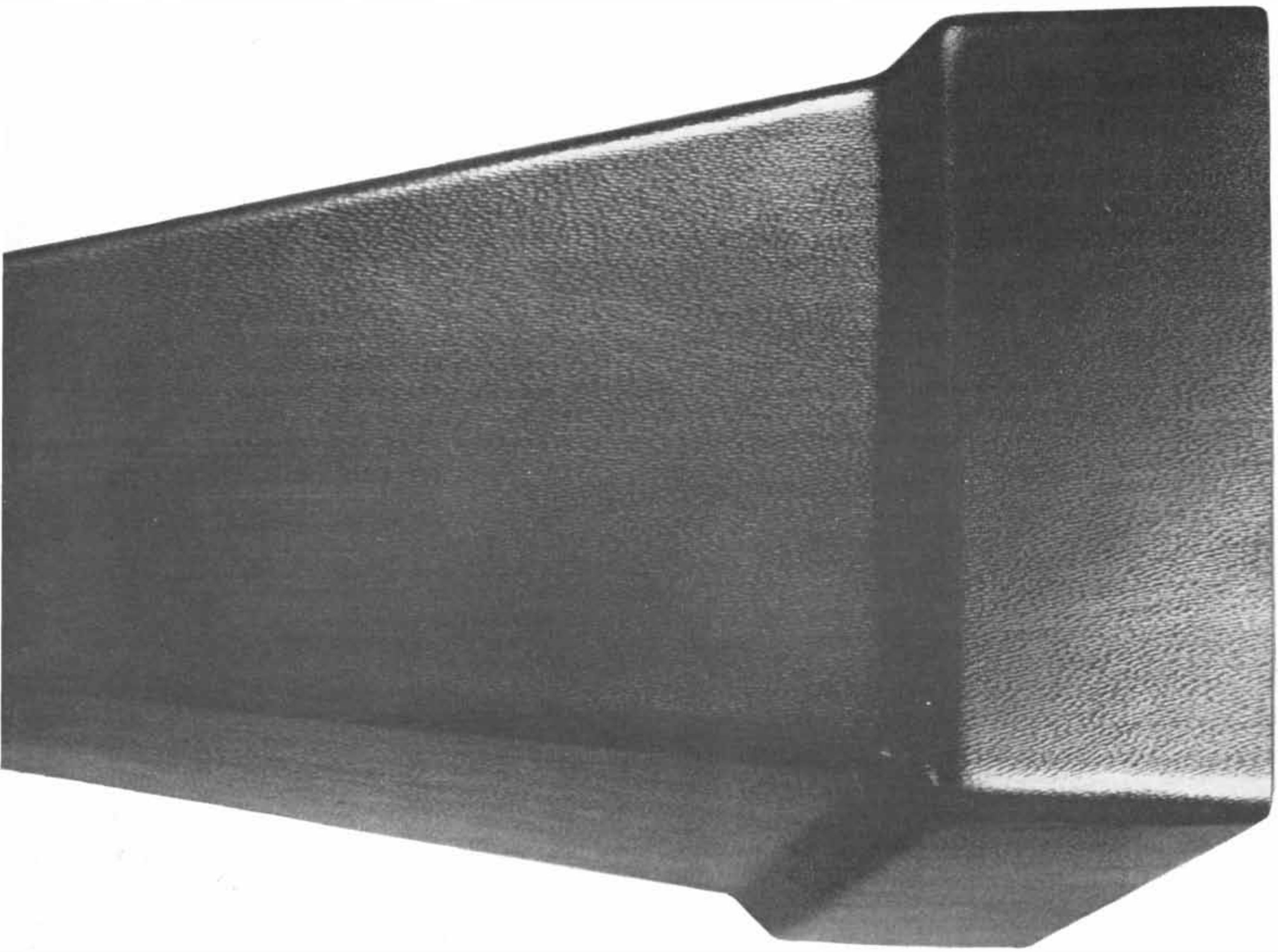
for a number of screens is no problem.

For detailed information, or a demonstration, write to: Polaroid Corporation, Dept. 57-183, Cambridge, Mass. 02139. In Canada, write to: 350 Carlingview Drive, Rexdale, Ont.

What's most remarkable about the CU-5 is the price. It's under $300, a fraction of what other equipment costs. So you won't have to shoot the works to own it.



Polaroid's new CU-5 Hard Copy Camera for CRT terminals. Under $300.



"perfect" gas, namely one made up of particles with no volume and with no forces between particles, the equation of state is $PV = RT$, where P is the gas pressure, V the gas volume, R a constant and T the temperature. This equation is quite accurate for real gases provided that they are quite dilute; however, even then the deviations from the ideal case are important, and one must modify the perfect-gas equation of state to take into account the fact that the atoms or molecules of the gas occupy volume and have forces operating between them. One of the most successful modifications of this type is called the virial equation of state, which is written $PV/RT = 1 + B(T)/V + C(T)/V^2 + D(T)/V^3 \ldots$ The coefficients $B(T)$, $C(T)$ and $D(T)$, which depend on temperature, are respectively called the second, third and fourth virial coefficients. Statistical mechanics can be used to evaluate these virial coefficients directly in terms of the forces between atoms or molecules. Thus computer calculations of interatomic and intermolecular forces, when coupled with statistical mechanics, can lead directly to an improved equation of state.

Another important class of bulk chemical properties, called the transport properties, includes viscosity (transport of momentum through a fluid), diffusion (transport of mass) and thermal conductivity (transport of thermal energy). These properties are directly related to the size and shape of individual atoms and molecules and to the forces between them. They are hence susceptible to investigation by theoretical computations.

A New Chemical Instrument

What I have been describing are typical mathematical models of molecular structure and simple chemical processes. These concepts and models have been developed and refined by chemists over the past 50 years. It is only in the past 20 years, however, that such models have been computationally developed, and it is only in even more recent years that they have been comprehensively programmed on large-memory, high-speed digital computers to be operative for many different molecules. When applied cautiously, they are now capable of yielding useful chemical information, and thus they provide an independent and competitive investigative technique, particularly when an experiment is very difficult or even dangerous. Accordingly, if the experimental worker faced with a chemical problem is to be encouraged to ask the question "Should I measure the answer or should I compute the answer?" some attention must be given to making it possible for the nonspecialized worker to utilize sophisticated computer technology.

Here I should like to discuss BISON, a computing tool we have developed in our laboratory that addresses itself to this problem. BISON is most properly viewed as a new chemical instrument to which the chemist can easily turn for certain types of chemical information. BISON has been designed with four basic principles in mind: (1) responsiveness to questions posed in the chemist's natural language; (2) ability to estimate the reliability of the computed answers; (3) foolproof operation with a great deal of procedural experience programmed into the system; (4) heavy use of computer graphics.

In BISON the first two requirements are accomplished by means of an INTERVIEW module, which converses by teletypewriter with the investigator in a conversational FORTRAN language to define his request clearly and to inform him of the time involved and the precision in the computed answer. An essential feature of INTERVIEW is that it converses in the chemist's natural language and not in a highly complex or specialized input code. Since INTERVIEW is based on a key-word vocabulary, the chemist's questions and answers can be stated in any way as long as a few key words natural to the chemical problem are included. A typical conversation between the chemist and BISON's INTERVIEW module might go like this:

Chemist: I should like the dipole moment of the lowest-lying doublet π state of the calcium oxide (CaO) molecule.

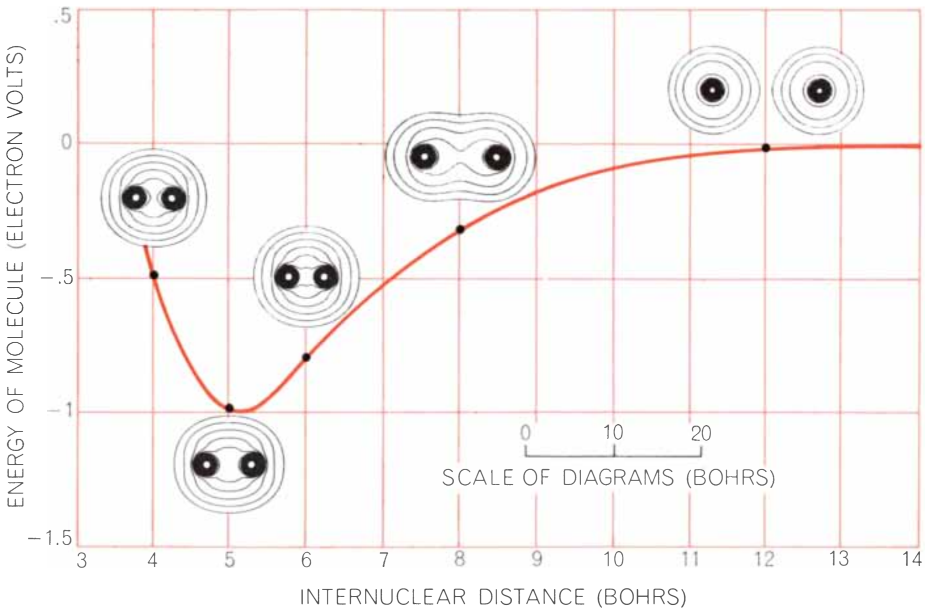
BISON: At which internuclear distance?

Chemist: The equilibrium separation.

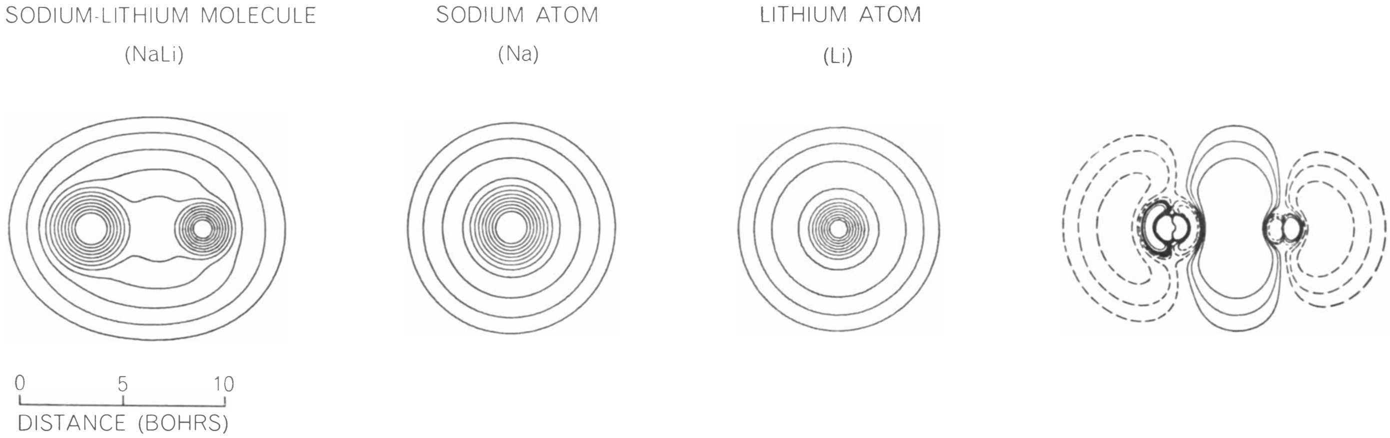
BISON: I shall require four hours of machine time. The probable error in the computed dipole moment will be approximately 20 percent. Should I proceed?

The third requirement—foolproof operation—is fulfilled by a PROCEDURE EXECUTIVE module. Once the chemist has conversed with BISON through the INTERVIEW module and placed his "order," the system "takes off" on its own without further inconvenience to the chemist. The PROCEDURE EXECUTIVE module supervises a sequence of calculations necessary in order to answer the chemist's question.

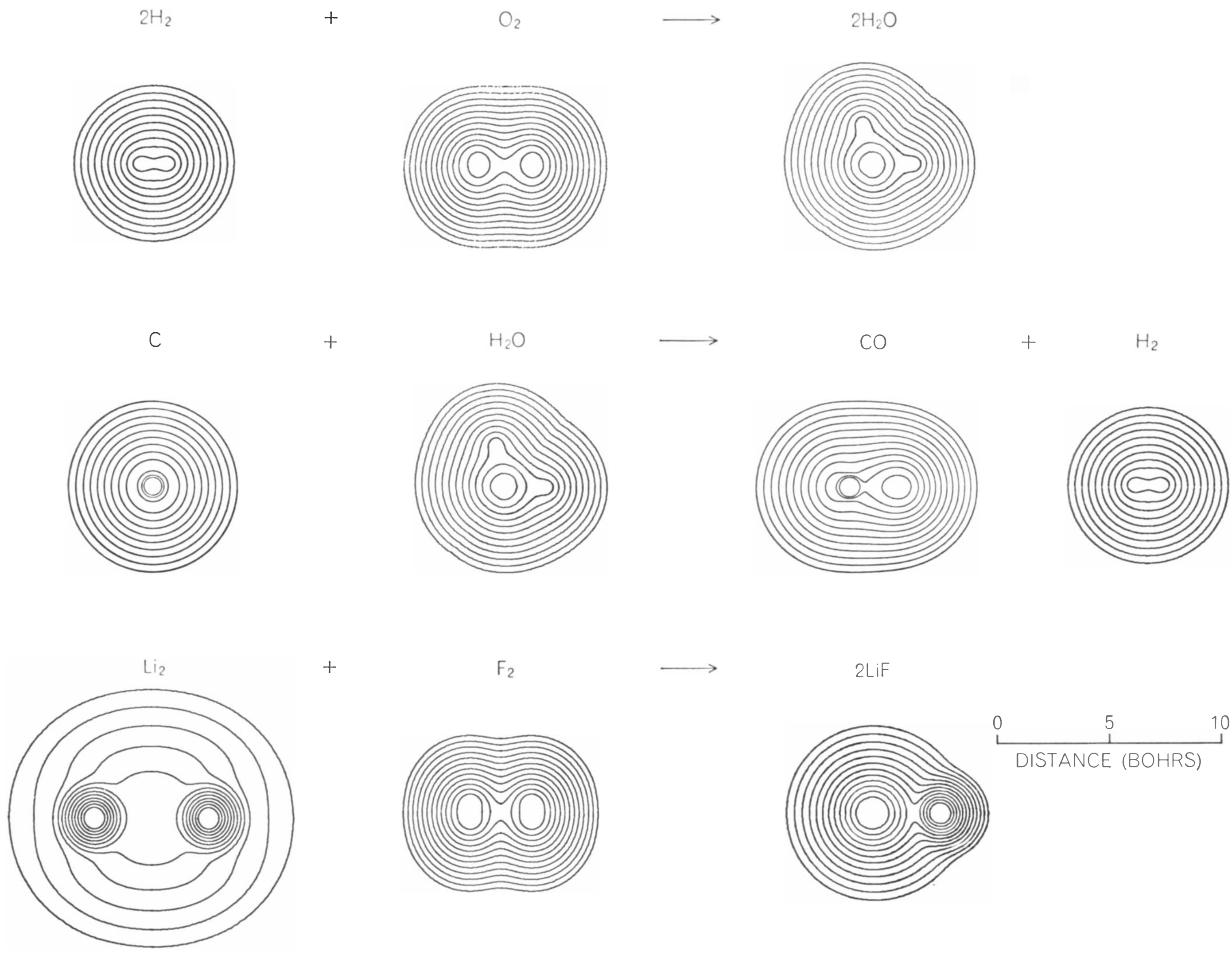
Currently BISON is based on the Har-



MOLECULAR VIBRATION, another way in which a molecule can absorb or emit energy in discrete quanta, is responsible for certain chemical properties that can be studied mathematically by solving the Schrödinger equation to obtain the value of the molecular energy for various fixed positions of the nuclei. This procedure results in a potential-energy curve in which the nuclei are considered to vibrate. The shape of this potential well determines the frequency of the molecular vibrations. The molecule can emit or absorb vibrational energy in multiples of this fundamental vibrational frequency. (The changes in energy that occur during molecular vibration are usually much smaller than those associated with electronic excitation.) As these contour diagrams of a diatomic lithium molecule (Li_2) show, the electron density changes quite smoothly as the nuclei vibrate in the potential well. If the molecule absorbs enough vibrational energy through radiation or collisions with other molecules, atoms or surfaces, it "dissociates," or breaks up into its constituent atoms.



CONCEPT OF CHEMICAL BOND can be studied by observing the changes that take place in the computed electronic charge density as the molecule forms. For example, these diagrams show the electron density of a stable sodium-lithium molecule (*left*), the electron density of its separated constituent atoms (*center*) and the "difference density" (*right*), that is, the difference between the density of the stable molecule and the density of the undistorted atoms brought together to the equilibrium molecular position. The solid contour lines at right denote regions of positive difference density (regions where the charge density has increased); the broken lines denote regions of negative difference density (regions where the charge density has decreased).



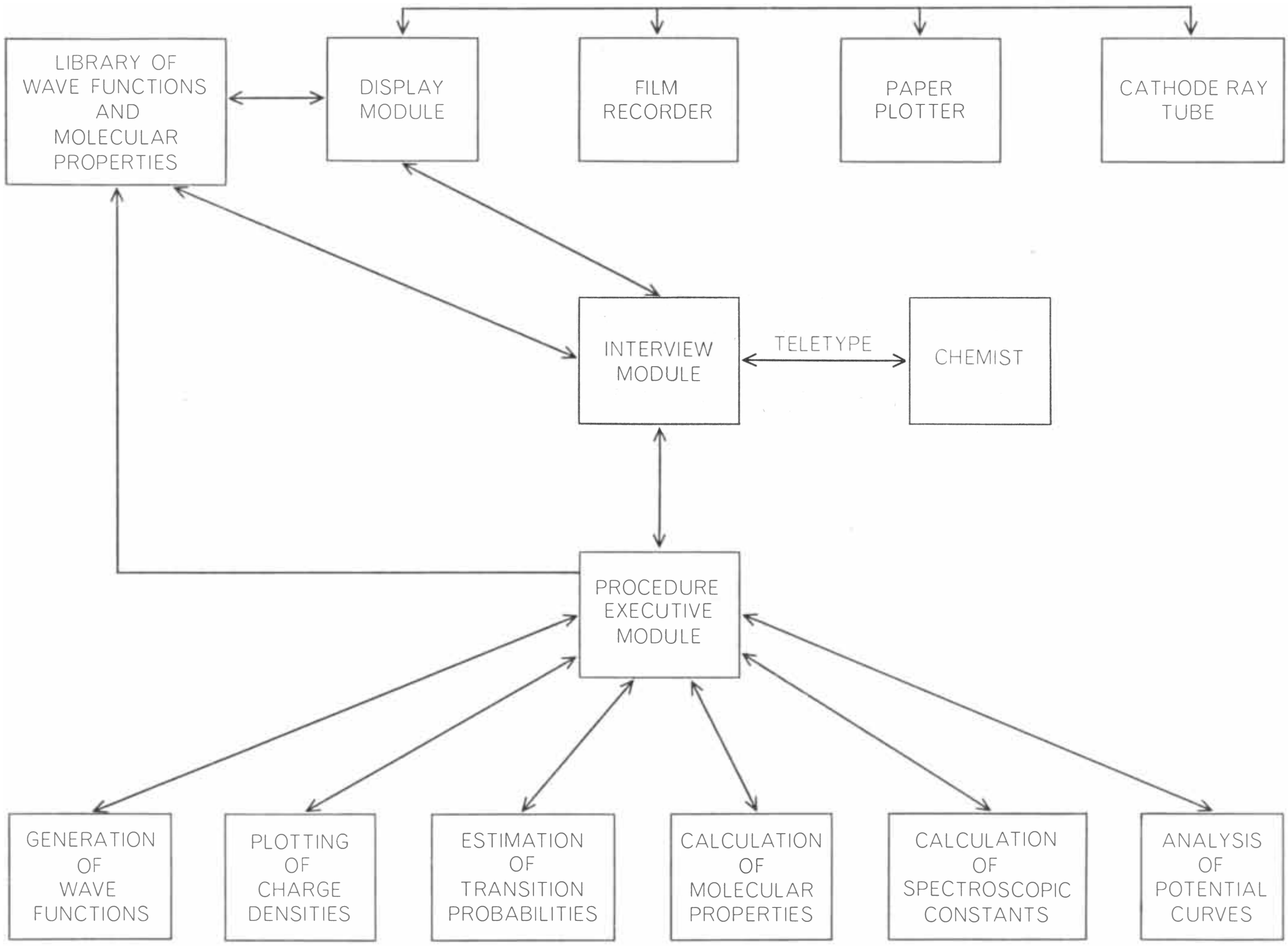
THREE CHEMICAL REACTIONS are portrayed here in terms of changes in computed electron-density diagrams. The reaction at top shows two hydrogen molecules (H_2) combining with an oxygen molecule (O_2) to form two water molecules (H_2O). The reaction at middle shows a carbon atom (C) and a water molecule (H_2O) combining to form a carbon monoxide molecule (CO) and a hydrogen molecule (H_2). The reaction at bottom shows a lithium molecule (Li_2) and a fluorine molecule (F_2) combining to form two lithium fluoride molecules (LiF). At present even such relatively simple reactions present a considerable challenge to computer chemistry, but it appears reasonable to expect that this general approach will be extended to much more complicated reactions.

tree-Fock molecular orbital model of diatomic molecules, and PROCEDURE EXECUTIVE, by supervising the "workhorse," or unit-operation, program, can yield reliable charge densities, molecular sizes and shapes, ionization potentials, dipole moments and other related molecular properties. For certain classes of diatomic molecules it also yields useful potential curves, vibrational frequencies, binding energies and transition probabilities.

BISON will generate and plot on film, paper or a cathode ray screen contour diagrams of the orbital and total density of a molecule or a chemical process. All the diagrams used in this article were drawn by BISON. This display feature is particularly fascinating when it is used to watch a molecule form, or pass through a series of energy states, or encounter another molecule or an atom, or ultimately engage in a chemical reaction. The display feature will soon be operative, using precomputed and stored charge densities interpolated between computed points so that they can be quickly manipulated in "real time." Currently the calculation required for this purpose is too time-consuming except for the most trivial molecules.

It is important to stress that BISON is at present an information-creation system. Starting from first principles, BISON obtains by computation the answer to the chemist's questions. Thus it is an independent source of information, not a system that simply retrieves information or interpolates or extrapolates it from large tables of stored data. The plan is to include in BISON such a retrieval capacity and to have BISON upgrade its own store of information as it answers new questions.

Future plans for BISON include the extension of the system to simple polyatomic molecules for the detailed study of chemical reactions, the inclusion of other molecular properties and the development of a transport-property module that will evaluate bulk physical properties from computed atomic and molecular properties. The incorporation of sophisticated computing technology into systems that fulfill "instrument" requirements is certainly becoming an important new development in the physical sciences. As theoretical techniques in all disciplines become more comprehensive and powerful, and as anticipated improvements in computer speed, sophistication, organization and accessibility through widely distributed terminals become a reality, more and more experimental workers will undoubtedly turn to the computer experiment as an alternative to the traditional one.



BISON, a new computing instrument developed by the author and his colleagues at the Argonne National Laboratory, is designed to make it possible for a chemist who is not a computer specialist to obtain certain types of chemical information with the aid of rigorous mathematical models and sophisticated computer technology. At present the investigator converses with BISON by teletypewriter through an INTERVIEW module in the chemist's natural language. Relying on a library of previous experience, INTERVIEW informs him of the time required to fill his request and the precision of the computed answer. If the chemist decides to place his "order," a PROCEDURE EXECUTIVE module then "takes off" on its own, supervising a sequence of calculations necessary to answer the chemist's question. The electronic charge densities of the atoms or molecules involved in a chemical process can be produced and displayed on film, paper or the screen of a cathode ray tube. All the diagrams used to illustrate this article were produced by BISON.

CRUSHED EGG in the nest of a brown pelican off the California coast had such a thin shell that the weight of the nesting parent's body destroyed it. The concentration of DDE in the eggs of this 300-pair colony reached 2,500 parts per million; no eggs hatched.

Pesticides and the Reproduction of Birds

High concentrations of chlorinated hydrocarbon residues accumulate in such flesh-eaters as hawks and pelicans. Among the results are upsets in normal breeding behavior and eggs too fragile to survive

by David B. Peakall

The birds of prey have had an uneasy coexistence with man. Apart from the training of certain hawks for falconry and the veneration of the eagle as a symbol of fortitude, the predatory birds have been preyed on by the human species. In many parts of the world farmers, hunters and bird-lovers have waged unceasing warfare on the rapacious birds as pests, and egg collectors have further threatened their survival by raiding their nests for the beautifully pigmented eggs. Nevertheless, over the centuries the birds of prey on the whole survived well. The peregrine falcon, for example, is known to have maintained a remarkably stable population; records of aeries that have been occupied more or less continuously by peregrines go back in some cases to the Middle Ages.

About two decades ago, however, the peregrines in Europe and in North America suddenly suffered a crash in population. The peregrine is now rapidly vanishing in settled areas of the world, and in some places, particularly the eastern U.S., it is already extinct [*see illustration on page 74*]. The abrupt population fall of the peregrine (known in the U.S. as the duck hawk) has been paralleled by sharp declines of the bald eagle, the osprey and Cooper's hawk in the U.S. and of the golden eagle and the kestrel, or sparrow hawk, in Europe. The osprey, or fish hawk, has nearly disappeared from its haunts in southern New England and on Long Island; along the Connecticut River, where 150 pairs nested in 1952, only five pairs nested in 1969.

The population declines of all these raptorial birds are traceable not to the killing of adults but to a drastic drop in reproduction. It has been found that the reproduction failures follow much the same pattern among the various species: delayed breeding or failure to lay eggs altogether, a remarkable thinning of the shells and much breakage of the eggs that are laid, eating of broken eggs by the parents, failure to produce more eggs after earlier clutches were lost, and high mortality of the embryos and among fledglings.

Examination of the geographic patterns suggests a cause for the birds' reproductive failure. The regions of population decline coincide with areas where persistent pesticides—the chlorinated hydrocarbons such as DDT and dieldrin—are widely applied. Attrition of the predatory birds has been most severe in the eastern U.S. and in western Europe, where these pesticides first came into heavy use two decades ago. Analysis confirmed the suspicions about the pesticides: the birds were found to contain high levels of the chlorinated hydrocarbons. In areas such as northern Canada, Alaska and Spain, where the use of these chemicals has been comparatively light, the peregrine populations have remained normal or nearly normal. Recent studies show, however, that even in the relatively isolated North American arctic region the peregrines now have fairly high levels of chlorinated hydrocarbons and their populations apparently are beginning to decline.

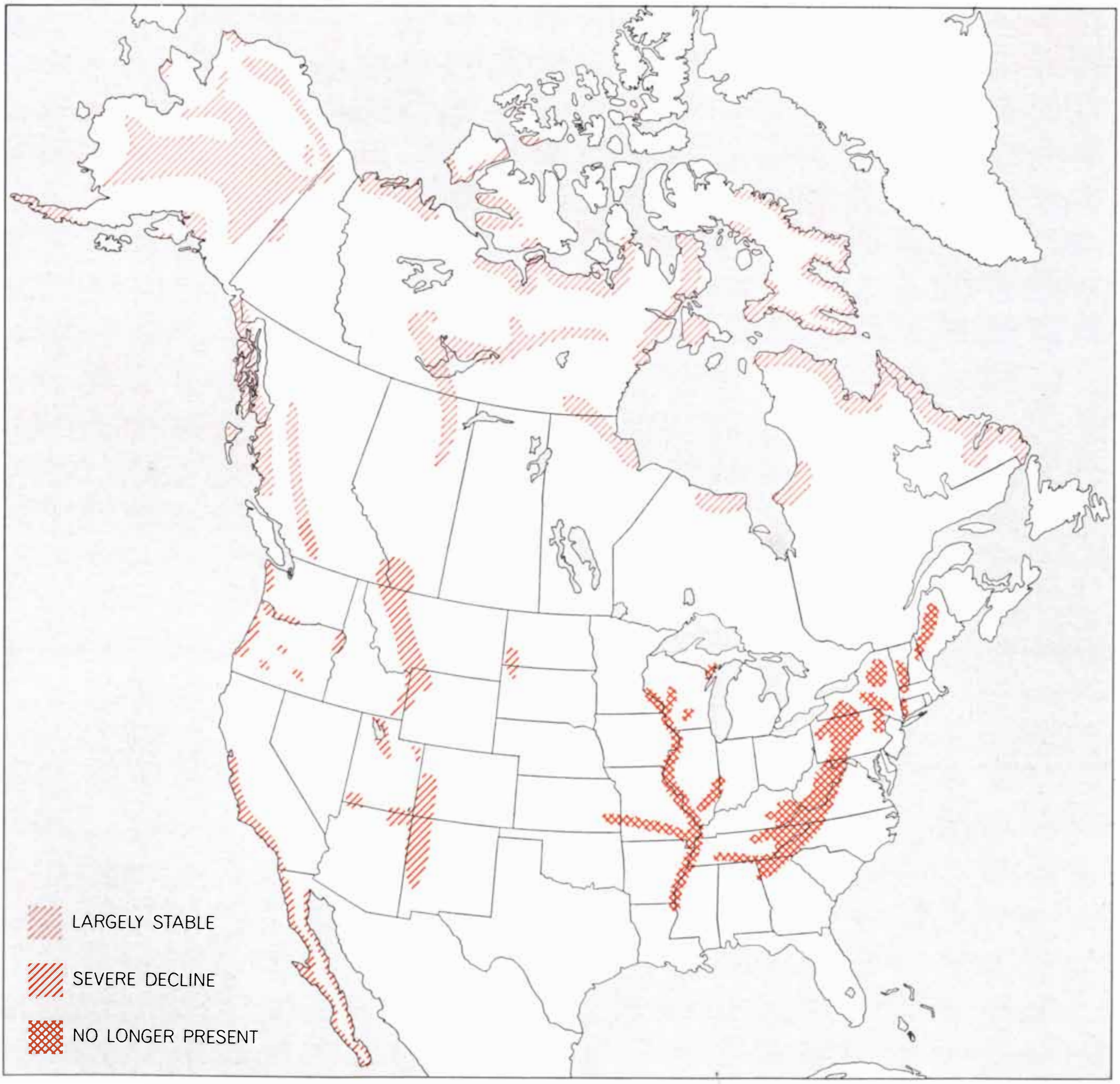
The birds of prey are particularly vulnerable to the effects of a persistent pesticide such as DDT because they are the top of a food chain. As George M. Woodwell of the Brookhaven National Laboratory has shown, DDT accumulates to an increasingly high concentration in passing up a chain from predator to predator, and at the top of the chain it may be concentrated a thousandfold or more over the content in the original source [see "Toxic Substances and Ecological Cycles," by George M. Woodwell; SCIENTIFIC AMERICAN, March, 1967]. The predatory birds, as carnivores, feed on birds that have fed in turn on insects and plants. Hence the birds of prey accumulate a higher dose of the persistent pesticides and are more likely to suffer the toxic effects than other birds.

The idea that the predatory birds' decline is due to an internal toxic effect, rather than to a change in their behavior or their habitat, has been verified by many experiments. One of the most interesting was a field test made by Paul Spitzer, now at Cornell University, working in cooperation with the Patuxent Wildlife Research Center in Maryland. He transferred eggs from nests of the failing osprey population in New England to nests of a successful population in the Chesapeake Bay area and placed the Chesapeake eggs in the New England nests. The Chesapeake eggs hatched as successfully in the New England nests as they would have at home with their own parents, whereas the New England eggs transferred to Chesapeake nests produced as few viable young as would have been expected if they had been incubated in their original nests in New England. The experiment thus indicated that the fate of the eggs was determined by an intrinsic factor in the egg itself.

The first clue to what was happening to the predatory birds' reproduction system came in the early 1960's when Derek Ratcliffe of the British Nature Conservancy, puzzled by the extraordinary number of broken eggs he found in peregrine nests, examined the shells of peregrine eggs that had been collected over a period of many years. He found that the eggs collected since the late 1940's show a sharp drop in thickness of the shell, averaging 19 percent. Similar findings were subsequently made on peregrine eggs in North America and on the eggs of other species of predatory birds whose populations were decreasing. It became apparent that something must be wrong with the birds' calcium metabolism and that the effects of the suspected pesticides would bear looking into.

Experiments were started in several laboratories. At the Patuxent Wildlife Research Center, Richard D. Porter and Stanley N. Wiemeyer, working with kestrels, found that a mixture of DDT and dieldrin in doses measured in a few parts per million brought about a significant decrease in the shell thickness of the birds' eggs. Robert G. Heath of the Patuxent center tested the effects of DDE, the principal metabolic product of DDT, on mallard ducks. DDE is now a ubiquitous feature of the earth's environment; it is estimated that there are a billion pounds of the substance in the world ecosystem, and traces of it have been found in animals everywhere, from polar bears in the Arctic to seals in the Antarctic. Heath found that DDE caused the failure of mallard eggs in two ways: by increasing the fragility of the eggs, leading to increased breakage soon after laying, and by the death of the embryos in intact eggs toward the end of the period of incubation. James H. Enderson of Colorado College and his associate Daniel D. Berger, studying the eggs of prairie falcons in the Southwest desert, established that the amount of thinning of the shells and the mortality rate for the embryos were related to the quantity of DDE in the egg. Enderson and Berger also found that when they fed starlings loaded with dieldrin to falcons, the falcons' eggs showed similar thinning.

The ultimate in thinness of birds' eggshells was discovered recently in colonies of the brown pelican off the California coast. The DDE content in the eggs of this wild population (as measured by Robert Risebrough of the University of California at Berkeley) ranged as high as 2,500 parts per million, and the eggshells were so thin that the eggs could not be picked up without denting the

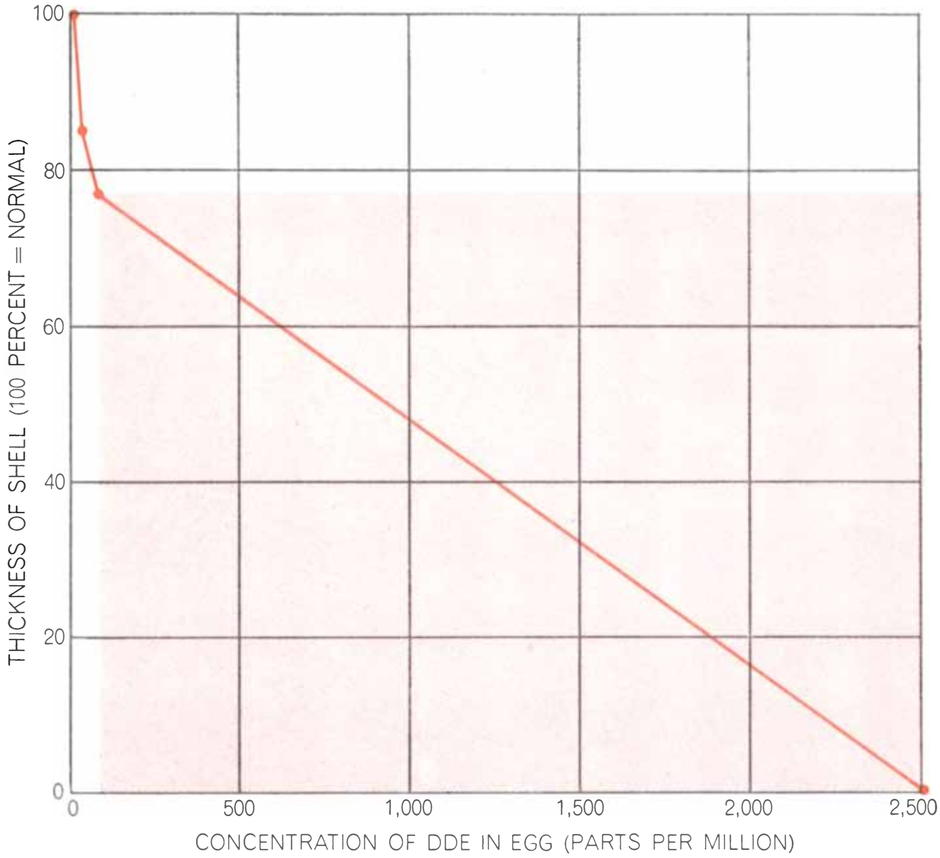


NESTING AREAS of the peregrine falcon, or duck hawk, in the Northern Hemisphere of the New World are shown on this map. Shades of color show the extent of interference with normal reproduction resulting from ingestion of pesticides by the birds.

shells [*see illustration on page 72*]. In a colony on the Anacapa Islands off the coast it was found that the 300 pairs of nesting pelicans had not produced a single viable egg. Their nests, visited shortly after the eggs were laid, contained many broken eggs.

Field studies and laboratory experiments suggest that the thinning of eggshells does not increase in direct proportion to the DDE dose. In fact, small doses can produce dramatic effects. A content of only 75 parts per million in the egg reduces the shell thickness by more than 20 percent; beyond that, as the dose increases the decrease in shell thickness is more gradual [*see illustration at right*]. In the case of the brown pelican very heavy doses may thin the shell to a mere film.

Studies of white pelicans and cormorants have implicated the polychlorinated biphenyls (PCB's), now widely used as plasticizers, as another threat to birds of prey. These compounds cause thinning of the eggshells, although not as effectively as DDT and its metabolites do. Preliminary laboratory studies show that PCB's are particularly effective, however, in delaying the onset of breeding. The PCB's are given off when plastic materials are burned, and they are widely distributed over the earth. They resemble DDT in molecular structure and produce similar physiological actions in animals.



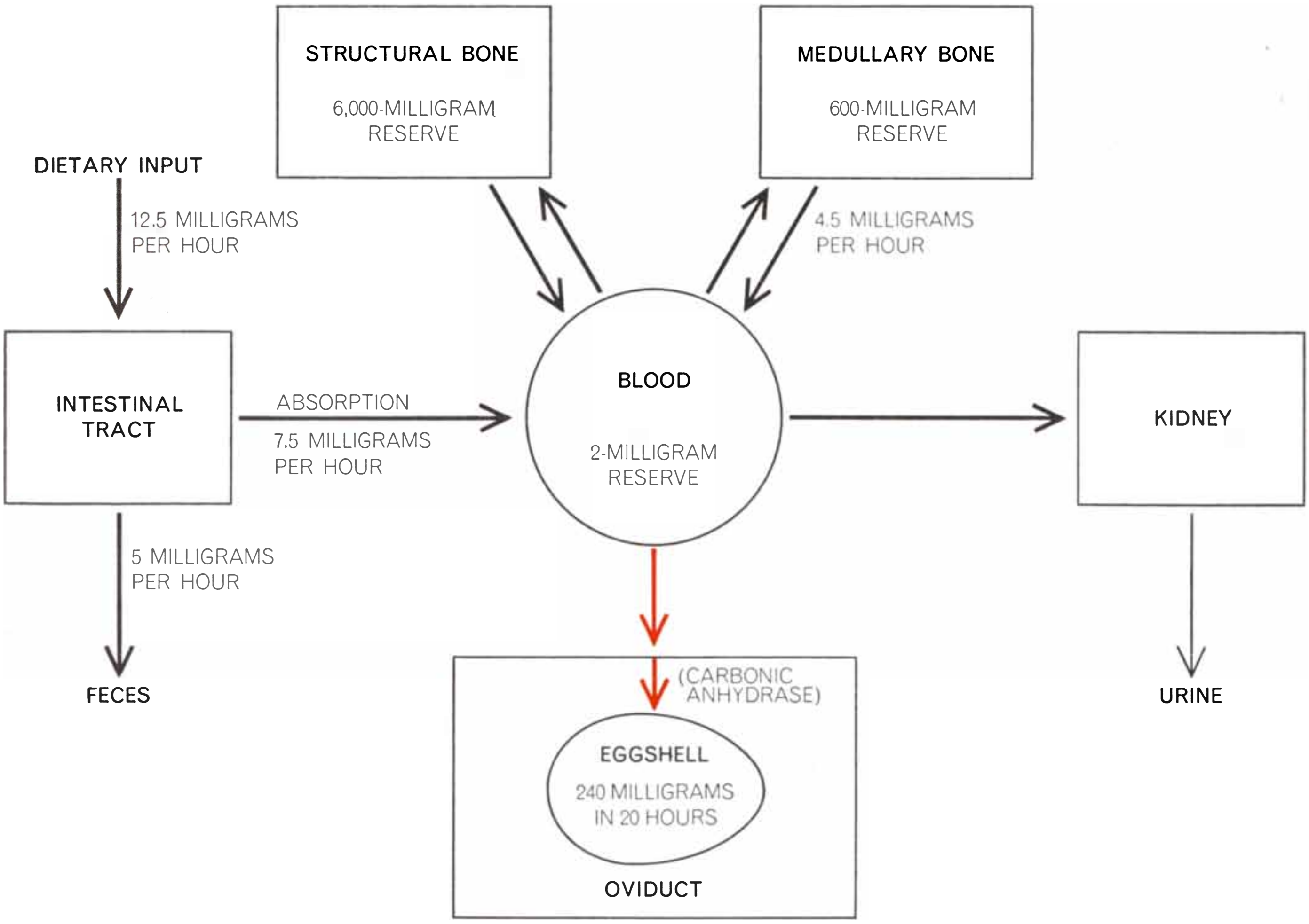
SEVERE EFFECT of the concentration of relatively small amounts of the persistent chlorinated hydrocarbon pesticides is evident in this graph. When the parent's concentration is enough to add as few as 25 parts per million of pesticide to the egg, the shell becomes 15 percent thinner than normal. Soon after the shells become more than 20 percent thinner than normal (*area of light color*) eggs are usually not found in nests because of breakage.

Much interest has focused on the question of how the chlorinated pesticides produce their destructive effects in the predatory birds—a question that is of no small concern to man, who also is the top of a food chain. Oddly enough, the beginning of light on this question came about through an accidental discovery involving an animal totally unrelated to the birds: the laboratory rat. Larry G. Hart and James R. Fouts of the University of Iowa College of Medicine were investigating the effects of food deprivation on the metabolism of drugs in rats. The drug they were using was hexobarbital, and in one experiment they were startled to find that the rats' sleeping time after receiving a standard dose of the barbiturate was much shorter than it had been in previous tests. Reexamining the conditions of the experiment, they found that the only unusual factor was that the cages had been sprayed with chlordane to control bedbugs. Pursuit of this clue led to the finding that chlordane induced rat liver cells to synthesize enzymes that speeded up the metabolism of hexobarbital. The enzymes brought about hydroxylation of the barbiturate, thereby making it more soluble in water and hastening its excretion. Further experiments showed that these enzymes could hydroxylate a wide variety of substances, including the sex hormones: estrogen, testosterone and progesterone.

Because the investigators were interested primarily in drug research and their reports were published mainly in pharmacological journals, these discoveries did not come to the attention of workers studying the effects of pesticides on wildlife until several years later. I myself came on the published findings only incidentally in the course of preparing lectures for medical students. The fact that chlordane could change the balance of sex hormones in animals immediately suggested a possible explanation of the mechanism whereby the chlorinated pesticides inhibit reproduction in birds. It was capable of explaining their reproductive failure in general and the alteration of the calcium balance in the egg in particular.

My colleagues and I at Cornell University launched on a program of experiments designed to explore the interesting questions suggested by this new aspect of the problem. To explain them I must briefly outline the complex chain of physiological events that characterizes breeding by birds. The cycle is initiated by a seasonal or climatic stimulus: the lengthening of daylight in spring in the northern Temperate Zone or rainfall in the arid and tropical regions. These signals cause an increase in the production of hormones in the nerve cells of the medial eminence of the bird's brain. The bloodstream carries these hormones to the anterior pituitary gland, which in turn dispatches to the gonads (the testes or ovaries) hormones that stimulate these organs to produce the sex hormones. The sex hormones not only generate physical changes in the reproductive organs and evoke breeding behavior but also promote the storage of a supply of calcium for the eggs.

Let us look first into the question of how a pesticide may affect the calcium supply. We carried out our experiments on the rather small Asian pigeon known as the ringdove, so that I shall describe the situation in this bird. The female forms the shell of the egg in the uterus within a period of 20 hours, and she needs 240 milligrams of calcium to pro-



CALCIUM FOR EGGSHELL, which is formed around each egg in the last 20 hours before laying, is drawn in part from the bird's food supply and in part from calcium reserves in the bird's bones. The key to shell formation, however, is the enzyme carbonic anhydrase, which makes the supply of calcium carried in the ringdove's bloodstream available to the bird's oviduct at a rate of 12 milligrams per hour. When laying ringdoves are injected with DDE, the action of the enzyme is severely inhibited, causing thin shells.

duce a shell of normal thickness. Since the calcium content of the circulating blood, even at the time of ovulation, is only two milligrams (barely a 10-minute supply), the bird must draw on other sources to meet the demand. About 60 percent of the demand is supplied by the bird's food intake; the rest is provided by a store of calcium in the marrow of the bones [see "How an Eggshell Is Made," by T. G. Taylor; SCIENTIFIC AMERICAN, March]. This calcium reserve is laid down in the bone cavities early in the breeding cycle, and the amount of the deposit is controlled by the levels of estrogen in the blood and tissues. Obviously, therefore, a deficiency of estrogen will reduce the bird's calcium reserve. It seemed unlikely, however, that the reduction of this reserve alone could account for the drastic shell-thinning observed in eggs loaded with pesticides. If the *supply* of calcium were the sole problem, the birds could augment the supply by drawing on the calcium embodied in the skeleton; furthermore, birds on a very low calcium diet have been found to cease egg-laying rather than laying eggs with abnormally thin shells. Was it possible, then, that the thinness of the eggshells was due less to the deficiency in supply than to a failure in delivery of calcium to the shell?

In our experiments we bred pairs of ringdoves in cages and delayed feeding the birds a pesticide until after they had completed at least one successful breeding cycle, thereby demonstrating their natural capability. For the experiment we separated the members of each pair, isolated them in individual cages where they had an eight-hour day instead of their normal 16-hour day and fed them a standard dose of DDT in their food. After three weeks we gave each bird an oral dose of radioactive calcium and returned the birds to cages with their original partners for pairing under long-day conditions. A number of days later we examined the birds, some before they laid eggs, others immediately after they finished laying their clutch. In both cases the birds showed a considerable rise of enzyme activity in the liver. A substantially lower level of estrogen was found in the bloodstream of the birds that had not yet laid eggs. After the eggs had been laid, low estrogen levels were found in both experimental and control birds; this was to be expected because the level of estrogen falls at the time of egg-laying. We found that less labeled calcium was stored in the bone marrow of the experimental birds than in the marrow of control birds that had not been fed the pesticide.

Eggs laid by the pesticide-treated birds were notably thin-shelled, as was to be expected. We proceeded to experiments designed to determine whether this was due simply to the shortage of stored calcium or to something that prevented calcium from reaching the shell. In order to resolve this question we resorted to the tactic of injecting pesticides into females within a period of hours before they laid their eggs. In that short interval there would not be time for any significant change in the supply of calcium by way of an alteration of the estrogen levels through the activity of liver enzymes; consequently if the pesticide produced an effect, it would be not on the stored supply but on the delivery of calcium to the eggshell, which as we have noted is laid down within 20 hours of the laying of the egg. And with regard to delivery it was known that an enzyme, carbonic anhydrase, plays an important role in making calcium available to the eggshell in the oviduct. One could therefore look for a possible effect on the activity of this enzyme.

We tried two chlorinated hydrocarbons: dieldrin and DDE. Dieldrin, when injected into a ringdove shortly before it laid its egg, did not produce any significant thinning of the eggshell or inhibit the activity of carbonic anhydrase in the oviduct. DDE, on the other hand, severely depressed the activity of the enzyme and brought about a marked decrease in the thickness of the eggshell.

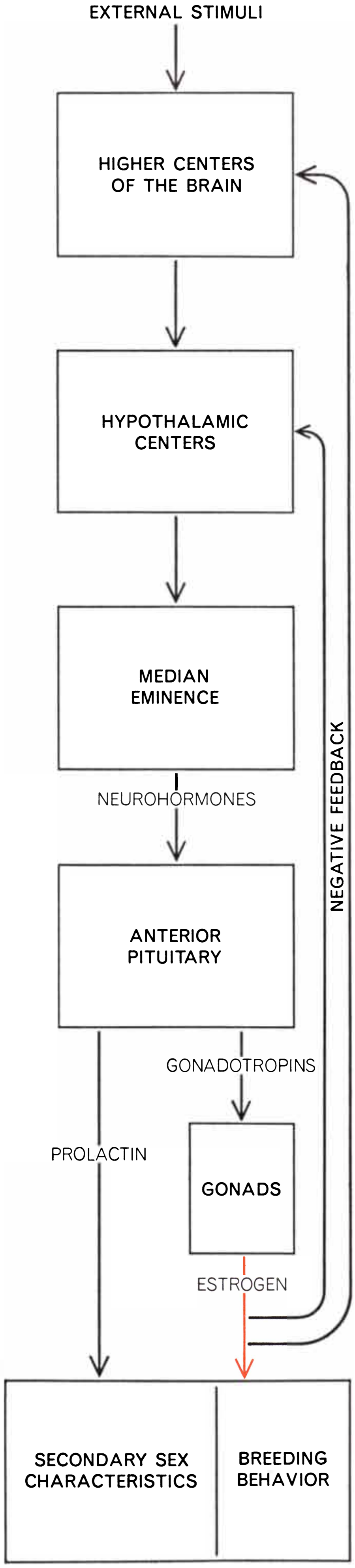
Our experiments with ringdoves also showed that the chlorinated hydrocarbons cause a significant delay in breeding by birds. Females that were fed pesticides did not lay eggs until 21.5 days (on the average) and sometimes as long as 25 days after pairing, whereas the normal interval, as indicated by the control birds, is 16.5 days on the average. The delay evidently was caused by the depression of the estrogen level resulting from the induction of liver enzymes by the pesticide. It turned out that dieldrin and the polychlorinated biphenyls were more powerful inducers of these enzymes than DDT was.

Delayed breeding is another factor in the predatory birds' population decline. Most birds do their breeding in the season when food is most plentiful, thus giving their young an optimal chance for survival. An artificial delay in their breeding consequently reduces the chances for reproductive success, and it is most serious for large birds, with their long egg-incubation period and the slower growth of the fledglings to maturity. It was found that the now extinct peregrine colonies along the Hudson River, the declining cormorant rookery at Lake DuBay in Wisconsin and the failing pelican colonies in California were all notably late in breeding.

From this point of view it appears that dieldrin and the PCB's are greater threats to the predatory birds than DDT. Certain field and laboratory studies tend to bear out that deduction. Derek Ratcliffe and J. D. Lockie, in long-term observation of the nests of golden eagles in Scotland, found that although abnormal eggshell breakage began in 1952, about the time that DDT was introduced, marked decline in the breeding success of these birds did not begin until 1960, after the introduction of dieldrin. In laboratory experiments on the bobwhite quail James B. DeWitt and John L. George of the U.S. Fish and Wildlife Service found that one part per million of dieldrin was effective in reducing the success in hatching and survival of chicks, whereas it took 200 parts per million of DDT to produce the same effect. Robert Heath found in his studies of mallard ducks, however, that DDE severely impaired reproductive success at doses as low as 10 parts per million. Thus there appears to be a considerable difference in the effect of DDT and its metabolites on different species of birds.

We come to the following conclusions concerning the physiological mechanisms responsible for the various harmful effects on bird breeding that are brought about by the persistent insecticides. Abnormally late breeding and the failure of birds to lay eggs after their early clutches have been lost can be explained in terms of the induction of liver enzymes that lower the estrogen levels in the birds. The failure, or apparent failure, of birds to lay any eggs at all may be due either to depression of the estrogen level or to the circumstance that the eggs were broken and eaten by the parents shortly after they were laid, so that observers found no eggs in the nest on visiting them. The reduction in clutch size may also be accounted for by early breakage and eating of some of the eggs, as this has been noted mainly in cases where the nests were not checked frequently. The thinning of eggshells and breakage of the eggs evidently is due largely to the inhibition of carbonic anhydrase by DDT and its metabolites. We are left with some phenomena that are still unexplained. Why does a low dose of pesticide produce relatively more thinning of the eggshell than larger doses do? What is the mechanism that kills embryos in the shell? These questions need further investigation.

The effect of the pesticides in disturb-



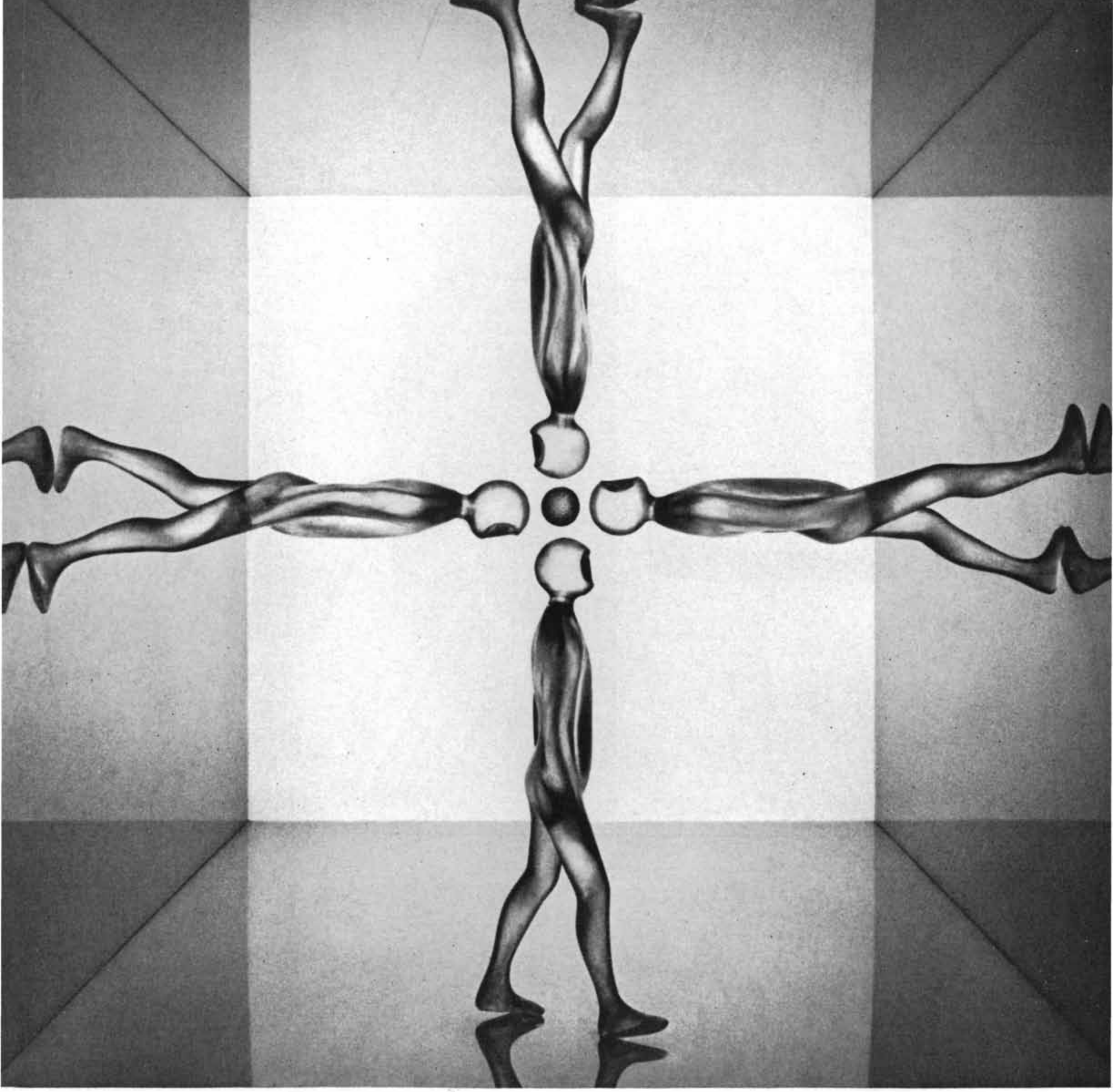
BREEDING SUCCESS in birds involves the five sequential responses to external stimuli shown in the illustration at right. Breeding failures, due to late breeding or an inability to lay more eggs after earlier clutches are destroyed, result from the action of pesticides on the fifth response. They stimulate the activity of enzymes in the breeding bird's liver; the enzymes cut the amount of estrogen in the system below the level that is needed for normal sexual behavior.

ing the calcium balance of birds probably is not of direct concern to man, because birds are a special case in their high calcium requirement at breeding time. It seems, however, that we should be concerned about the pesticides' effects on the hormone balance and on other physiological systems. The induction by pesticides of liver enzymes that lower the estrogen levels has been found in a wide variety of vertebrates, including a primate, the squirrel monkey. There is little doubt that this effect applies to man as well. Moreover, the chlorinated hydrocarbons are known to alter the glucose metabolism and inhibit an enzyme (adenosine triphosphatase, or ATPase) that plays a vital role in the energy economy of the human body.

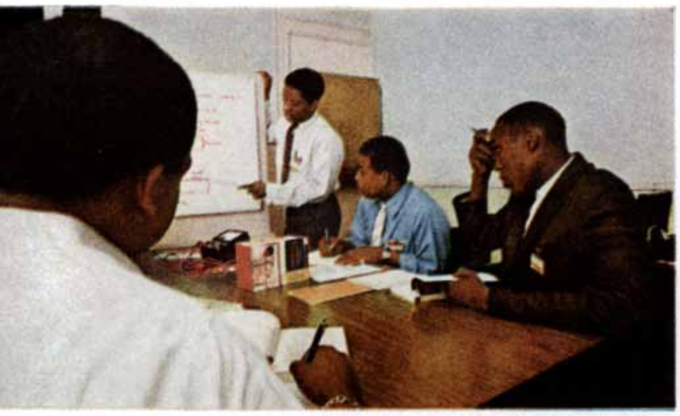
The recent finding by investigators at the National Cancer Institute that a dose of 46 milligrams of DDT per kilogram of body weight can produce a fourfold increase in tumors of the liver, lungs and lymphoid organs of animals indicates that DDT should be banned for that reason alone. Human cancer victims have been found to have two to two and a half times more DDT in their fat than occurs in the normal population. Investigators in the U.S.S.R. recently reported that DDD, another metabolite of DDT, reduces the islets of Langerhans, the site of insulin synthesis.

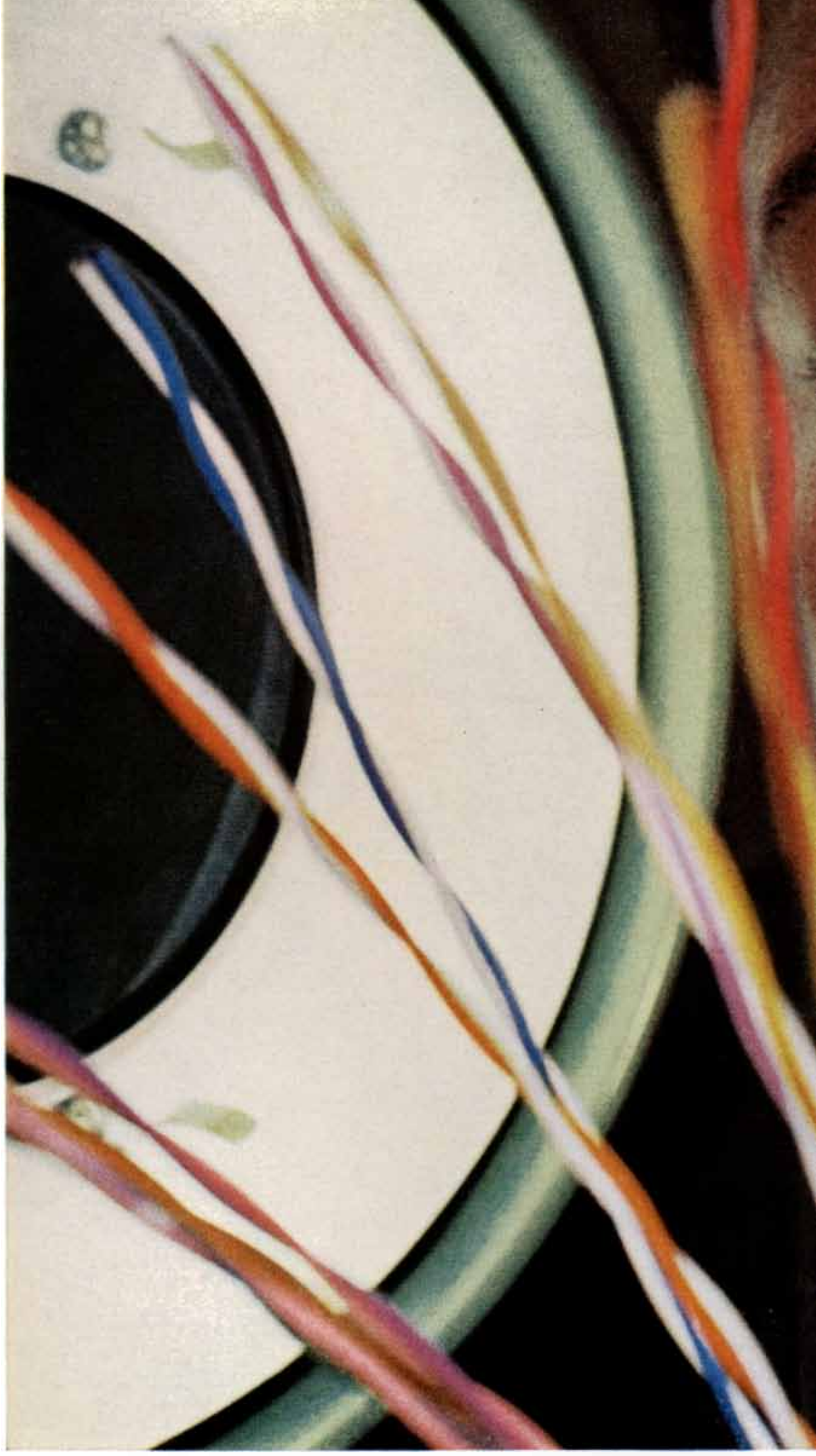
The peregrine population crash has prompted two international conferences of concerned investigators, in 1965 and again in 1969. It is encouraging to note that in Britain, where severe restrictions were imposed in 1964 on the use of chlorinated hydrocarbon pesticides, the peregrine population has increased in the past two years. The Canadian government recently announced licensing restrictions that are expected to reduce the use of these pesticides by 90 percent, and many states in the U.S. are also instituting or considering such restrictions. Environmental problems do not respect political boundaries, and in the long run it will do little good if restrictions on the use of these hazardous toxins are applied only to certain regions or parts of the globe.

The long-term effects of the chlorinated hydrocarbons in the environment on human beings are admittedly much more difficult to detect or assess than the spectacular effects that have been seen in the predatory birds. Still, the story told by the birds is alarming enough. It seems obvious that agents capable of causing profound metabolic changes in such small doses should not be broadcast through the ecosystem on a billion-pound scale.



"In addition to on-the-job training, IBM offers supplementary education. This is a class I taught in basic electronics."

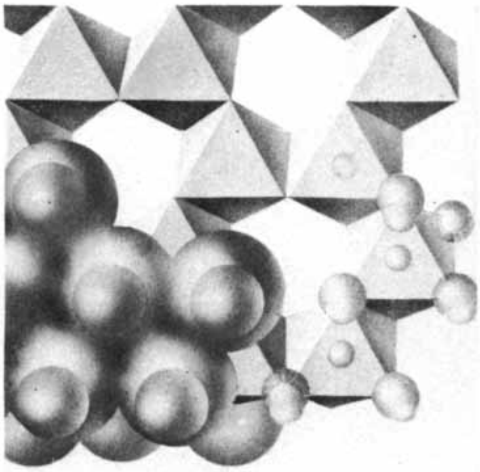




He helped a new plant employ the unemployed.

Turn an old warehouse into a plant and man it with untrained workers? Bill Collins helped prove it could be done. His story is another example of how IBM, its people or products often play a part in tackling today's problems.

Outstanding First-Year College Texts



BIOLOGY: ITS PRINCIPLES AND IMPLICATIONS

Garrett Hardin,
University of California, Santa Barbara

"Hardin's widely known text, through this second edition, continues its reputation as one of the most interestingly written and lucid exposés of modern biology. . ." —*Science Books, A Quarterly Review,* September 1966

"The author again displays his splendid gift for producing a text which has literary merit and interest for the reader. . . . Would that all text authors had this one's skill in writing."
—*American Biology Teacher,* September 1967

Second Edition, 1966, 771 pages,
375 illustrations, illustrated in two colors, $10.00

Just published

CHEMICAL SYSTEMS

Energetics, Dynamics, Structure

J. Arthur Campbell, Harvey Mudd College

Written by a former director of one of the most influential high school chemistry curriculum projects, CHEM Study, this college textbook in general chemistry is designed for students of varying preparation who have a strong interest in science, and it is specifically intended for those who plan to major in science or engineering. It provides a thorough introduction to general chemistry together with enough physical chemistry to serve as background for all further undergraduate science courses these students may take.

1970, 1050 pages, 452 illustrations, $12.50

Just published

GENERAL CHEMISTRY

Linus Pauling, Stanford University

Extensively revised and updated, this is the third edition of the textbook that—when first published—revolutionized the teaching of chemistry by presenting it as a subject to be understood in terms of unifying principles instead of as a body of unrelated facts. *General Chemistry* provides a sound and logical development of the theories of greatest importance in modern chemistry—along with enough descriptive chemistry to introduce the student to the multitude of chemical substances and their properties.

1970, 959 pages, 272 illustrations, $12.50

PRINCIPLES OF GEOLOGY

James Gilluly,
formerly of the U. S. Geological Survey,
Aaron C. Waters,
University of California, Santa Cruz,
and A. O. Woodford, Pomona College

"Our decision to adopt this text was made after a thorough examination of all the available introductory geology texts. There is no question that it is head and shoulders above all the rest."
—Alexander R. McBirney, University of Oregon

"It is undoubtedly the finest textbook on geology ever printed, one of which the authors and the publishers can be justly proud."
—S. W. Lohman, U. S. Geological Survey

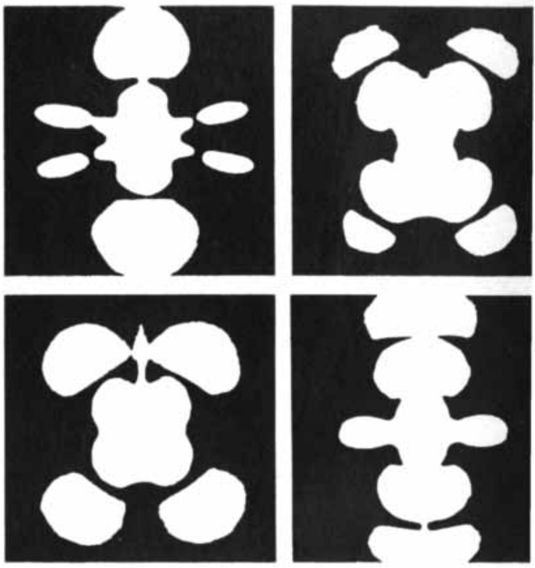
Third Edition, 1968, 687 pages, 520 illustrations, illustrated in two colors, $10.25

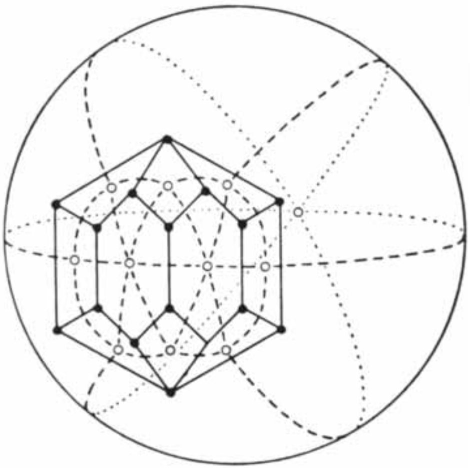
GEOLOGY ILLUSTRATED

John S. Shelton, formerly at Pomona College
Drawings by Hal Shelton

"The proud title of this eye-filling book is justified. Four hundred photographs, mostly stunning aerial views taken by the author himself in the West, with accompanying drawings by his cartographer brother, present the basis of physical geography in the field. . . A triumph of direct observation and clear thought. . . An outstanding book for self-study or for a college text."
—*Scientific American,* December 1966

1966, 434 pages, 382 illustrations, $10.50





PLANT SCIENCE

An Introduction to World Crops

Jules Janick, Purdue University,
Robert W. Schery, The Lawn Institute,
Frank W. Woods, Duke University, and
Vernon W. Ruttan, University of Minnesota

"There have been a number of textbooks in economic botany and very close allied fields during the past several years. This book is one of the best, one of the most inclusive, one of the most novel approaches. . . It is thorough and well balanced—including everything from history to botany and phytochemistry to simple economics." —Richard Evans Schultes, Botanical Museum of Harvard University

1969, 629 pages, 288 illustrations, 53 tables, $12.00

INTRODUCTION TO LIVESTOCK PRODUCTION

Including Dairy and Poultry

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

"A very comprehensive and thorough view of animal agriculture. . . . Of all introductory texts in the field, it is in a class by itself in presenting a wealth of basic information with a minimum of data that will quickly become out of date." —*Bios,* December 1966

Second Edition, 1966, 827 pages, 292 illustrations, 120 tables, $10.00

MATHEMATICS: THE MAN-MADE UNIVERSE

An Introduction to the Spirit of Mathematics

Sherman K. Stein, University of California, Davis

"Professor Stein's book remains remarkable in its second edition, first for the collection of topics that it treats, second for its attempt to cultivate the reader's mathematical intuition, and finally for its uncompromising development of mathematical ideas and procedure in full abstraction and elegance. . . Its content is calculated to impel the imaginative, art-minded student toward mathematics and its intent is carried out with skill." —*American Mathematical Monthly,* March 1970

"Widely praised and often used. . . . The first edition was very good; the second edition is even better." —*Science Books, A Quarterly Review,* December 1969

Second Edition, 1969, 415 pages, 280 illustrations, $8.50

THE NEW COLLEGE PHYSICS

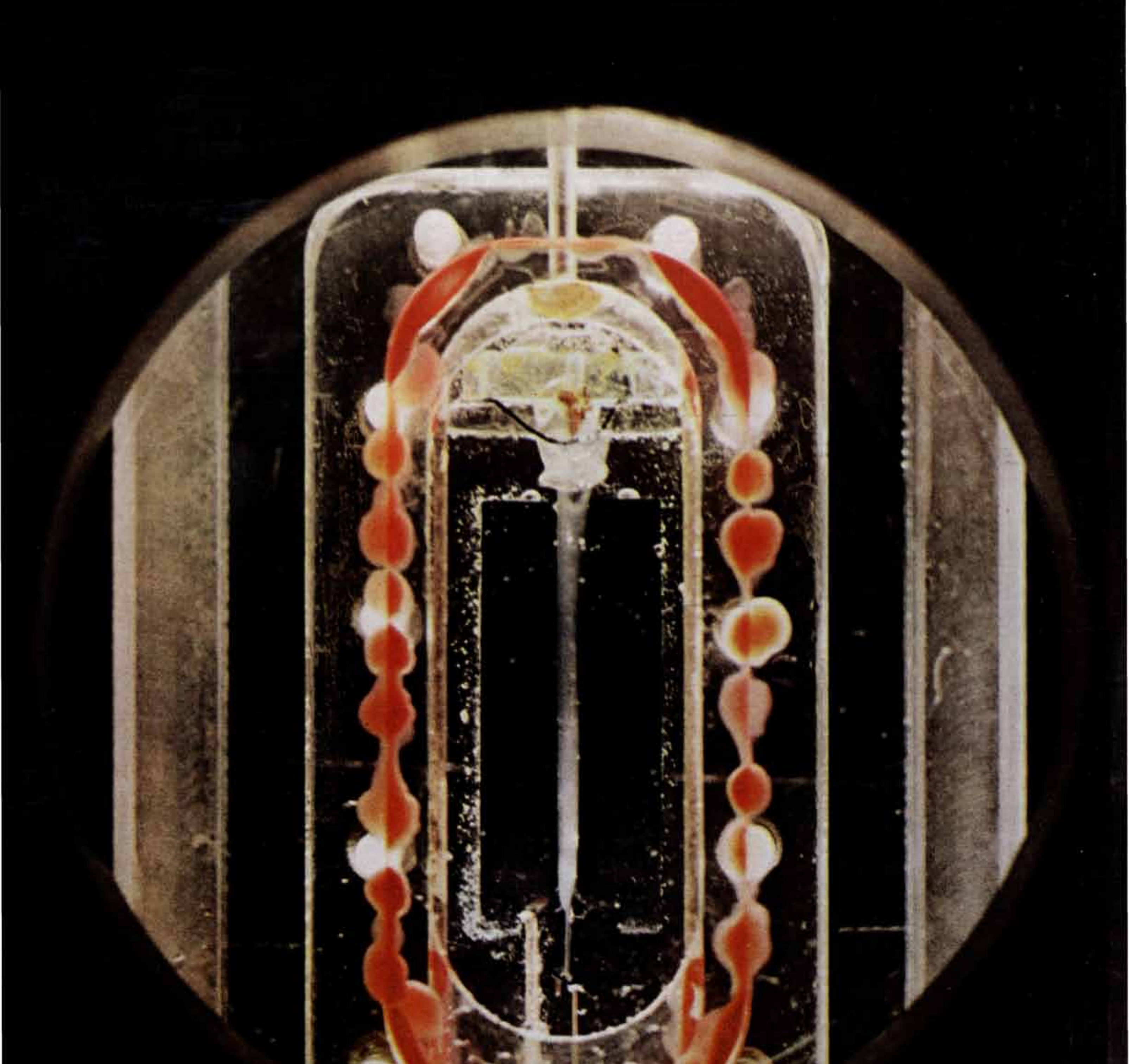
A Spiral Approach

Albert V. Baez

"A very creditable new approach to the matter of presenting a year course in general physics that is both introductory and terminal has been embodied in this text for liberal arts and education students. The major innovations are in the order subjects are presented, and in the well-considered mode of presentation. . . . A valuable addition to the literature of general physics texts." —*Science Books, A Quarterly Review,* September 1967

1967, 739 pages, 743 illustrations, illustrated in two colors, $12.25

From your bookseller or from Dept. A,
W. H. FREEMAN AND COMPANY
660 Market Street, San Francisco, California 94104
Warner House, Folkestone, Kent, England



MUSCLE FIBER of a giant barnacle was prepared for experiments at the University of Oregon by Christopher C. Ashley and Ellis B. Ridgway. The fiber is the pale blue strand mounted in the center of the chamber. It is bathed in a liquid medium that keeps it functional. The fiber has been injected with aequorin, a protein obtained from a species of jellyfish; aequorin emits blue-green light in the presence of calcium ions. By electrical stimulation fiber can be made to function. Red material around chamber is sealing wax.

HOW IS MUSCLE TURNED ON AND OFF?

Work with muscle fiber of a giant barnacle supports the hypothesis that a flow of calcium ions in response to a nerve signal gives rise to contraction, and that withdrawal of the ions results in relaxation

by Graham Hoyle

Twenty years ago the Royal Society of London organized an international meeting of physiologists interested in muscle, and one of the speakers was A. V. Hill, who in 1922 had shared the Nobel prize in medicine and physiology for his work on muscle. He cited a number of major unsolved problems. Was the source of energy for muscle contraction adenosine triphosphate (ATP), as had recently been proposed? What kind of molecular machinery is operative in the shortening of muscle and the development of force by muscle? How is muscle contraction turned on so quickly?

Progress in understanding these and other aspects of the physiology of striated, or voluntary, muscle (as distinct from smooth, or involuntary, muscle) has been dramatic since that time. The ATP question was resolved affirmatively in the laboratory of R. E. Davies of the University of Pennsylvania in the early 1960's. Plausible ideas regarding the operation of the ultimate molecular machinery of muscle are now emerging. This article is concerned with the question of how muscle contraction is turned on and off. The techniques of biochemistry, microscopy, biophysics, pharmacology and comparative physiology have all been brought to bear on the problem, and each of them has made significant contributions. Although many details remain to be elucidated, the chief outlines of the relevant events have been firmly established.

A typical voluntary muscle consists of a number of slender fibers. Each fiber is a long cell enclosed in a sheath called the sarcolemma. On close microscopic examination a fiber is seen to be made up of a large number of ribbonlike filaments, called myofibrils, that are packed closely together in the cell. A series of broad crosswise bands marks each fibril [*see illustration on page 87*]. The bands are alternately dark and light. The dark band is called the *A* band (for anisotropic). It is interrupted in its midsection by a narrow, less dense stripe called the *H* band. The light band, called the *I* band (for isotropic), is similarly divided across its middle by a dark stripe called the Z line.

On still closer examination the stripes of the fibril are seen to arise from an orderly arrangement of thick and thin filaments within the fibril. In contraction the filaments in each sarcomere (the region between two Z lines) slide past one another. Hence the fibril is the functional unit of muscle action.

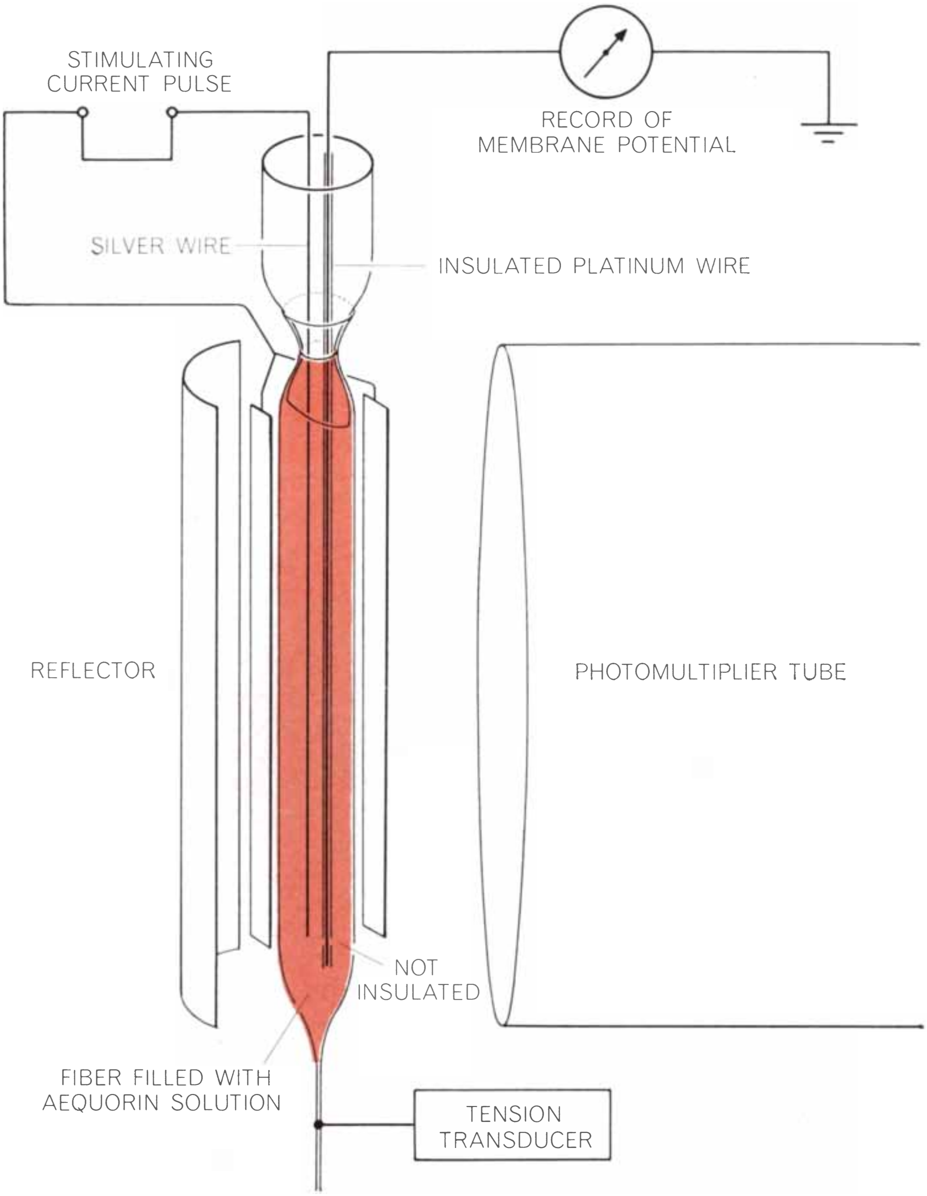
Hill had shown in his work that even in a cold-blooded vertebrate (the frog) the transformation of muscle from a state of rest to a state of full activity takes no more than a few thousandths of a second. How this transformation could take place so quickly was completely mysterious. An agent of excitation could not possibly diffuse into the muscle machinery in so short a time.

The first step in the excitation of a striated muscle fiber is the arrival of a signal along the nerve fiber that is connected to the muscle fiber at a junction called the end plate. In its resting state the outer membrane of the muscle fiber is electrically polarized, that is, its outer surface is positively charged with respect to the inner one. The nerve signal brings about the release of a substance that depolarizes the muscle membrane by increasing its permeability to ions. This depolarization in turn excites an "action potential" that propagates along the muscle fiber.

Two independent electric currents are set off in the fiber by the action potential. One is a weak longitudinal current. The Scandinavian physiologist Ove Sten-Knudsen showed in 1954 that this current does not induce contraction. The other current is a transverse wave that moves inward along a system of invaginated tubules. The recognition of this system is a noteworthy episode in the development of muscle physiology.

In 1955 Stanley Bennett at the University of Washington and Keith R. Porter at the Rockefeller Institute discovered by electron microscopy that striated muscle fibers are permeated by an orderly network of internal membranes. Some of the membranes were extremely fine, but others were substantial enough to have been detectable with the ordinary light microscope. Looking through earlier publications for evidence that the network had been observed, Bennett found papers that severely embarrassed the reigning princes of muscle physiology. The internal membranes had been well known to histologists and muscle physiologists up to about the time of World War I. The physiologists, however, had become suspicious of the evidence because of the possibility of artifacts arising from fixation and staining. Theories of contraction arose that did not require such systems, so that the physiologists first ignored and then forgot the earlier evidence. As a result the entire succeeding generation of muscle physiologists was unaware of one of the most important structural elements in the tissue.

The rediscovered system at last showed the existence of a physical pathway into muscle fibers. If the pathway could be shown to have a connection to the exterior of the fiber, plausible explanations of how an electrical signal moved inward could be advanced. Electron mi-



RECORDING SYSTEM employed with the apparatus shown in the photograph on page 84 has internal and external electrodes to stimulate the fiber so that it will contract. The release and withdrawal of calcium ions within the fiber following an electrical stimulus cause the aequorin in the fiber to emit light, which is then recorded by the photomultiplier at right.

croscopists were able to prove about five years ago that there are indeed such exits to the outside of the fiber.

The work also showed that there are two tubular systems rather than one. The main system—the sarcoplasmic reticulum—does not open to the exterior. A secondary system, consisting of flattened tubules, is invaginated from the exterior. This system makes intimate contacts with the sarcoplasmic reticulum at regularly arranged sites [see "The Sarcoplasmic Reticulum," by Keith R. Porter and Clara Franzini-Armstrong; SCIENTIFIC AMERICAN, March, 1965]. The units of the secondary system are commonly called *T* (for transverse) tubules, although in some kinds of muscle the tubules also run spirally and longitudinally.

Experiments carried out in 1949 by Robert E. Taylor of the National Institutes of Health and A. F. Huxley of University College London (then working at the University of Cambridge) showed that there are sensitive spots, arranged at regular intervals along the length and around the circumference of each muscle fiber, where depolarizing pulses of current applied to the surface through a tiny pipette cause a local contraction. These spots might well correspond to the points of contact of the external and internal tubular systems and be the points where the electrical signal could enter the interior. But what might the signal do next to initiate contraction?

A large number of substances had been injected into muscle fibers in 1949 by L. V. Heilbrunn and Floyd J. Wiercinski at the University of Pennsylvania, and the only one that caused contraction under physiological conditions was the calcium ion. Muscle fibers quickly cease to contract if they are deprived of calcium ions in the bathing medium. Although this inactivity might be caused indirectly, since calcium is highly important for the integrity of membranes and membrane phenomena, the possibility that calcium is itself an agent in initiating contraction soon became favored.

When adequate methods of fractionating cells became available, it was possible to isolate the sarcoplasmic reticulum of muscle fiber as a set of fragments called microsomes. They turned out to have an extremely strong affinity for calcium ions. When microsomes were added to muscle fibers in a contracted state, the fibers relaxed.

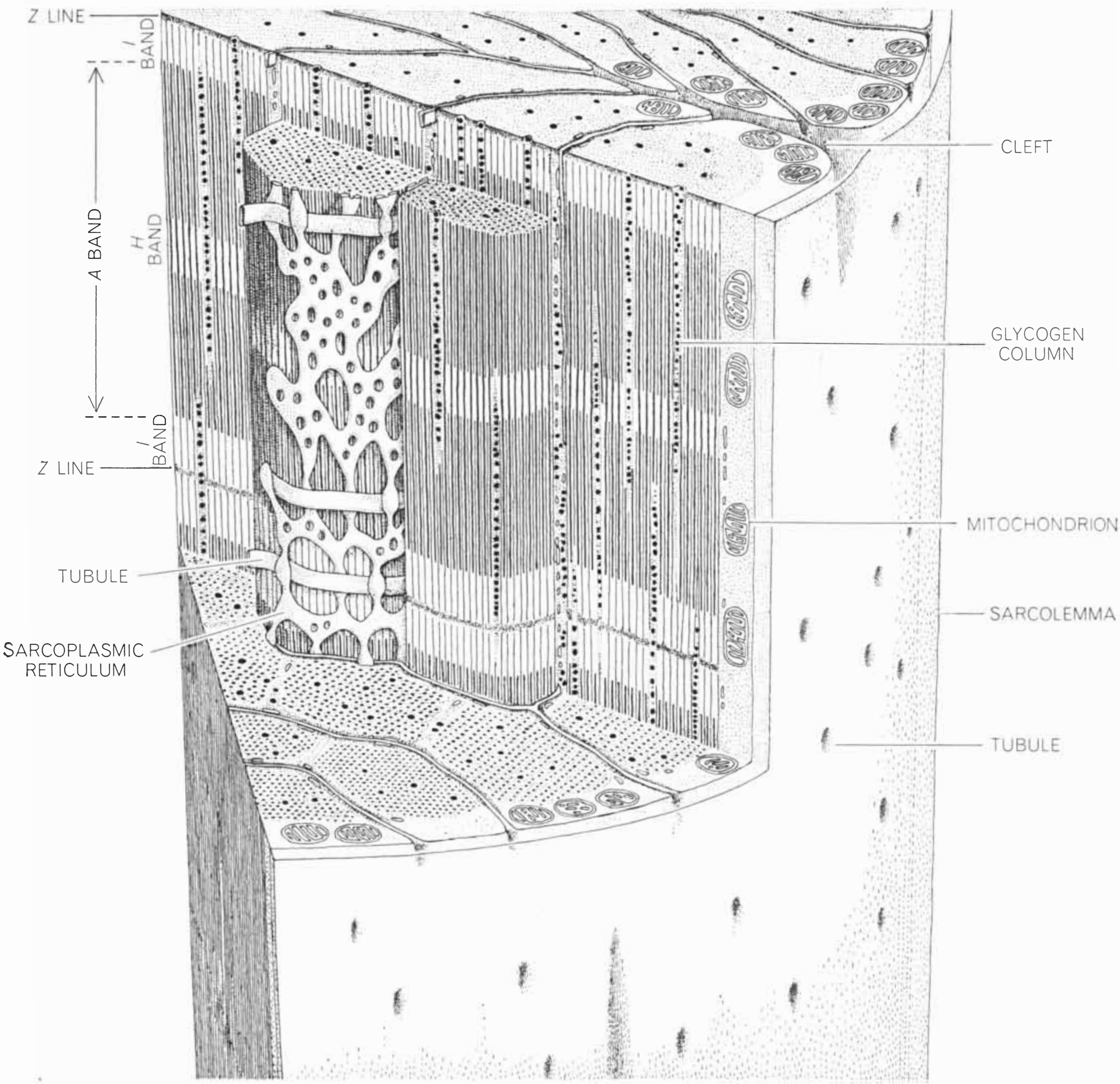
These findings led to the firm establishment of a calcium theory by Alexander Sandow, Wilhelm Hasselbach, Annemarie Weber, Abraham M. Shanes and others. The theory holds that contraction is initiated by calcium ions released from a binding site within the muscle by the action of electrical excitation, and that relaxation is the result of the subsequent uptake of this released calcium by the sarcoplasmic reticulum. The calcium is considered to activate the contractile machinery. These ideas, essentially Heilbrunn's, had been around for a long time; they were first formalized by Sandow in 1952, but they did not acquire weight until the work with the electron microscope in the early 1960's and the rediscovery of the invaginated tubular system.

At this stage it began to seem particularly desirable to find muscle fibers large enough so that investigators could both inject substances and record the results in order to test the theory. Muscle fibers of both cold-blooded and warm-blooded vertebrates have a diameter of 100 microns at most. Crab muscle fibers are much larger. The strands into which the leg muscles of a crab fall apart after cooking are single muscle fibers; in the Alaska king crab these fibers are as much as three millimeters in diameter. Peter Caldwell of the University of Bristol was the first to take advantage of such giant fibers, using leg muscle fibers of the spider crab *Maia squinado* to measure internal changes in the concentration of hydrogen ions (*p*H). These fibers are unfortunately quite fragile and have not proved suitable for combined studies in which the development of contractile force is also measured.

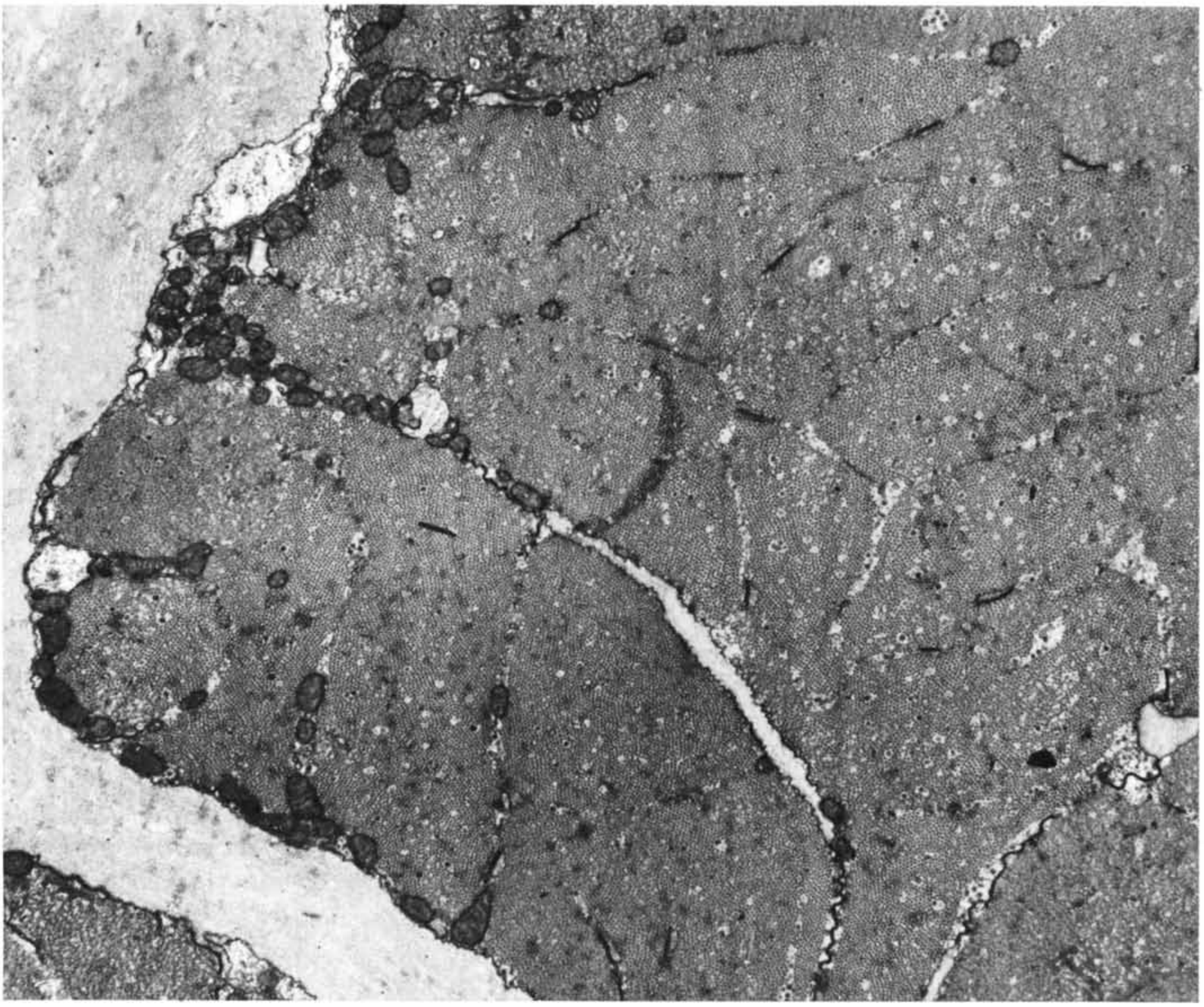
A previously unsuspected source of tougher giant fibers came to my attention in 1959 when I visited the University of Washington's marine laboratory near Friday Harbor in Puget Sound. At a dinner party given by Joseph H. Connell of the University of California at Santa Barbara the hors d'oeuvres had the appearance of miniature volcanoes, although the "lava" was merely tomato ketchup. These objects, some five inches high, were giant barnacles. Each one contained six delicious chunks of meat that were about the length and thickness of a finger. Each chunk comprised some 50 strands, several of which were two millimeters or more thick.

Close inspection of the living muscle by Tom Smyth, Jr., of Pennsylvania State University and me revealed that each strand is a single muscle fiber. There is very little connective tissue, so that the fibers are easily separated. The task of preparing them for experiments is further aided by the fact that each fiber is attached to a tough, inelastic tendon about eight millimeters long, which is useful as a point of attachment when one wants to test the fiber mechanically.

Charles Darwin had named the barnacle in a monograph published in 1854; as published, the name was *Balanus nubilus.* In the Smithsonian Institution's collection and in certain textbooks it is labeled *B. nubilis. Nubilus* means cloudy, which seems inappropriate, and *nubilis* means marriageable, which is even less appropriate for a hermaphroditic animal. I venture to suggest that Darwin intended to do justice to this magnificent invertebrate by naming it *B. nobilis,* and that the typesetter, work-



STRUCTURE OF MUSCLE FIBER consists of a number of fibrils, which in turn are made up of orderly arrays of thick and thin filaments of protein. A system of transverse tubules opens to the exterior of the fiber. The sarcoplasmic reticulum is a system of tubules that does not open to the exterior. The two systems, which are evidently involved in the flow of calcium ions, meet at a number of junctions called dyads or triads. Mitochondria convert food to energy. The sarcolemma is a membrane surrounding the fiber.



BARNACLE FIBER appears in cross section in this electron micrograph made by Patricia McNeill of the University of Oregon; enlargement is 11,200 diameters. Channel at bottom left is a major cleft; narrow channel below center, a minor cleft. Slender, dark channels that run into fiber from clefts are parts of the tubular system. At various points they make contact with the longitudinal sarcoplasmic reticulum, forming dyads; 17 are visible. Elliptical spots are mitochondria and the many small dark spots are the filaments.

ing from Darwin's scrawled handwriting, misread the name.

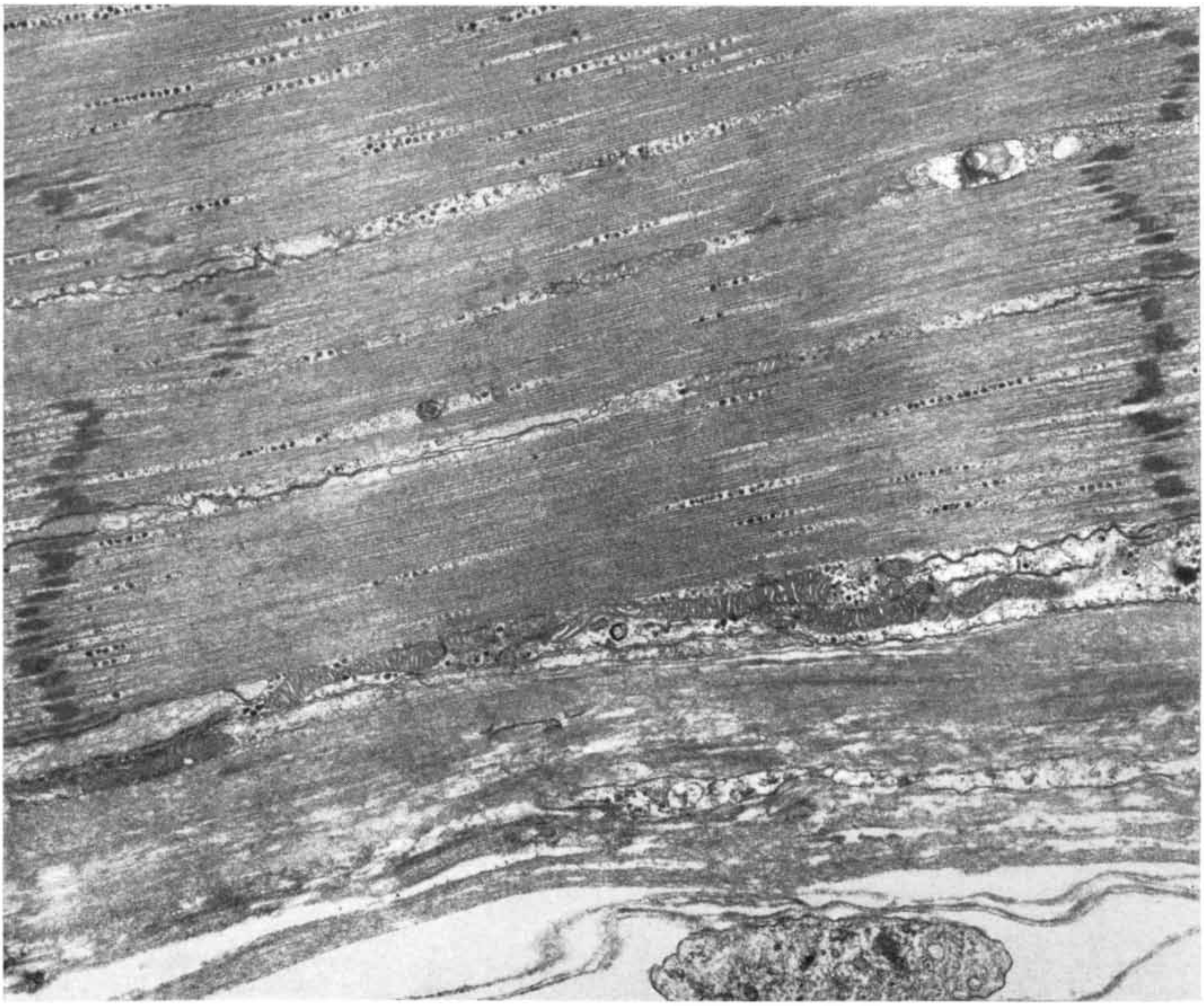
The apparatus we use to inject substances into a barnacle fiber and to record the results is depicted in two accompanying illustrations [*pages 86 and 90*]. When a fiber thus prepared is excited by a depolarizing current, it gives rise to only an abortive, nonpropagated action potential unless it has been specially treated. In a nerve fiber the inflow of sodium ions aids the stimulus causing the depolarizing phase and the outflow of potassium ions restores the original potential; in the barnacle muscle fiber the outflow of potassium ions also restores the original potential but the depolarizing phase is initiated by calcium ions. The inflow of calcium ions makes sense if they are to cause contraction.

How much calcium is required for muscle contraction? This measurement had been undertaken (with spider crab fibers) by Caldwell and his collaborators and was continued in our laboratory by Christopher C. Ashley, who used barnacle fibers. Ashley injected into the fiber the agent EGTA, which strongly binds calcium and so can be used to mop up free calcium or to serve, in company with an appropriate excess of calcium, as an effective buffer for the calcium ion.

Wet-weight determination showed that the muscle fibers contain the equivalent of about 10^{-3} mole of calcium per kilogram. Yet when a calcium-EGTA mixture with a free-calcium level of only 10^{-8} mole per liter was injected, detectable contraction ensued. The conclusion from this experiment is that most of the calcium normally in the cell must be tightly bound to cellular constituents and is not available to the contractile machinery.

Increasing the amount of free calcium ion injected enhances contraction proportionately, reaching a maximum at about 5×10^{-6} mole per kilogram. Thus the internal release of calcium, or internal release combined with the entry from outside of enough calcium to raise the level from less than 10^{-8} mole per liter to about 5×10^{-6} mole, will produce excitation equivalent to full normal excitation of the fiber. These results lend strong support to the calcium-release theory of muscle contraction.

Assuming the fiber to be a uniform cylinder four centimeters long and two millimeters wide, which is a typical size



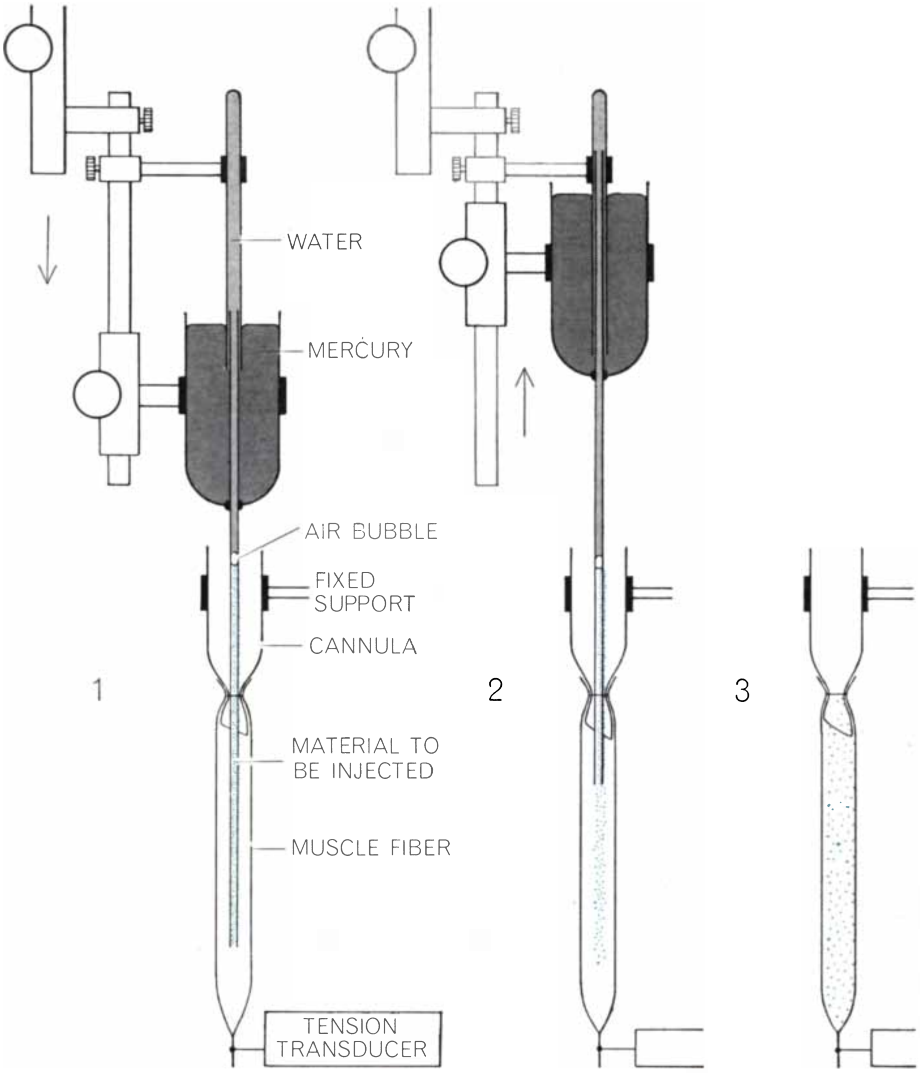
LONGITUDINAL VIEW of a barnacle fiber, in an electron micrograph made by Mrs. McNeill at an enlargement of 11,200 diameters, shows fine striation of filaments. Broader and lighter areas contain glycogen particles and elements of sarcoplasmic reticulum. Material in lower third is a protective sheath lying outside the excitable membrane. Left of center is a large dyad. Dark zigzag patterns at right and left are *Z* lines; distance between them is one sarcomere. The channels separating *Z* bands are minor clefts.

for giant barnacle fibers, about 8×10^{-12} mole of calcium would have to be released to complete contraction. The electric current required to translocate that amount of calcium is about 10^{-6} coulomb. This is close to the amount required to give rise to a brief full contraction. Susumu Hagiwara of the University of California at Los Angeles has calculated that about 6×10^{-12} mole of calcium enters for every square centimeter of perimeter during a single twitch if the membrane gives an all-or-none action potential. The area of the perimeter of the fiber we are considering is 2.5 square centimeters, so that about 15×10^{-12} mole of calcium ions enter. This amount is sufficient by itself to allow for the tension developed by the muscle fiber.

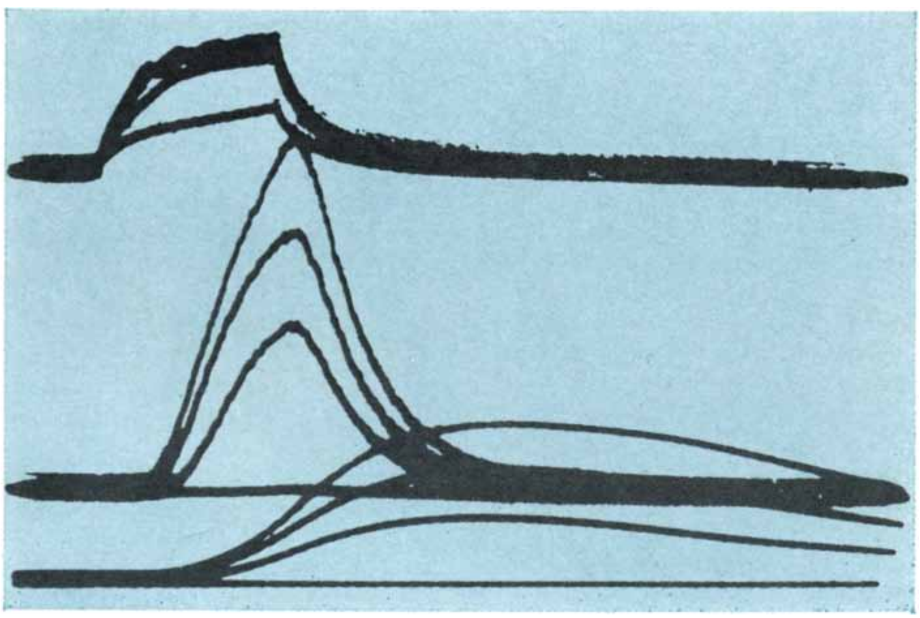
Several factors, however, argue against the likelihood that calcium entering from the outside is the only calcium that combines with the contractile machinery. Most of the entering calcium comes from the clefts of the fibers, and the entire amount of calcium in the clefts is barely sufficient in principle for a single contraction. The barnacle fiber does not usually evince an all-or-none action potential, and the amount of entering calcium is therefore only a fraction of the requirement for producing the ensuing contraction.

Moreover, not all the calcium that does enter can make its way to the contractile elements, since the sarcoplasmic reticulum (and possibly other binding elements) will remove it before it gets to them. Hence entering calcium will need to be supplemented, or even completely supplanted, by the internal release of calcium. I shall return to this question, but first it is desirable to consider some new direct evidence supporting the calcium theory.

At about the time Ashley was doing his work in 1966, Frans F. Jöbsis and Michael O'Connor of Duke University published a preliminary report of experiments on toad muscles that lent considerable weight to the notion that release of internally bound calcium causes contraction. Jöbsis and O'Connor were able, with the aid of the agent dimethyl sulfoxide, which renders membranes highly permeable, to make at least some of the muscles take up significant quantities of Tyrian purple, the regal dye of



INJECTION OF AEQUORIN and other substances into muscle fiber is done in the author's laboratory at the University of Oregon with an apparatus that makes it possible by turning the upper knob (*1*) to insert in the fiber a capillary containing the material to be injected. With the lower knob the capillary is then raised (*2*) while the upper section is held in place. As capillary is withdrawn its contents are injected and diffuse through the fiber (*3*).



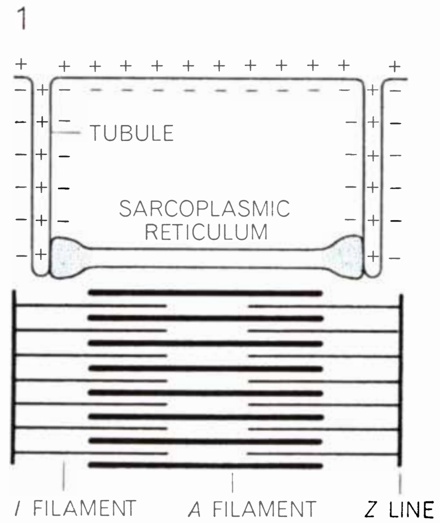
OSCILLOSCOPE TRACES show changes in membrane potential (*top*), output of light from injected aequorin (*middle*) and tension (*bottom*) of a fiber after an electrical stimulus.

the Roman emperors. This dye, which is obtained from the shellfish *Murex*, changes color in the presence of calcium ions.

By means of a difficult spectrophotometric comparison on a fast time scale, Jöbsis and his associate found that the incorporated dye changed color very quickly following excitation of a fiber and then reversed almost at once, even before the tension had reached its peak. The group working in my laboratory at the University of Oregon was intrigued by these results, and we wanted to repeat them with barnacle fibers. It was easy to get murexide into the fibers, but other problems arose, and it became apparent that some other calcium indicator would be desirable. In searching for one Ashley and Ellis B. Ridgway hit on an extraordinary idea.

In 1962 Frank H. Johnson and Osamu Shimomura of Princeton University had completed preliminary studies on the nature of the luminescence produced by the jellyfish *Aequorea aequorea*. They had found that the luminescence results from the interaction of seawater and a protein secreted by the jellyfish when it is disturbed. The protein, which they named aequorin, emits a beautiful bluish light, and the agent that causes it to do so is the calcium ion. The reaction is quite specific and extremely sensitive: light is emitted at a calcium concentration as low as 10^{-8} mole per kilogram. It is produced over a range of calcium concentration similar to the amounts of calcium thought to be freed in a muscle fiber following excitation. Ashley and Ridgway proposed injecting aequorin into the barnacle fiber to test the calcium-release hypothesis. If released calcium is the initiator of contraction, it might react just as readily with aequorin as with muscle protein. Therefore a fiber injected with aequorin should emit light following electrical stimulation.

The jellyfish are available at the Friday Harbor Laboratories, where we collect the giant barnacles, and obtaining aequorin presents no special problems beyond the fact that the tissue containing the photic organs must be removed from several thousand specimens to provide enough pure protein for injection experiments. The first samples were tested in December, 1966, but no light was detected by our photomultiplier tube. Ashley and Ridgway stuck with it and eventually produced a much purer sample of aequorin. When this aequorin was injected (in August, 1967) and the fiber was stimulated, light emission was detected. This result provided clear proof of a rise in the level of free calcium with-



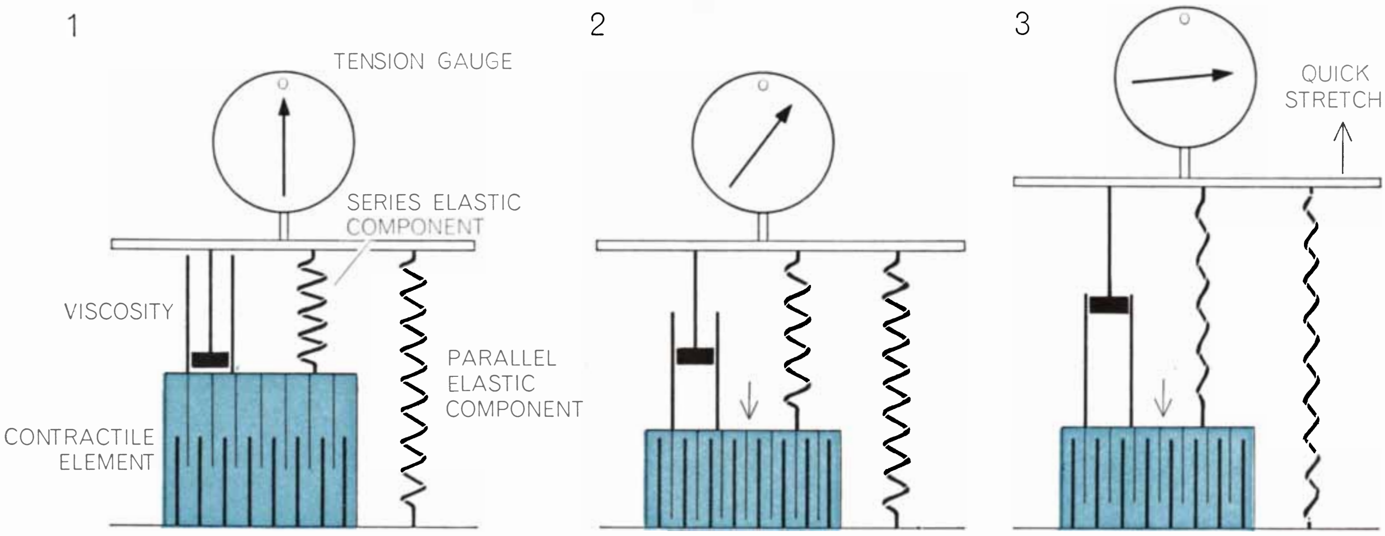
ROLE OF CALCIUM in muscle action is depicted as it is indicated in experiments by Saul Winegrad of the University of Pennsylvania using radioactive calcium. A fiber at rest (*1*) is electrically polarized, with the outside positive with respect to the inside, and the calcium (*color*) is stored in sacs of the sarcoplasmic reticulum. Tubules of the transverse tubular system are shown near each sac. On excitation (*2*) the polarization is reversed; the calcium leaves the sacs and activates the filaments constituting the basic contractile machinery. The filaments, which are shown below the diagrammatic fibers, slide past one another. In relaxation (*3*) the fiber's original polarization is restored, and the calcium is picked up by the sarcoplasmic reticulum and returned to the storage sacs.

in the muscle fiber following stimulation. The course of light output over a period of time closely resembled the curve representing the change of color of murexide observed in Jöbsis' laboratory.

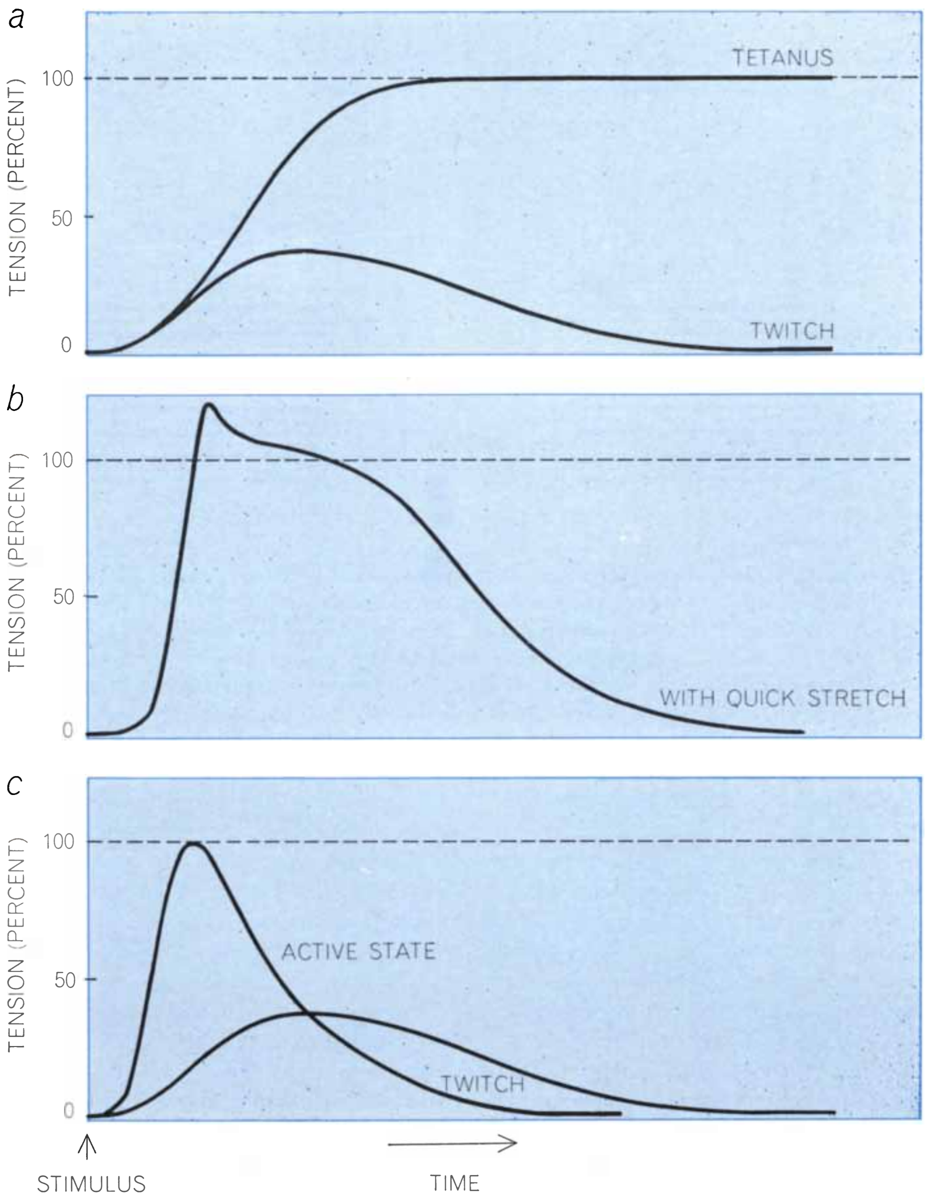
The emission of light rises rapidly to a peak intensity and then falls almost immediately after the electrical stimulus has been switched off. Meanwhile tension in the muscle fiber has reached its maximum. If the calcium had remained free within the fiber, light would have continued to be emitted. That there was plenty of aequorin left in the free space within the fiber was shown by the fact that many repetitions of the light pulse could be obtained following only a single injection.

The rapid waning of light as fiber tension rises means that the released calcium is taken up during contraction by elements that must bind it more tightly than aequorin does. On the other hand, there is no output of light during relaxation, which means that the calcium is transferred back to the binding elements a little at a time and does not rise to a high concentration until the next excitation. It is to be expected that the contractile machinery itself will momentarily take up a major fraction of the calcium, inasmuch as calcium is taken up strongly by these proteins before they go into the contracted state. The recently discovered protein troponin, which is associated with the thin filaments, seems to play a major role in calcium-binding.

It is already apparent that calcium acts indirectly by removing a continuing suppression of contraction that is present in the relaxed state. At rest, when the concentration of free calcium is below 10^{-8} mole, the molecules of troponin inhibit interaction between myosin molecules of the thick filaments and actin molecules of the thin ones. When calcium is released and its concentration rises, it combines with the troponin. This



EFFECT OF ELASTICITY on muscle action is portrayed schematically. A muscle fiber (*1*) contains elastic elements in series and parallel to the contractile elements, and there are also viscous damping factors. When the fiber is stimulated (*2*), the contractile elements must first stretch the elastic elements. Their influence and the damping effect of the viscous elements are so large that the externally measured peak tension in a contraction is considerably less than the force actually developed in the fiber. If at the time of stimulation the fiber is given a stretch that pulls out the elastic elements (*3*), the fiber's full contractile force can be measured.



FIBER TENSION is charted (*a*) for a whole fiber during a twitch and a tetanus and (*b*) for a twitch by the contractile elements after a quick stretch of the elastic elements. At *c* the active state, which is the full force thus registered, is compared with a twitch. The time ranges from .005 second for rat toe muscle to .05 second for a giant barnacle fiber.

releases the restraint that troponin places on the interaction of actin and myosin, and the contractile mechanism then goes into operation. Removal of the calcium during relaxation reverses the process. Information on the importance of troponin has been derived largely from the work of Setsuro Ebashi of the University of Tokyo. The way calcium is given up after contraction and recaptured by the sarcoplasmic reticulum remains to be resolved.

Returning now to the earlier stages in the coupling of nerve signal with contraction, we must consider two questions. What is the source of the internal calcium that supplements the external calcium entering the fiber during excitation? What causes the internal calcium to be released?

The possible sources include the membranes of the fiber surface, the clefts, the invaginated tubules, the sarcoplasmic reticulum and the mitochondria, as well as the lumen of the sarcoplasmic reticulum. At the outer margins of the sarcoplasmic reticulum in each sarcomere the reticulum terminates in nonperforated sacs. The sacs adjoin the invaginated tubular system and are also the regions where calcium deposits appear after a fiber has been treated with agents that precipitate calcium. Hence the sacs may well be the major source of supplementary internal calcium, although all possible sources may make a contribution.

For vertebrate fibers confirmation of the calcium theory has been obtained in painstaking experiments by Saul Winegrad of the University of Pennsylvania. He has shown by the use of radioactive calcium that the ion is concentrated in the outer regions of a sarcomere—the *I* band—when the fiber is at rest but that during tension the ion becomes concentrated in the central region, namely the *A* band. During relaxation the ion moves back toward the outer region again. The outer regions are the sites of the sacs of the sarcoplasmic reticulum. Winegrad's work therefore reinforces the hypothesis that the sacs are the storage place for internal calcium.

As for the question of what causes the release of internal calcium, there is no doubt that the initial stimulus to contraction is an outside negative depolarizing charge applied at the membrane and conducted down the invaginated tubular system. Hugo Gonzalez-Serratos, working at University College London, determined that the rate of inward conduction along the tubules of a frog fiber is about eight centimeters per second. Ions pass down the tubules and across the junction between the tubules and the reticulum. The most important ion appears to be the ubiquitous calcium ion. Bernhard Katz and Ricardo Miledi of University College London have recently shown that the movement of calcium ions from the external medium into nerve terminals is instrumental in initiating the release of the chemical substance that transmits the nerve impulse. There may be a parallel in muscle.

The final act—the process of relaxation—is dependent first on the return of the charge on the surface membrane to its original value, although relaxation will eventually ensue even if the membrane polarization is maintained. In normal activation the excitatory depolarization is followed immediately by a rapid repolarization. Since the stimulus to the release of calcium is so quickly turned off, there is an equally rapid termination of calcium release.

This is surely the gross mechanism of relaxation, but there is evidently more to it. It had been thought possible that relaxation simply reflects the diminishing amount of free calcium as calcium is rebound to the reticulum, but it is now known from the transient light output of fibers injected with aequorin and then stimulated that the free calcium has already fallen to a low level by the time contraction, recorded externally, has reached its peak.

The problem is that what one records

externally from a whole fiber is only a distorted reflection of the true rise and fall of tension in the contractile elements, which are affected by internal conditions such as elasticity and viscosity. When the contractile machinery goes into operation, it must stretch elastic elements (in series and parallel with itself) that are in the muscle and the tendons. Moreover, both the contractile machinery and the elastic elements are subject to damping by internal viscosity.

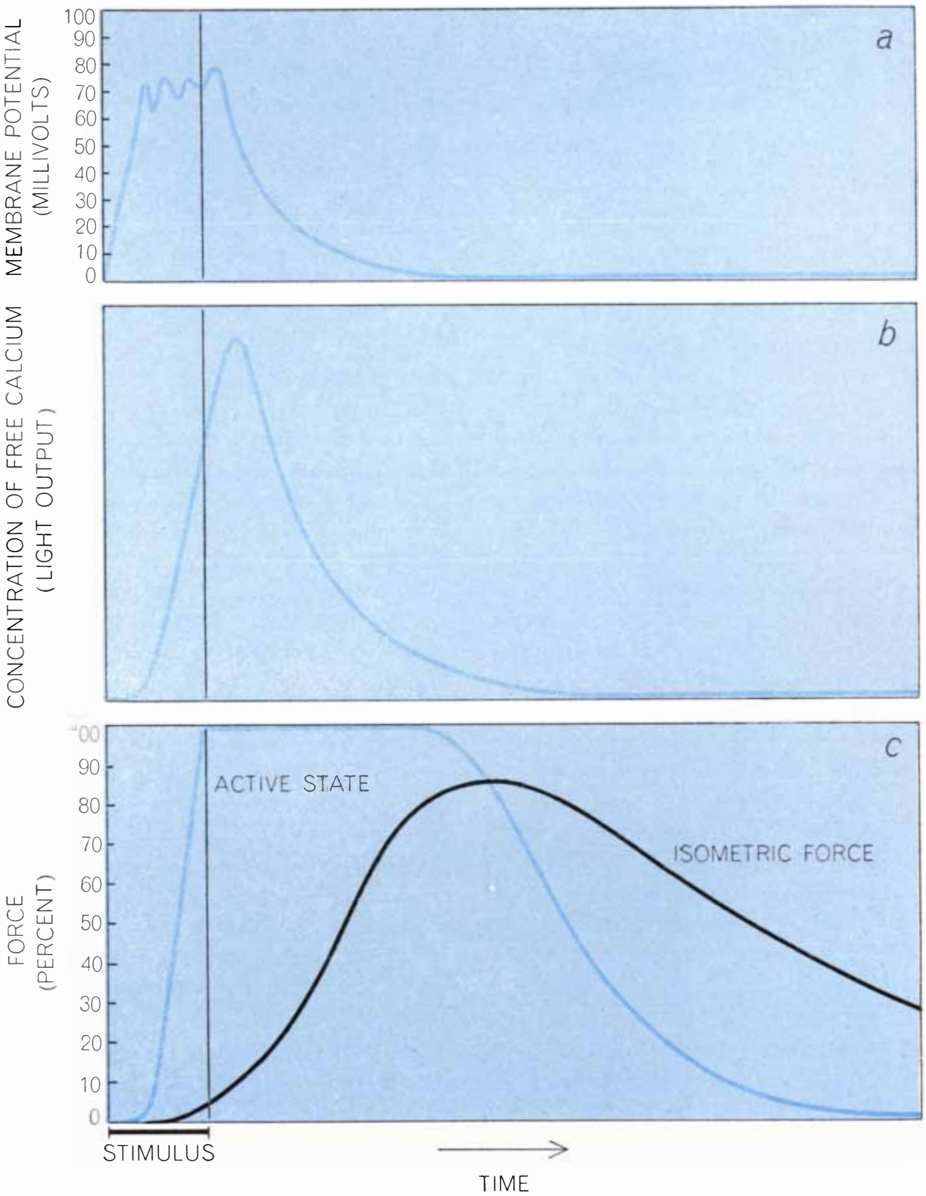
The influence of these factors is so large that the externally measured peak force in a muscle twitch is much less than the force actually developed by the contractile machinery. In a barnacle fiber the ratio is about one to five. An even greater distortion is encountered when one measures externally the time course of a twitch. Both rise and decay times are much prolonged in the whole fiber compared with the contractile elements.

The effects of viscoelasticity on internally developed tension at a given moment during its rise can be counteracted by the experimental trick of giving the muscle fiber a short, quick stretch just greater than the effective excursion of the elastic elements. The stretch pulls out those elements, thus relieving the contractile element of this activity, and so the full force of the contractile element can be registered. This force is called the active state.

The onset, rise time and duration of maximum intensity of the active state are determined with the aid of the quick stretch, but the decline of the active state is determined by a different method that was devised by Douglas Wilkie of University College London. The fiber is stimulated but not allowed to shorten until after its full active state has been developed. It is then released suddenly to a slightly shorter length and the redevelopment of tension is observed. The tension rises more rapidly than in a normal twitch because the elastic elements are already largely stretched out, but less force is developed because the active state is now declining. By conducting a series of such releases and plotting a curve of the peak tensions against time one obtains a curve reflecting the decay of the active state.

An entire curve obtained by these procedures gives the true time course of the development and decay of the contractile machinery's response to the rise and fall of free calcium. The active state rises rapidly following the onset of depolarization; the rate of rise is about five times as fast in the leg muscle of a frog as it is in a giant fiber from a barnacle. In the frog it reaches a plateau in response to a single action potential with a depolarizing duration of only .001 second. In the barnacle fiber brief depolarizations must be repeated many times or a single depolarization must be continued for about .1 second before a plateau is reached. Even then a plateau has not been reached in the curve reflecting the output of light by a fiber injected with aequorin. This means that the fiber is capable of releasing still more calcium in response to continued stimulation.

What the active-state plateau signifies in those fibers where it appears is that the contractile machinery has become saturated with calcium and is operating at peak capacity. These fibers may be presumed to operate with a comfortable margin of safety, the amount of calcium released in excitation being larger than the amount needed to achieve full activation. The end point of the active-state plateau should follow by a few thousandths of a second the drop in the output of light (indicating a drop in the concentration of free calcium) to below the saturation level. When allowance is made for the lag in the rise or fall of light intensity following a change in the concentration of calcium, our experiments show good agreement with this expectation. The experiments therefore provide strong support for the theory that contraction is turned on by the release of calcium and turned off by its withdrawal.



FACTORS IN CONTRACTION resulting from a stimulus include changes in the membrane potential (*a*) and in the concentration of free calcium (*b*). At bottom (*c*) are curves comparing the active state (*color*), which is the true force developed by the contractile elements, with the isometric force (*black*) recorded externally for the entire muscle fiber.

HYPERACTIVE CHILDREN

Certain children are more than usually restless, noisy, destructive and distractible. Their behavior appears to be a distinct disease syndrome that may well be innate

by Mark A. Stewart

Parents and teachers have long been aware of a youthful syndrome that is succinctly described in a short story in verse for children written a century ago (and here translated) by a German physician, Heinrich Hoffmann:

Fidgety Phil,
He won't sit still;
He wriggles,
And giggles...

at the dinner table, and when his father admonishes him, it only results in

The naughty restless child
Growing still more rude and wild.

Fidgeting in itself is hardly an unusual or alarming behavior in children, but it is a matter for concern when it is accompanied by a cluster of other symptoms that characterize what is known as the "hyperactive-child syndrome." Typically a child with this syndrome is continually in motion, cannot concentrate for more than a moment, acts and speaks on impulse, is impatient and easily upset. At home he is constantly in trouble because of his restlessness, noisiness and disobedience. In school he is readily distracted, rarely finishes his work, tends to clown and talk out of turn in class and becomes labeled a discipline problem.

Clinicians developed an active interest in the syndrome during the 1918 epidemic of encephalitis in the U.S. Among the children who were stricken and recovered from the acute phase of the attack, many later showed a catastrophic change in personality: they became hyperactive, distractible, irritable, unruly, destructive and antisocial. It then began to be noted that the same cluster of behavior problems commonly occurred in children who had suffered brain damage from other causes, particularly from head injury or oxygen lack during or shortly after delivery. Hyperactivity therefore came to be called the "brain damage" syndrome. It has been found, however, that most children diagnosed as hyperactive do not have a history suggesting brain injury. An early history, for instance, of prenatal or birth complications that might have caused brain damage is no more common among hyperactive children than among normal children. Some clinicians still hold to the brain-damage theory, noting that many hyperactive children show suggestive signs such as clumsiness, squinting and speech difficulties, but these symptoms might well arise from functional disorders of the brain rather than from structural damage.

The hyperactivity syndrome is not confined to children. Many adults exhibit the same cluster of symptoms. In adult life, however, certain of the basic characteristics—high energy, aggressiveness, lack of inhibitions—may be helpful in one's work, whereas in childhood, when one is required to sit still at a desk and concentrate on studies for long periods, the restlessness associated with the syndrome may be a great handicap and give rise to severe problems.

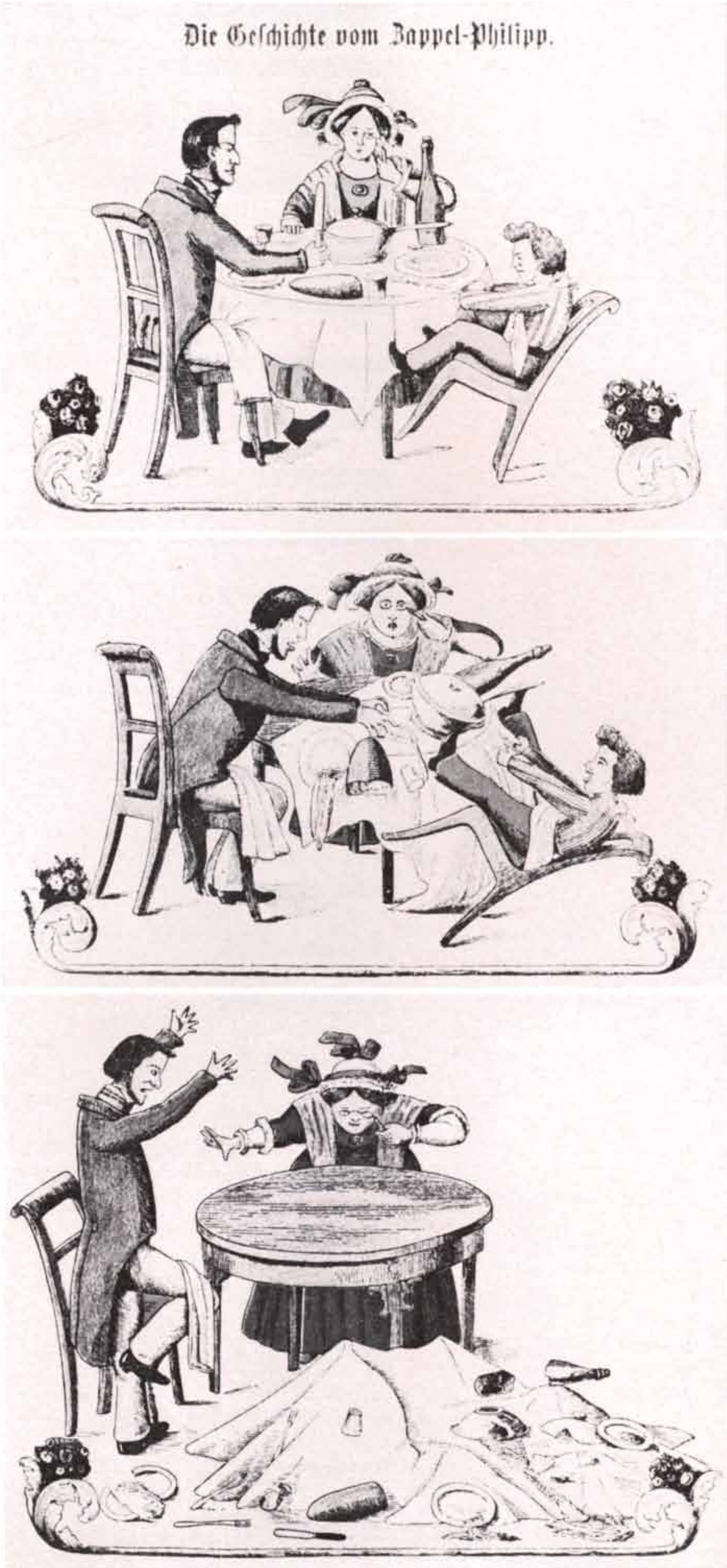
Many years ago Charles Bradley of the Emma Pendleton Bradley Home made the paradoxical discovery that stimulating drugs, such as amphetamine (benzedrine), tend to calm hyperactive children and improve their behavior. The drug enables such children to sit still, concentrate and get their work done. On the other hand, barbiturate sedatives, it has been found, tend to *increase* the restlessness of a hyperactive child.

My own interest in the syndrome developed from a more general interest in the chemical basis of psychiatric disorders. In the psychiatry clinic of the St. Louis Children's Hospital we had seen many hyperactive patients, and we estimated that about 4 percent of suburban grade school children were afflicted with this disorder. The syndrome suggested intriguing questions in basic biology. Is the hyperactive temperament hereditary? Does it have a basis in disordered metabolism? How early does it show itself in a child? Do children outgrow the troublesome behavior or do the problems persist through adolescence and into adulthood? As an approach to clarification of these questions I decided to study the natural history of the syndrome in children. With the help of associates at the Washington University School of Medicine and with support from the National Institute of Mental Health we undertook a program of investigations.

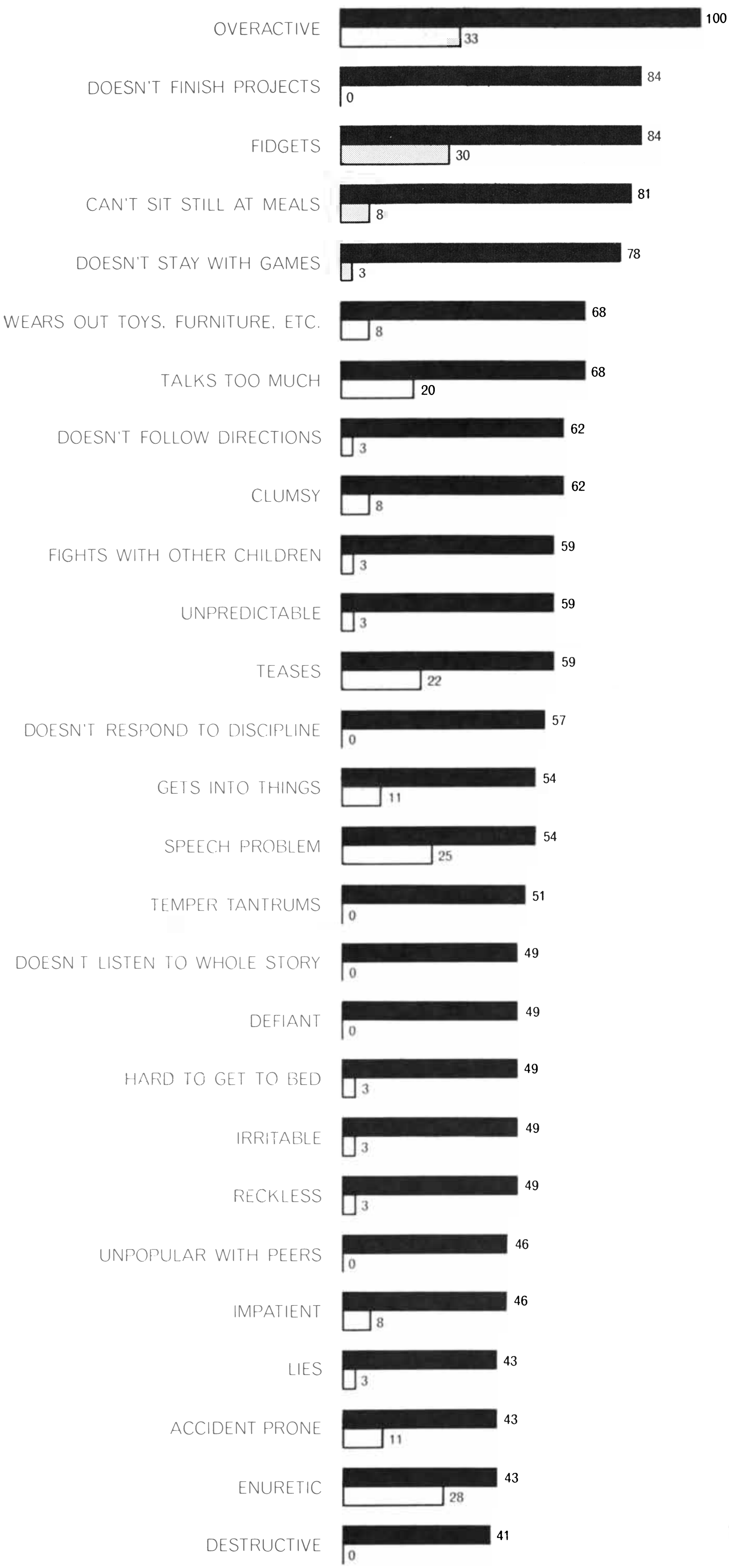
Our first project was to establish a systematic description of the nature and incidence of the symptoms as a base for follow-up studies of patients. For this purpose we selected a sample of hyperactive children and compared them with a control group of normal children. The patients were 37 schoolchildren (32 boys and five girls) aged five through 11 who were being treated in the psychiatry clinic of Children's Hospital; all showed pronounced symptoms of overactivity and inability to maintain concentration but had no chronic disease or special sensory defect. The controls were first-grade children who generally matched the patient group except for their younger average age. This age difference could be disregarded in comparing the two groups for symptoms of hyperactivity, because the hyperactive children had developed most of their symptoms before they entered the first grade.

Using a questionnaire that covered the child's present and past symptoms, his medical and developmental history, his school record and the family history, we interviewed the mother of each child in the patient group and the control group. The interview took between one hour and two hours, and as far as possible the replies to the questions were recorded verbatim. The answer for each symptom was later scored positive or negative according to predetermined criteria. For example, the answer to the question "Has he worn out furniture and toys?" was scored positive if the child had worn out a new bicycle in less than a year or if he had used his baby crib so badly that it could not be handed on to the next child. On questions that did not provide such objective criteria we looked for other forms of confirmatory evidence. For instance, to the question "Does he rock, jiggle, fidget?" the answer was scored positive only if the mother thought the child's behavior in these respects was very different from that of her other children and if other observers had remarked on the behavior. In most cases a symptom was scored positive only if the behavior had persisted over a period of years.

The results showed that the hyperactive patients were strikingly different from the controls. The differences were most marked on symptoms that have been accepted as particularly characteristic of the syndrome [*see illustration on next page*]. For example, 81 percent of the patients were described as unable to sit still at meals, as against only 8 percent of the controls; 84 percent of the patients were said by their mothers to be unable to finish projects, whereas among the controls none was found to be lacking in this ability. Substantial per-



"THE STORY OF FIDGETY PHILIPP" is one of the cautionary tales in *Struwwelpeter* (*Shock-headed Peter*), a children's book in verse written a century ago by Heinrich Hoffmann. The tale of a "hyperactive" child named Philipp is told in three drawings and 36 lines of doggerel. In the first picture (*top at right*) Philipp begins rocking back and forth on his chair after his father asks "I wonder if Philipp is able to sit still today at the table?" In the second picture Philipp loses his balance and grabs frantically at the tablecloth. In the third picture Philipp has crashed to the floor, where he lies covered by the tablecloth, food and broken dishes.



centages of the children in the control group were reported to be overactive, fidgety, overtalkative or given to teasing, but even in these necessarily subjective answers the control children had a much lower positive score as a group than the patients did. All in all the catalogue of symptoms indicated clearly that the patients were distinctly different in temperament from normal children.

Along with their fidgetiness and inability to concentrate the hyperactive children showed many forms of antisocial behavior. They were given to fighting with other children, irritability, defiance, lying and destructiveness, and nearly half were said to be unpopular with other children. About one in four of the patients had been caught stealing (usually money from members of their family), and about one in 10 had been guilty of vandalism, setting fires, cruelty to animals and truancy. Consulting their teachers, we found that half of the patients had had to be disciplined in school, more than a third had had to repeat grades and the same proportion had histories of repeated fighting in school.

The hyperactive children's troubles had generally started at a very early age. About half of the mothers had begun to notice that their child was unusual before he was two years old. We found no indication that the behavioral disorder was significantly related to complications in the mother's pregnancy or delivery, to a family history of mental disease or to absence of the child's parents from home; there was no statistical difference between the patients' family backgrounds and the control children's in these respects. The patients did tend, however, to have a history of feeding problems, disturbed sleep and generally poor health in the first year of life, and many had been handicapped by delayed development of speech and poor coor-

COMMON SYMPTOMS of hyperactivity were scored (*at left*) in a study that compared 37 young patients (32 boys and five girls) from the psychiatric clinic of the St. Louis Children's Hospital with a control group of children attending first grade in two suburban schools. The symptoms were scored by interviewing the mothers of the two groups. The black bars indicate the percentage of young patients with each symptom; the gray bars show percentages for the control group. There are obviously many more "fidgety Philipps" among the 37 patients than among the nonpatients.

dination. All of this suggested the possibility of inborn difficulties.

We followed up this study of young children with a similar survey of teen-agers who had previously been seen in our clinic for the same disorder. This sample consisted of 45 youngsters (41 boys and four girls) between the ages of 12 and 16. On the average they had first come to the clinic about five years previously, and all had definitely been diagnosed at that time as hyperactive on the basis of several symptoms. For the follow-up study we used a questionnaire for interviewing the mothers that was much like the one we had employed in the survey of the sample of younger children. In this case we added interviews with the teen-agers themselves, asking them about their symptoms, their general behavior at home and in school, their attitudes toward school and their self-evaluation.

Our interviews with the mothers indicated that these children had not changed much since we first saw them. Of the 45 teen-agers 14 had deteriorated or at least not improved in behavior, 26 had improved somewhat and only five were said to be more or less free of their original symptoms. Most of the youngsters were still notably restless, unable to concentrate or finish jobs, overtalkative and poor in school performance. A large majority were described by their mothers as being low in self-esteem and tending to feel picked on (questions that we had unfortunately neglected to include in the earlier study of young children). It turned out that the teen-agers showed a distinct increase (over the younger sample) in impatience, resistance to discipline, irritability and lying. Substantial proportions of them engaged in fighting and stealing, and deviant behavior such as running away from home, going with a "bad crowd" and playing hooky; drinking was not uncommon. In our interviews with the teen-agers themselves, many said they found it hard to study and were not interested in school. A third of the mothers said their child was so hard to handle that they had seriously considered sending him away to a boarding school or an institution. Four out of 10 of the mothers could think of no career for which their child would be suited.

These youngsters were clearly abnormal, but not seriously so in the usual psychiatric terms. Three of the 45 have a record of antisocial behavior so extensive that they might be called "sociopaths." The others are best described as individuals with personality problems.

We have not yet compared these teen-agers with a control group. That their problems are not typical of teen-agers' problems in general has already been indicated, however, by the results of a study by Jean W. Macfarlane and her associates at the University of California at Berkeley. They found that in a large sample of normal teen-age boys from roughly the same socioeconomic background as our group the frequency of overactivity was only 17 percent; of irritability, 12 percent; of quarrelsomeness, 4 percent; of lying, 8 percent; of stealing, zero.

We have found evidence of another kind that hyperactive children start life with a temperament that is distinctly abnormal. In clinical practice I have been impressed by the frequency with which hyperactive children turn out to have had a history of an accidental poisoning early in life—usually before the age of three. This might be expected, because the medicine cabinet is a prime target for children's curiosity, and a hyperactive child is more likely than a normal one to get into such things as soon as he can toddle and climb. The question has considerable practical importance; if active children do indeed run a higher than normal danger of accidental poisoning, extra precautions to prevent access to drugs and toxins should be taken in such households. We decided to look into the facts concerning the extent of this hazard for hyperactive children.

Two medical students at Washington University followed up 90 young children who had been treated at Children's Hospital for accidental poisoning six years earlier. They interviewed the mothers and teachers of the children with our standard questionnaire for eliciting symptoms of the hyperactivity syndrome. At the time of the interviews these children were eight or nine years old. It turned out that a third of the 58 boys could be diagnosed as hyperactive, using fairly rigorous criteria, an incidence considerably higher than the 7 percent figure we have found in a control population of boys. We also sent questionnaires to the mothers of 80 hyperactive children visiting our clinic and to the mothers of an equal number of normal second-grade children. Again the returns showed that 22 percent of the hyperactive children, as against only 8 percent of the controls, had had an accidental poisoning.

This finding, it seems to me, strongly supports the thesis that the syndrome manifests itself at an early age and that hyperactive children may be innately different from other children. It is consistent with the fact that 80 percent of the responding parents in our first study of young children in the early grades and 60 percent of those in our study of teen-agers reported they knew their children were unusual before they reached school age. Alexander Thomas, Stella Chess and Herbert G. Birch of the New York University School of Medicine, who have made an extensive study of the behavioral development of children from birth, have found that certain patterns observable at a very early age foreshadow later disorders of behavior. The investigators conclude that many disorders may be traceable to inborn temperament.

In our own experience with hyperactive children in the clinic we have commonly found that the child's father had been troublesome as a youngster, that he may have dropped out of school and that as an adult he is characteristically restless and short-tempered. Our interviews with the mothers in our first study did not disclose any significant difference between the patient group and the control group in this aspect of the family history, but the interviews did not actually yield much information on the subject. We plan to explore the question directly and in detail in further studies. An investigation at the genetic level is already in progress: a medical geneticist at Washington University is analyzing the chromosomes of a group of children from our clinic. This inquiry was prompted by the recent discovery of an association of aggressive antisocial behavior with a peculiarity of the XYY karyotype. This is a chromosomal abnormality in which a male is born with two Y chromosomes instead of one.

It seems highly significant that the hyperactivity syndrome is much more common in boys than in girls (the ratio in the various groups studied is six to one or more) and that boys are also afflicted more frequently with other behavioral problems such as infantile autism, reading disability and delayed speech development. There is every reason to believe these are inborn differences and not the result of biased treatment of boys by parents and teachers. Moreover, difficulties in reading and speech are often familial. It appears that some inherited eccentricities of behavior or learning may be sex-linked or that the male nervous system may be peculiarly prone to certain failures in early development; conceivably both of these hypotheses are true.

The idea that hyperactivity has a biological basis is further strengthened by the dramatic change in behavior produced in many of these children by a stimulating drug (such as amphetamine or methylphenidate). Under the influence of the drug the hyperactive child (in at least half of all cases) becomes quieter, exhibits a longer attention span and greater perseverance with assigned work, performs better in school and is generally easier to get along with. It has been found that amphetamine has a somewhat similar effect on the performance of normal adults who are assigned a boring or complex task. Russell Davis of the University of Cambridge reported, for example, that in an experiment along these lines men who were given the drug became absorbed in the task, apparently as a result of the focusing of all their attention on it. The stimulating drug, in short, seems to bring about a more acute and better-organized responsiveness to the environment.

It is known that the amphetamines act on the reticular formation in the brain stem, a key area controlling consciousness and attention. When amphetamine is administered to a subject, one can usually tell he is aroused simply by observing his behavior: he becomes more attentive, alert and frequently more talkative. Objective evidence of "arousal" can also be seen in changes that occur in his brain waves as shown by an electroencephalogram. It is also known that amphetamine produces specific effects on the metabolism of norepinephrine, or noradrenalin, in the brain cells. Norepinephrine probably controls the transmission of nerve impulses by some key nerve cells; it is highly concentrated in areas such as the hypothalamus and brain stem, which have much to do with mood and awareness. In recent experiments Sebastian P. Grossman of the University of Chicago found that the injection of a minute amount of norepinephrine in the reticular formation of a rat lowers the animal's activity level and responsiveness; injection of acetylcholine has the opposite effect. Since amphetamine is known to stimulate the release of norepinephrine from nerve endings, it seems entirely possible that the drug's effect on the behavior of hyperactive children may be due to its action at this critical juncture. It may repair a deficit in the activity of norepinephrine or in some other way restore the normal balance of activity between norepinephrine and acetylcholine.

This idea gains credence from the fact that hyperactive children often behave very differently from their usual selves when they are under tension. A child who has been described by his mother as a demon may be an angel when he comes to the psychiatrist's office. Most hyperactive children tend to be subdued in a strange situation and to display their bad behavior only when they feel at home. The explanation may lie in a stress-induced release of norepinephrine in the brain cells. Thus a state of anxiety may produce the same effect as a dose of amphetamine—through exactly the same mechanism.

It has been known for many years that removal of the frontal lobes of the brain produces hyperactivity in monkeys. Harry F. Harlow and his associates at the University of Wisconsin narrowed down the critical area: hyperactivity and apparent distractibility could be produced in monkeys by removing a section of granular cortex toward the rear of the frontal lobe. In a related series of experiments George D. Davis of the Louisiana State University School of Medicine has found that the effects of lobectomy in monkeys can be reversed with a stimulating drug; it reduces the animals' overactivity and improves their concentration.

As a practicing child psychiatrist I am of course concerned primarily with treatment of the hyperactivity syndrome. Amphetamine and other stimulants produce such good results that it is tempting to base treatment on use of a drug. Its effect is only temporary, however; when the drug wears off, the child reverts to his usual behavior. Furthermore, continuance of the drug into the teens runs the danger that the child may overuse it or become a habitual drug user. We therefore employ the drugs only to enable a hyperactive child to make a good start in school and prevent him from becoming resentful and insecure. My colleagues and I devote ourselves principally to adjusting the environment to the needs of the handicapped child.

This approach entails giving practical advice to the parents and helping them to apply techniques of behavioral therapy. We also assist the child's teachers in planning ways to work around his difficulties in learning. Educating the parents and teachers in what the problems of hyperactive children are and how to handle them appears to offer the best hope for enabling the patients to grow up to be confident and happy in spite of the limitations of their temperament.

LIQUID-CRYSTAL DISPLAY DEVICES

Liquid crystals (fluids that have certain crystalline properties) respond to an electric field by becoming cloudy or changing color. Effects of this kind can be used for the presentation of images

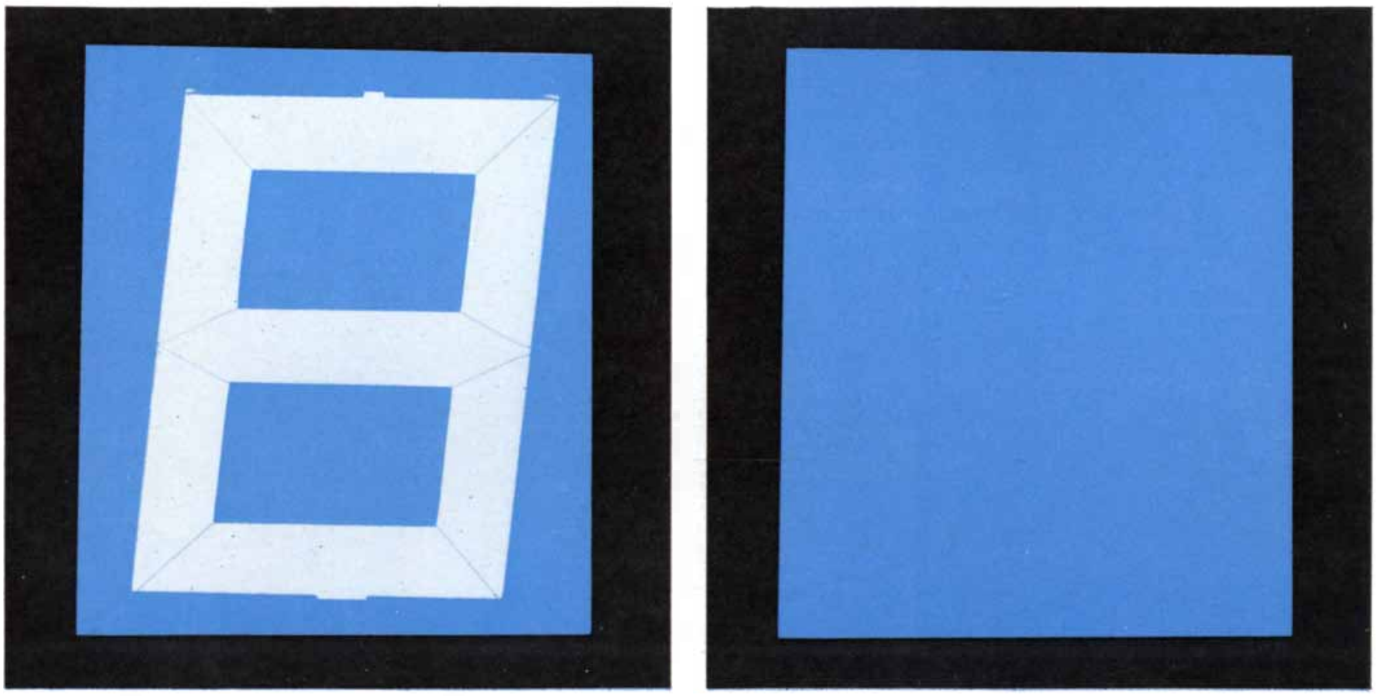
by George H. Heilmeier

Liquid-crystal substances have been a scientific curiosity since the 1890's, when their peculiar properties first began to be recognized. A substance of this type flows, pours and assumes the shape of its container as if it were a liquid. At the same time its molecules, unlike the molecules of a liquid, tend to form loosely ordered arrays rather like the regular lattice of a crystal. In recent years liquid crystals have stimulated the imagination of engineers. These substances are currently being used to create a new family of devices for the display of symbols such as numbers and letters. They may also make it possible to devise a window that can be made cloudy or transparent at the flick of a switch, and a television set no thicker than a picture frame.

A liquid-crystal device differs fundamentally from an electronic display device such as a cathode ray tube. These devices create images by generating visible light. A liquid-crystal device generates no light of its own; it scatters ambient light much as a printed page does. The basic medium by which numbers, letters and other images are presented in such a device is certain kinds of liquid crystal sandwiched between two sheets of glass. Normally the liquid crystal is clear, but when an electric field is applied to it, some regions in it become turbulent and scatter light. By controlling the size and shape of the turbulent regions, images can be formed.

Such a device offers two advantages. First, since it reflects light instead of generating light, it can be viewed under a wide range of lighting conditions (including direct sunlight or a floodlight, either of which would "wash out" the image on a light-generating device). Second, since a liquid-crystal device does not emit light, it should require relatively little power.

The general operating principles of these devices can be adapted to achieve a number of different visual effects, and my colleagues and I at the RCA Labo-



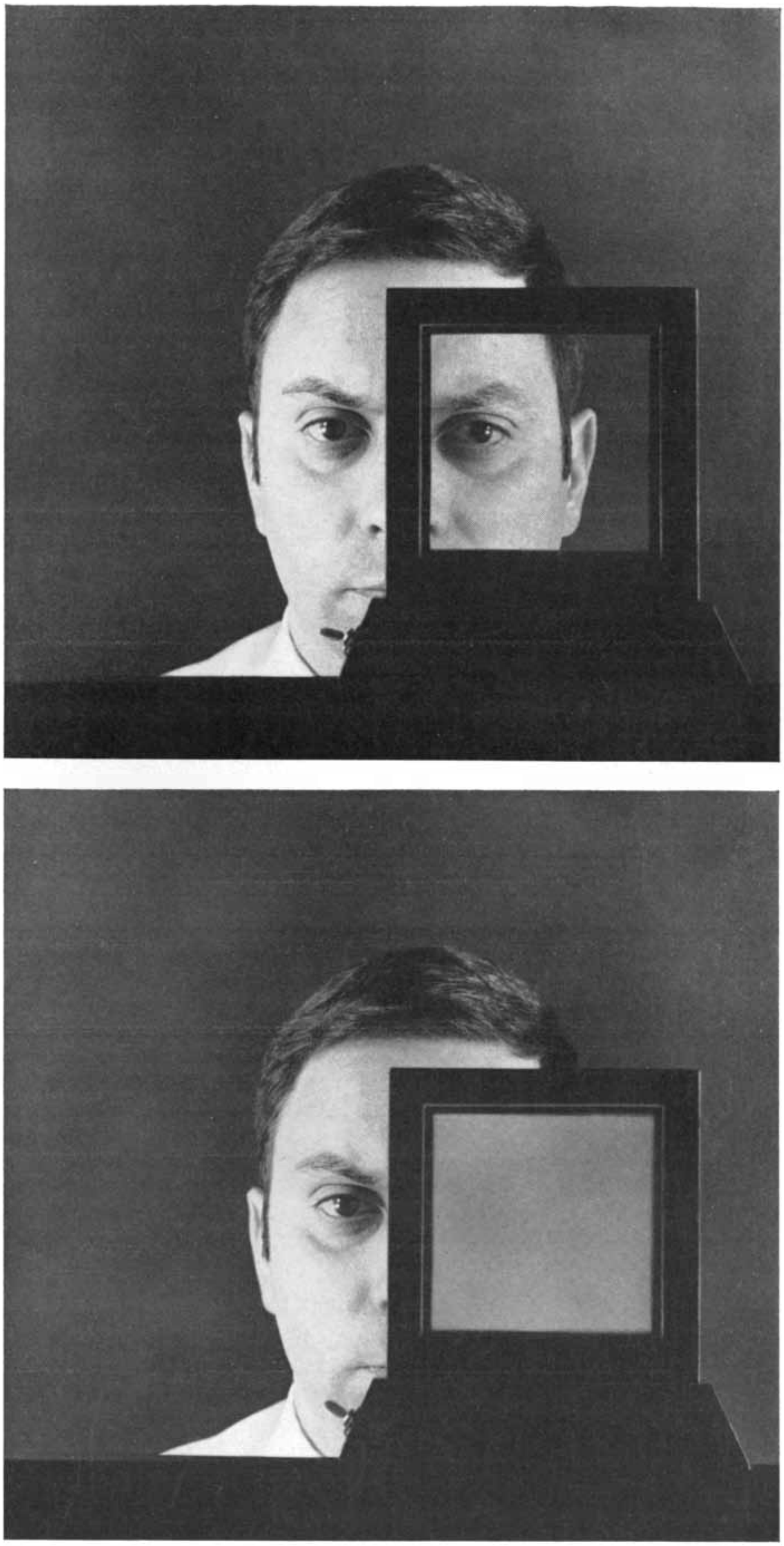
NUMERICAL INDICATOR consisting of a mixture of liquid crystal and dye molecules between glass plates can display any numeral from 0 through 9. At left an 8 is formed by activating all the transparent electrodes (*geometric shapes*) coated on the plates. Electric field between electrodes creates a molecular arrangement that prevents the dye molecules from absorbing any of the plane-polarized light shining through the panel. All light is transmitted and a whitish 8 appears. Other numerals can be formed by activating various patterns of electrodes. At right no electrodes are turned on, the dye molecules can absorb light and indicator is blue.

ratories have developed several prototypes. Both the promise and the limitations of this approach to information display are established by the nature of the basic phenomenon that makes such devices possible: the behavior of the loosely ordered liquid-crystal molecules in an electric field.

There are three types of liquid crystal, termed nematic, smectic and cholesteric [see "Liquid Crystals," by James L. Fergason; SCIENTIFIC AMERICAN, August, 1964]. Nematic liquid crystals consist of rodlike organic molecules. With respect to their long axes these molecules can move from side to side and up and down, but their many other possible motions are constrained by the forces between them. They maintain a parallel or nearly parallel arrangement, although each molecule can rotate around an axis pointing in its direction of alignment. This arrangement has been compared to wooden matches in a box; the matches can move to some extent, but they tend to remain parallel within the box [*see top left in illustration on next page*]. The term nematic, which is derived from the Greek word for thread, refers to the fact that when one examines a nematic substance with a microscope, one sees tiny threadlike structures representing the boundaries between regions of different molecular orientation. Until recently nematic behavior was observed over a rather narrow temperature range near 110 degrees Celsius (230 degrees Fahrenheit). Below that range the substances are fatty solids; above it they are liquids. Substances that behave as nematic liquid crystals over an 80-degree range that includes room temperature have been developed at the RCA Laboratories by Joel E. Goldmacher, Joseph A. Castellano and Michael T. McCaffrey.

Smectic liquid crystals are named for the Greek word for soap, which is the most familiar member of this class. The molecules of certain soaps and other smectic materials array themselves in layers. Any two layers can slide over each other because the molecules cannot move up and down but only forward and backward or side to side. Like nematic molecules, smectic molecules can rotate freely around their direction of alignment [*see middle and bottom left in illustration on next page*].

Cholesteric liquid crystals bear some resemblance to both smectic and nematic ones. Cholesteric molecules are smectic in that they are arranged in layers. Within each layer, however, the molecular pattern is nematic. Because of the size and shape of the cholesteric mole-



LIQUID-CRYSTAL WINDOW can be made opaque at the flick of a switch. The window consists of two glass plates enclosing a layer of liquid crystal. Transparent electrodes of tin oxide coat the inside surfaces of both plates. At top the pane is clear, and the man's face can be seen clearly because the device has not been turned on. At bottom a voltage has been established across the electrodes and the electric field creates turbulence in the liquid crystal. The turbulent areas make the pane opaque; accordingly the man's face is obscured.

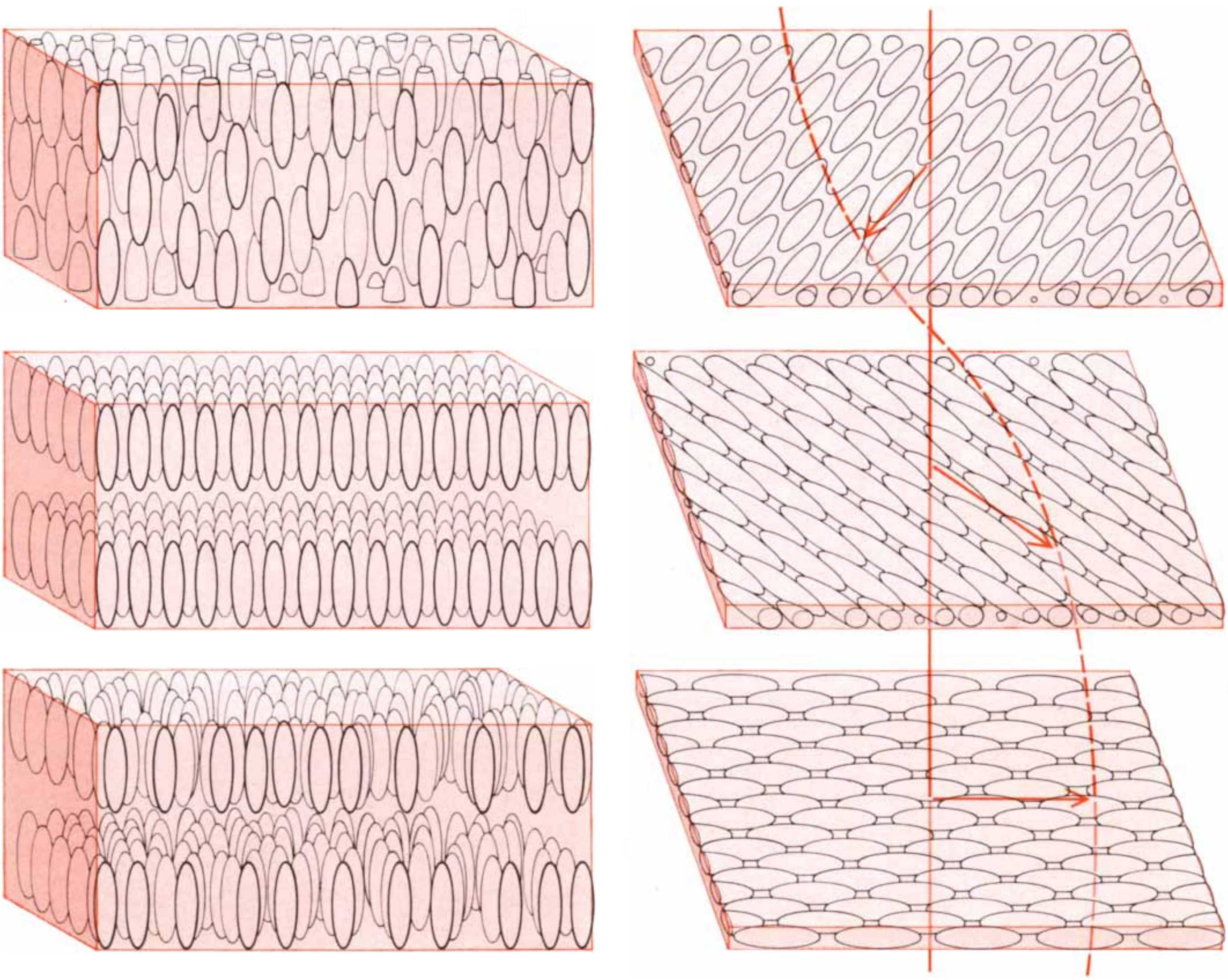
cules, those in neighboring layers displace one another so that their long axes are shifted. This displacement forms the entire structure into a helical pattern [*see right in illustration below*].

The pitch and period of the helical structure (the angle of each turn and the distance between turns) give rise to interesting interference colors when light falls on cholesteric substances. Changes in temperature or pressure alter the pitch and period so that new colors are produced. In some undetermined way the color can also be changed by chemical vapors. Cholesteric substances can therefore serve as the active elements in devices that map the distribution of temperatures and in devices that detect vapors.

An electric field affects a liquid-crystal material in two conflicting ways. First, it enhances the natural tendency of liquid crystals to assume orderly patterns. An example is provided by the nematic liquid crystal p-ethoxybenzylidene-p′-aminobenzonitrile (PEBAB). The molecules of this substance are normally arranged so that all of them in any one region are pointing in the same direction, although the prevailing orientation is different from region to region. When the molecules of a thin film of this material are sandwiched between two plates of glass and are subjected to an electric field, they will behave as if they were little magnets in a magnetic field; they all align themselves so that their electric-dipole moments lie in the field direction.

A molecule has an electric-dipole moment simply because it is an electric dipole, that is, it can be described as an object having two electric charges separated by a distance. In the case of a molecule one end tends to be positively charged and the other negatively charged because of the asymmetrical distribution of the electrons that bind the atoms in the molecule. In ordinary liquids the electric forces are not strong enough to keep the molecules aligned because of the molecules' natural tendency to move randomly and independently. As a result perhaps only one in 1,000 molecules would be aligned by an electric field.

As an electric field is imposing order on a liquid crystal it can also set in motion a chain of events that disrupts the molecular pattern forming under its influence. Nematic solutions contain ionic impurities (positively or negative-

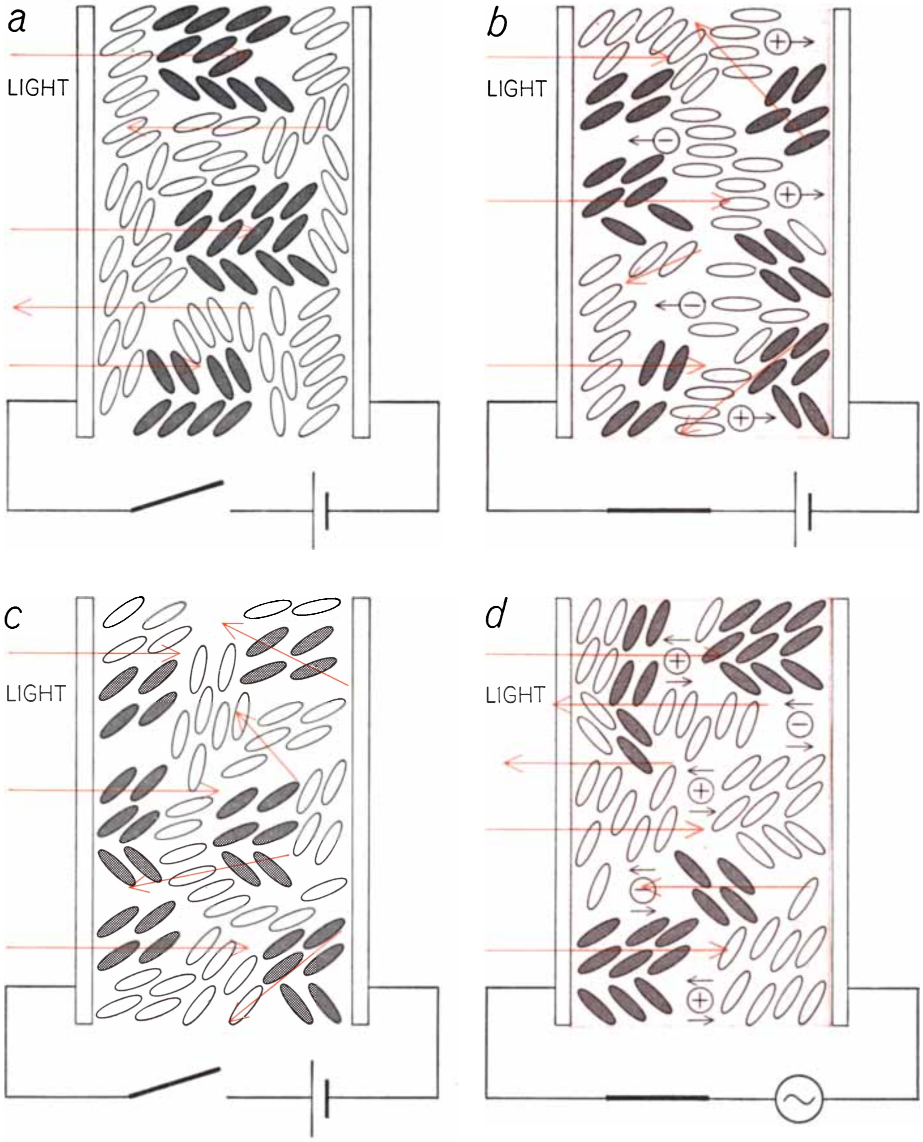


THREE KINDS OF LIQUID CRYSTAL are distinguished from one another by the arrangement of their molecules. Nematic liquid crystals (*drawing at top left*) consist of molecules that are parallel, resembling matches in a box. Each molecule can, however, rotate around its axis and move from side to side or up and down. Smectic materials (*drawings at middle and bottom left*) have a layered arrangement. The layers can slide over one another because the molecules in each move from side to side or forward and backward but not up and down. Within each layer molecules may be ordered in ranks or randomly distributed. Cholesteric molecules (*right*) consist of layers, as smectic crystals do. Within each layer, however, molecules are parallel, as nematic molecules are. Molecules in one layer displace those above, so that a helical pattern (*vertical line and broken helical line*) forms from layer to layer.

ly charged molecular fragments that are not from the nematic compound) and other ions that are probably produced by dissociation of the nematic compound itself. The electric field pulls the ions toward one or the other of its poles. In a nematic substance such as PEBAB the dipole moment of a molecule lies along its structural axis, and in an electric field the axes of the molecules of the substance line up parallel to one another. Ions can pass through such an array without creating large disturbances.

Suppose, however, that the permanent dipole moment does not lie along the structural axis of the molecule. Such a molecule is by no means rare, because many molecules have side chains of atoms attached to their main chain. The electric-dipole moment is along these branches rather than along the "backbone" of the molecule.

One substance of this kind is the nematic liquid crystal anisylidene-p-aminophenylacetate (APAPA). When this substance is subjected to an electric field, its molecules line up not along their main chain but perpendicularly to it because of the strong influence of the side chains. The main chains are therefore oriented in various directions with respect to the electric field. Aligned in this way, the molecules present a barrier to the moving ions. The ions push through the log jam and disrupt the array, creating comparatively large regions of turbulence (from one micron to five microns across). The turbulence causes the thin layer of nematic material, which was originally transparent, to become milky white because the turbulent fluid scatters light.



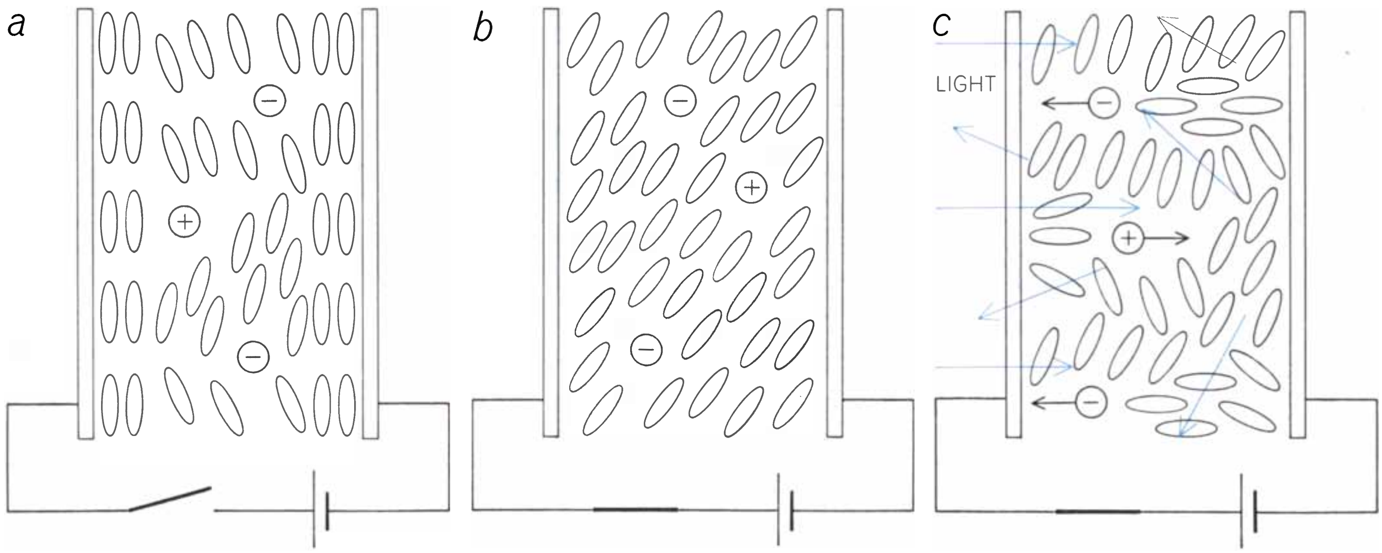
STORAGE MODE of liquid-crystal device is achieved with mixtures of cholesteric molecules (*gray*) and nematic ones. In *a* molecules are ordered, so that there are few scattering centers (interfaces between the two materials that scatter light). Therefore light entering glass plate at left is reflected by aluminized electrode at right. Viewed from front, mixture would be clear. In *b* a direct current is applied (*closed circuit*), and many scattering centers develop because order is disrupted by ions moving under the influence of the field (*colored area*). Since each material has a different index of refraction, light is scattered and material becomes opaque. In *c* field is off (*open circuit*) but disorder persists for weeks. In *d* a high-frequency alternating field reorders the molecules. Since field reverses rapidly, ions are unable to move and create disorder. Instead each ion oscillates around an equilibrium position, the molecules become ordered and material becomes transparent again.

This effect is called dynamic scattering. Dynamic scattering can be halted and the clarity of the liquid crystal restored simply by turning off the voltage. Once the electric field is no longer present, there are no more disruptive ions in motion and the molecules reestablish their ordered local patterns. Dynamic-scattering effects can be controlled to make indicator displays and small windows that can be transparent or cloudy.

Another scattering effect caused by moving ions is called the storage mode. When a nematic liquid crystal of the type that exhibits dynamic scattering is mixed with a cholesteric liquid crystal such as cholesteryl chloride at a weight ratio of nine to one, the resulting material is relatively clear. It too becomes milky white when it is subjected to a direct current or a low-frequency alternating current with a potential greater than 20 volts. When the field is turned off, however, the mixture remains white; it regains its transparency only after several weeks. The material can be made transparent quickly by applying an alternating current of more than 50 volts and a frequency of 4,000 cycles per second. Thus an image can be "written" by means of a direct-current signal and erased by means of an alternating-current one. No power is required to retain the image once it is written.

In such a mixture the ions can be regarded as creating turbulence by emulsifying the two components of the mixture, although the actual physics of the process is much subtler. In the transparent state the two kinds of liquid-crystal molecule have lined up with their axes pointing in the same direction. In this state there are relatively few light-scattering centers, which consist of interfaces between the two kinds of material. The moving ions disrupt this arrangement, so that the order is upset, many new interfaces develop and light is scattered as it passes through the turbulent material because each component has a different index of refraction.

When the mixed liquid-crystal system is subjected to the alternating field, the molecules line up once again and the

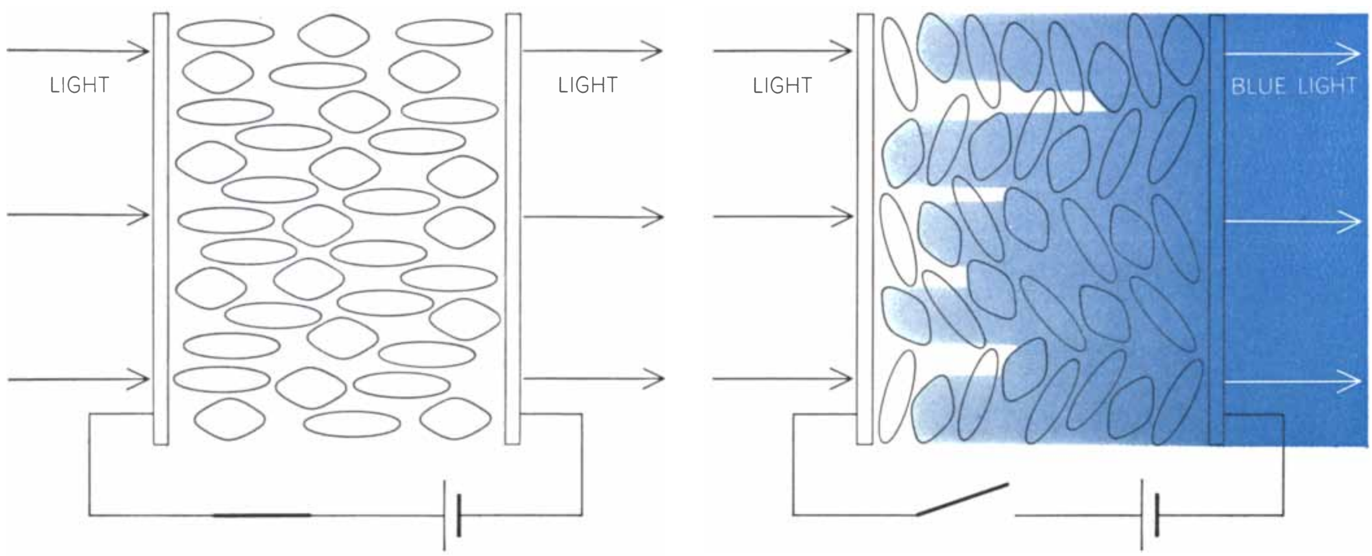


DYNAMIC SCATTERING of light is an effect produced in nematic crystals by electric fields that can be controlled in order to form images. In *a*, a side view of nematic material between glass plates, there is no field (*open circuit*). Nematic molecules in any local area point in one direction, although the orientation differs from area to area. Ions (*pluses and minuses*) stand still. In *b* a field exists (*shading*) between plates, causing molecules to line up with their long axes at an angle to the field direction. In *c* the ions move toward electrodes pulled by field. As they do so they disrupt the molecules' order, so that the light is scattered. Viewed from the front, screen would appear to be opaque. When field is turned off, the molecules are locally reordered and the material becomes clear.

scattering centers disappear. The molecules are no longer disturbed by the ions because the ions cannot travel any great distance in a rapidly alternating field; they are pulled and pushed as the field reverses. At high frequency the distance they cover on each half-cycle is only a fraction of the thickness of the liquid crystal, and the ions simply oscillate around an equilibrium position.

As I have noted, when the dipole moment of a nematic liquid-crystal molecule lies along the structural axis of the molecule, ions pass through the material without creating much turbulence. Accordingly little light is scattered. Such materials can, however, be used to produce color effects. Under the sponsorship of the National Aeronautics and Space Administration we have been experimenting with the "host-guest" relationships that nematic liquid crystals and dichroic dyes establish with each other. A dichroic dye is a compound whose molecules absorb plane-polarized light only when they are oriented in a certain way with respect to the plane of polarization.

When one of these dyes, indophenol blue, is mixed with a PEBAB host, the combination is a vivid blue. If polarized light is shined through the mixture while there is a voltage across it, the blue color

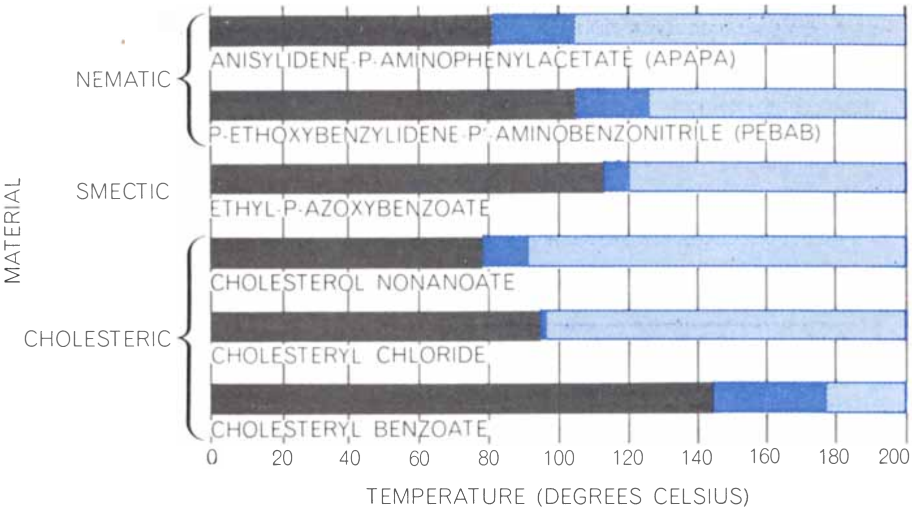


GUEST-HOST RELATIONSHIP between nematic molecules (*ellipses*) and dye molecules allows both to be manipulated in order to change the color of plane-polarized light. At left an electric field (*shading*) lines up nematic molecules, whose long axes point in field direction. The "host" nematic molecules then force the "guest" dichroic-dye molecules to line up in the same direction. A dichroic-dye molecule is one that can absorb plane-polarized light only when it is oriented in a certain way with respect to the plane of polarization. In the orientation represented dye molecules cannot absorb polarized light and all light is transmitted. At right, when the circuit is open and there is no field, the dye molecules assume various positions with respect to the beam's polarization. Therefore some light is absorbed, and only one color of plane-polarized light is transmitted as it travels through the sample.

disappears and the material becomes transparent. When the voltage is removed, the blue color reappears. I should emphasize that the sample does not change chemically; the voltage simply causes the host molecules of the liquid crystal to line up. As they do so they force the guest molecules of dye to line up as well. If the orientation of the dye molecules is such that they do not absorb polarized light, the light passes through the material without being scattered. Care must be taken to use nonionic dyes, that is, dyes that do not respond to the electric field; otherwise the dye molecules will move through the system and introduce unwanted light-scattering effects.

In cholesteric materials the strong tendency of liquid-crystal molecules to align themselves in an electric field can be used to produce color effects. In a strong field each additional increase in field strength changes the pitch of the helical structure of the material. Each change in pitch gives rise to a corresponding change in color. In still stronger fields the helical structure is completely unraveled and thus the material becomes transparent. When the electric field is removed, the material regains its color.

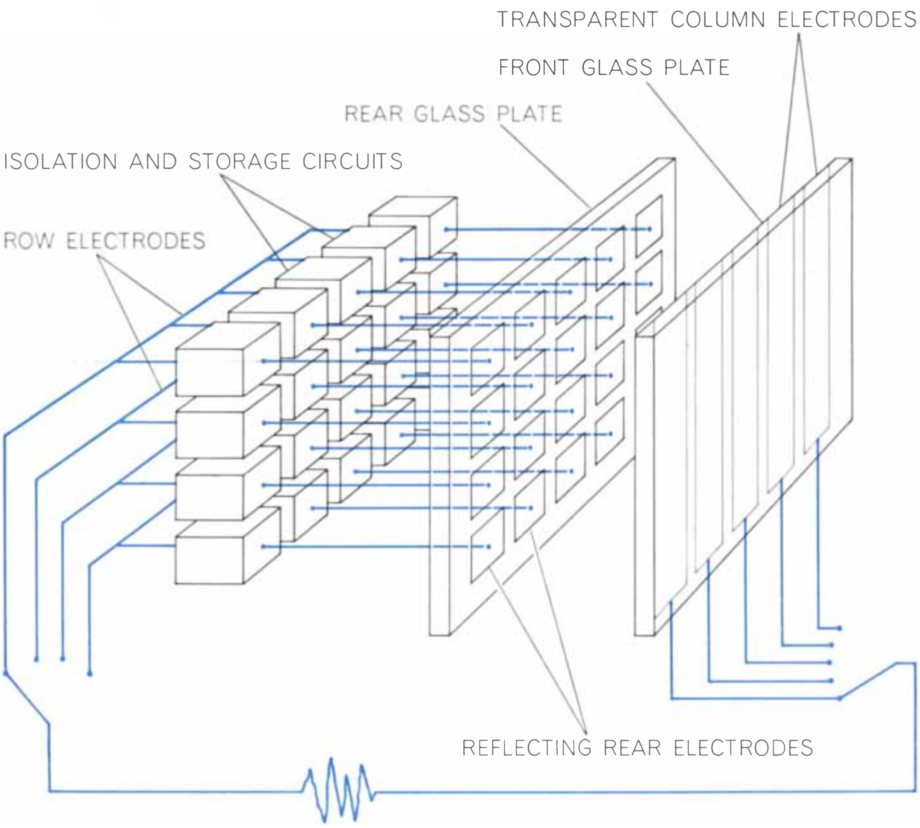
Liquid-crystal display devices are easily made: the thin film of liquid crystal is placed between two pieces of glass, each of which has been coated on one side with a conductive material. At least one of the coatings must be transparent for viewing, and in many devices a transparent film of tin oxide serves this purpose. If the device is intended to control light transmission, both electrodes must consist of such a material. If it is meant to display an image in reflected ambient light, the rear electrode can be a highly reflecting film of aluminum. In any device the electrodes can be patterned so that different segments or elements of the device can be energized in order to present a number, a letter or some other kind of image. Since the liquid-crystal layer is only about a thousandth of an inch thick and is held between the plates by capillary action, the problems usually associated with the handling of liquids do not arise.



LIQUID-CRYSTAL PHASE is affected by temperature. Some materials, such as anisylidene-p-aminophenylacetate (APAPA), have a broad range in which they exist as liquid crystals. Below 82 degrees Celsius this material is a solid (*gray*). At that temperature it becomes a liquid crystal (*color*), and at 105 degrees the material becomes a liquid (*shading*). The most temperature-sensitive is cholesteryl chloride. It exists in a one-degree range.

Dynamic-scattering devices operate on less than 50 volts and require a power density of less than one milliwatt per square inch of display area. The image looks like printed lettering. Such liquid-crystal indicators might be particularly useful in an airplane cockpit or on an automobile dashboard, where low voltage and low power are desirable and legibility under high ambient light is important. The storage-mode materials—the combinations of nematic and cholesteric liquid crystals—may find application in devices that display information that changes infrequently, for example highway signs, arrival-and-departure boards in airports and certain cockpit and dashboard instruments.

The lifetime of these devices, particularly those based on pure nematic substances, would seem to be determined by the lifetime of the liquid crystal. If the molecules of nematic liquid crystals

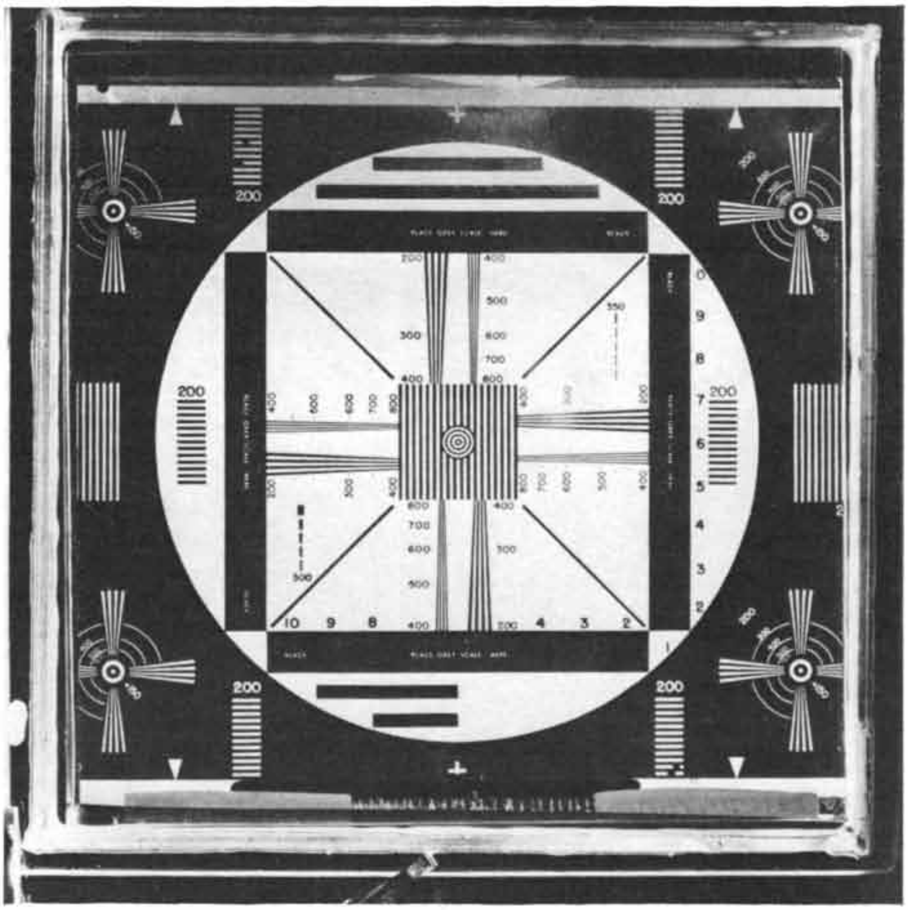


THIN TELEVISION RECEIVER no deeper than a picture frame might be made from a film of nematic liquid crystal held between the front and the rear glass plate. The electrodes coating the plates would form images by causing the nematic material to scatter ambient light. The electrodes on the rear plate would reflect light so that the moving images would be projected out to the viewer. The electrodes on the front plate would be transparent.

tend to break down (and there is little doubt that they do), the process must be carefully controlled in order to prolong the lifetime of nematic devices. The prevention of such breakdown, however, would critically reduce the number of ions available in the liquid-crystal system. It may therefore be necessary to find some other method of introducing ions into the system. The injection of electrons from the negative electrode seems promising. The presence of an applied voltage would help some electrons to escape from the electrode into the liquid crystal, where they would be captured by neutral molecules. This combination of a molecule and an associated electron represents a negative ion that would be attracted to the positive electrode. On reaching the anode the molecule would give up the electron and resume its neutrality. This process would supply ions without substantially degrading the liquid crystal.

Someday liquid crystals may become the picture-producing element in the most ubiquitous display device of all: the television receiver. Engineers have long sought a display concept that would enable them to build a television receiver that would operate on very little power and would do away with the bulky equipment behind the picture screen. These ground rules suggest that the operation of the picture screen would be based not on the electron beam of a cathode ray tube but on solid-state devices such as transistors and semiconductor diodes. The dynamic-scattering mode in nematic liquid crystals could easily be made to produce images by impulses from such circuitry.

Test patterns of such images have in fact been broadcast and received. The turbulence-controlling electrodes, however, were activated by a scanning electron beam. The organization and operation of the hundreds of thousands of light-reflecting elements and the associated solid-state components required for a flat display unit remain a difficult technical problem. The cost of a technically satisfactory solution is also a difficult problem. These and other difficulties must be overcome if liquid-crystal display devices are to perform all the diverse services of which they appear capable. One point is clear: a new kind of device is ready to join light-generating electron tubes and other devices as a part of display technology.



TELEVISION TEST PATTERN etched on the electrodes of a nematic liquid-crystal screen demonstrates both the high resolution and the variable contrast of this kind of display.

MATHEMATICAL GAMES

Some mathematical curiosities embedded in the solar system

by Martin Gardner

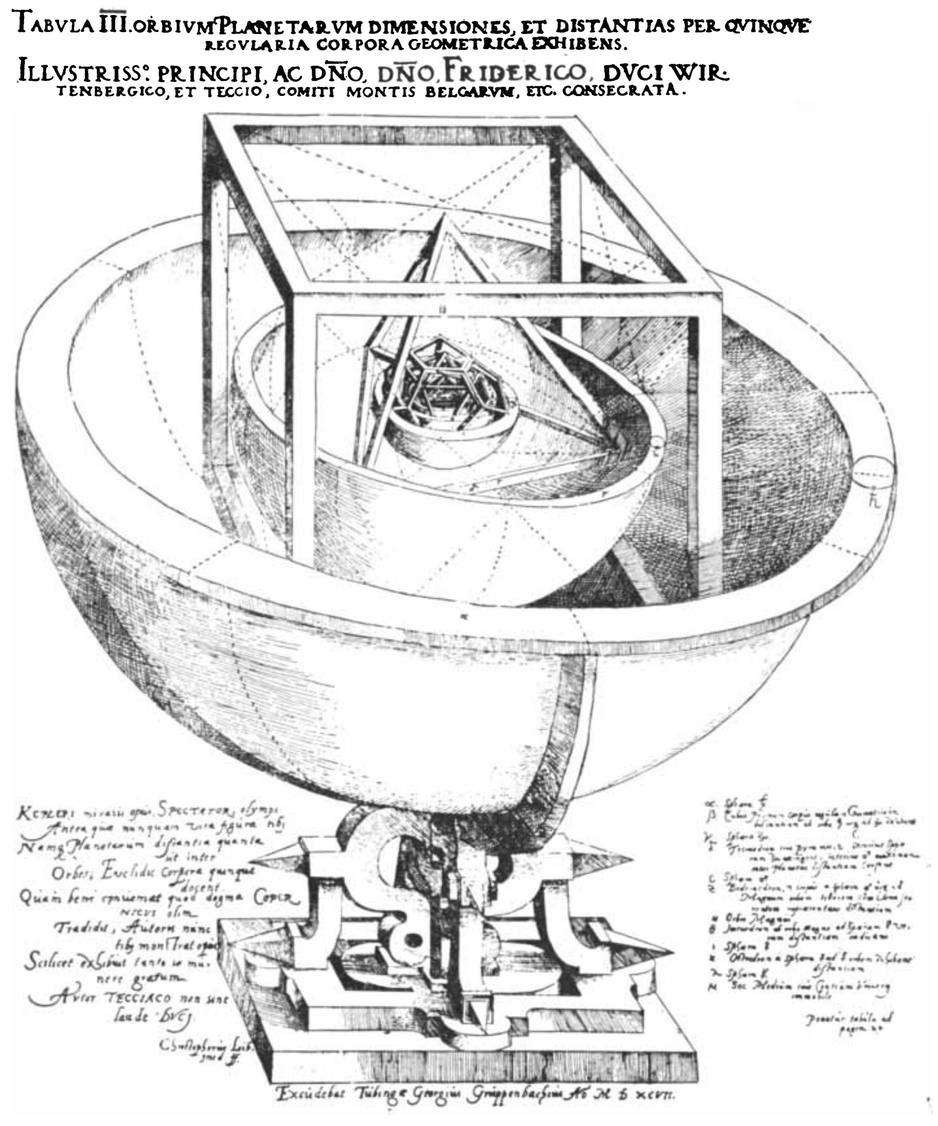
Astronomy, like every other science, has curious bypaths where one may stumble over mathematical problems with recreational aspects. This month we take a quick look at the solar system, about which so many startling new discoveries are being made, and consider some amusing mathematical questions that have arisen in the history of speculation about the structure of the sun's family of orbiting bodies.

First a bit of historical background. It is a common error to suppose all the ancients believed the earth to be flat and the center of the universe. The Greek Pythagoreans, for instance, taught that the earth was both round and rotating. The system's center was not the sun but a central fire that the sun reflected. The earth, sun, moon and the five other known planets circled the central fire. Since the earth always kept its uninhabited side toward the fire during its 24-hour revolution, the fire could never be seen. Aristotle suggested that it was the Pythagorean cult's obsession with the triangular number 10 (the sum of 1, 2, 3, 4) that led its members to add a 10th body called antichthon (counter-earth). It too was always invisible because its orbit lay between the earth and the central fire. Aristarchus of Samos, a third-century-B.C. Greek astronomer, actually proposed a heliocentric model, with all planets circling the sun, although his treatise on this was lost and is known only through comments by Archimedes.

The model that dominated Greek astronomy, however, as well as medieval science was the geocentric model of Aristotle: an unmoving spherical earth at the core of the universe with all other heavenly bodies, including the stars, going around it. Aristotle defended an earlier and excellent argument for the earth's roundness. During a lunar eclipse the earth's shadow on the moon has a rounded edge that can best be explained if the earth is a ball. The Ptolemaic model of the second century A.D., a refinement of Aristotle's, was designed to account for the erratic paths of the five visible planets as they cross our sky. The trick was done by having the planets move in smaller circles, called epicycles, as they travel larger circular orbits around the earth. The model was quite adequate to explain the apparent motions of heavenly bodies, including irregular movements of planets and moons caused by elliptical orbits, provided that enough epicycles were posited and bodies were allowed to move along them at nonuniform speeds.

We all know how, after a long controversy culminating in Galileo's persecution, the heliocentric model of the 16th-century Polish astronomer Nicolaus Copernicus finally won out. It was not so much because it had more explanatory and predictive power as because it was simpler and more elegant. Centuries later it did provide explanations of previously unexplained phenomena such as the bulging of the earth's equator by the centrifugal force of the earth's spin.

The final twist to this vacillating history came with Einstein's general theory of relativity. If this theory is correct, there are no absolute motions with respect to a fixed space and therefore no "preferred frame of reference." One can



Kepler's model of the solar system

assume that the earth is fixed—not even rotating—and the tensor equations of relativity will account for everything. The earth is fat around its waist not because of inertial forces but because the rotating cosmos produces a gravitational field that causes the bulge. Since all motion is relative, the choice of a sun-centered model over an earth-centered one for the solar system is one of convenience. We say the earth rotates because it is enormously simpler to make the cosmos a fixed inertial frame of reference than to say it is rotating and shifting around in peculiar ways. It is not that the heliocentric theory is "truer." Indeed, the sun itself is moving and is in no sense the center of the cosmos, if indeed the cosmos has a center. The only "true" motion is the relative motion of the earth and the cosmos.

This arbitrariness about the frame of reference is involved in a funny argument that still pops up in parlor conversations. The moon circles the earth, as the earth circled the central fire in the Pythagorean model, so that it always keeps the same face toward the earth. This has intrigued poets, major and minor, as well as astronomers. Robert Browning's "One Word More" likens the moon's two sides to the two "soul-sides" of every man: "one to face the world with, one to show a woman when he loves her!" Edmund Gosse claimed that his housekeeper penned the following immortal quatrain:

O moon, when I gaze on thy beautiful face,
Careering along through the boundaries of space,
The thought has often come into my mind
If I ever shall see thy glorious behind.

The moon's habit of concealing its backside raises the following trivial question. Does the moon "rotate" as it goes around the earth? An astronomer would say yes, once for each revolution. It is hard to believe, but intelligent men have been so incensed by this assertion that they have published (usually at their own expense) lengthy pamphlets arguing that the moon does not rotate at all. (Several such treatises are discussed in Augustus De Morgan's *Budget of Paradoxes*.) The problem is basically the same as a penny paradox given in this department in February, 1966: If you roll one penny around a fixed penny, keeping the rims together to prevent sliding, the rolling penny rotates twice during one round trip.

PLANET	BODE'S SERIES	ACTUAL MEAN DISTANCE
MERCURY	.4	.39
VENUS	.7	.72
EARTH	1	1
MARS	1.6	1.52
(CERES)	2.8	2.77
JUPITER	5.2	5.2
SATURN	10	9.55
URANUS	19.6	19.2
NEPTUNE	38.8	30.1
PLUTO	77.2	39.5

Bode's law of the spacing of the planetary orbits

Or does it? Joseph Wisnovsky, an editor of *Scientific American*, has called my attention to a furious controversy over this question that raged in the letters department of this magazine for almost three years. In Volume 16 (1867), page 347, a reader asked: "How many revolutions on its own axis will a wheel make in rolling once around a fixed wheel of the same size?" "One," the editors replied. A torrent of correspondence followed from readers who disagreed. In Volume 18 (1868), pages 105–106, *Scientific American* printed a selection from "half a bushel" of letters supporting the double-rotation view. For the next three months the magazine published correspondence from both "oneists" and "dualists," including engravings of elaborate mechanical devices they had made and had sent to establish their case.

"If you swing a cat around your head," wrote oneist H. Bluffer (March 21, 1868), attacking the moon's rotation, "would his head, eyes and vertebrae each revolve on its own axis . . . ? Would he die at the ninth turn?"

The volume of mail reached such proportions that in April, 1868, the editors announced they were dropping the topic but would continue it in a new monthly magazine, *The Wheel*, devoted to the "great question." At least one issue of this periodical appeared, because *Scientific American* readers were told in the May 23 issue (page 326) that they could obtain *The Wheel* at newsstands or by mail for 25 cents. Perhaps the controversy was a put-on by the editors. Obviously it is no more than a debate over how one chooses to define the phrase "rotates on its own axis." To an observer on the fixed penny the moving coin rotates once. To an observer looking down from above it rotates twice. The moon does not rotate relative to the earth; it does rotate relative to the stars. Can the reader decide, without making a model, how many times the outside coin will rotate per one revolution (relative to you as the observer) if its diameter is half that of the fixed coin?

The same ridiculous question about lunar rotation could have been asked from 1890 to 1965 about Mercury. The Italian astronomer Giovanni Schiaparelli (the man who started all the nonsense about Martian irrigation canals by drawing maps of straight lines he imagined he saw crisscrossing the planet) announced in the late 1880's that his observations proved that Mercury always kept the same face toward the sun. In other words, it rotated once for every revolution of 88 days. For the next 75 years hundreds of observations by other eminent astronomers confirmed this. Because Mercury lacks an atmosphere to transfer heat it was assumed that its illuminated side was perpetually sizzling at 700 to 800 degrees Fahrenheit and that its dark side was perpetually close to absolute zero. "Mercury has the distinction," wrote Fred Hoyle as late as 1962, "of possessing not only the hottest place but also the coldest place in the whole planetary system."

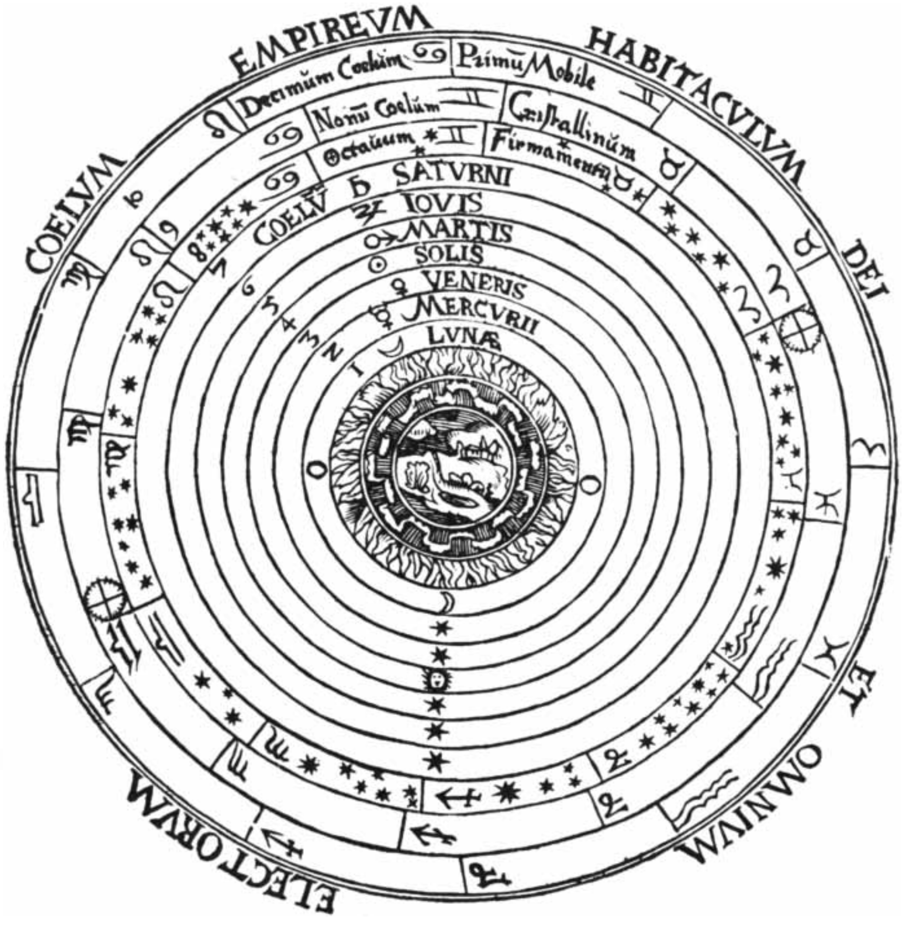
Between Mercury's hot and cold sides there would of course be a girdle of everlasting gloaming, presumably with a climate mild enough to support life. The notion long intrigued writers of science fiction. "Twilight. Always twilight," says a visitor to Mercury in Arthur Jean Cox's 1951 story "The Twilight Planet." "The days pass, or so the clocks, the calendars tell you. But time, subjective time, is frozen delicately in midflight. The valley is an ocean of shadows; shade-tides lap upon the shores of mountains." In Robert Silverberg's "Sunrise on Mercury" (1957) astronauts land on Mercury's "Twilight Belt" between "the cold, icebound kingdom of Dante's deepest pit" and "the brimstone empire." The belt is a region where fire and frost meet, "each hemisphere its own kind of hell." When the story appeared in the 1969 Dell paperback anthology *First Step Outward,* editor Robert Hoskins had to append a note saying that it had now passed from science fiction into the realm of fantasy.

The first hint that something was wrong came in 1964 when radio-telescope observations by Australian astronomers indicated that the supposed frozen side of Mercury has a temperature of about 60 degrees F.! Could the planet, they wondered, have an atmosphere after all? In 1965 Gordon H. Pettengill and Rolf B. Dyce, using radar reflections from opposite edges of the planet, discovered the real reason. Schiaparelli had been as wrong about Mercury's spin as he had been about Mars's canals. Mercury rotates once every 59 days, exactly two-thirds of its orbital period. Apparently the little planet has a lopsided mass, like our moon, or a tidal bulge that allowed its capture by the sun in a stable 3/2 "resonance lock." For every two orbits it spins three times. One reason astronomers had been wrong for 75 years was that they usually looked at Mercury at a favorable time that occurs once a year. Because they always saw the same dusky markings, they assumed that, since Mercury had made four orbits, it had rotated four times when actually it had rotated six. Although such rationalizations can be made, wrote Irwin I. Shapiro [see "Radio Observations of the Planets," by Irwin I. Shapiro; SCIENTIFIC AMERICAN, July, 1968], it is still "unsettling to contemplate this persistence of self-deception." How Charles Fort, that eccentric iconoclast of science, would have gloated over such a gigantic goof!

Still more astonishing was the discovery made in 1962 about the spin of Venus. Its slow spin was believed to be so close to its orbital period of about 225 earth days that many astronomers (Schiaparelli for one) were convinced that, like Mercury and our moon, Venus had identical rotational and orbital periods. In 1962 astronomers using the Goldstone radar of California's Jet Propulsion Laboratory established two incredible facts. Venus spins slowly *backward* with respect to all other planets. (Uranus' direction of spin is ambiguous. Its axis is so close to being parallel to the plane of the ecliptic that either pole can be called north.) Venus is the only planet on which the sun rises (very slowly) in the west. Moreover, its spin period of 243.16 days—making its day longer than its year—is just such that, whenever Venus is closest to the earth, it always presents the same face toward *us!* In *Don Juan* Lord Byron speaks of "a rosy sky, with one star [Venus] sparkling through it like an eye." Why Venus should keep her eye on the earth in such a curious fashion is still a mystery. Presumably, like Mercury, it either is asymmetric in mass or has a large enough tidal bulge to have allowed capture by the earth in this unexpected resonance lock.

The story of Venus' nonmoon is another Keystone Cops episode in astronomical history. In 1645 an Italian astronomer, Francesco Fontana, asserted he had seen a moon of Venus. His observation was substantiated in 1672 by Jean Dominique Cassini, who had discovered two satellites of Saturn and was later to find two more. Venus' moon was also seen by many leading astronomers of the 18th century. The famous German mathematician, physicist and astronomer Johann Heinrich Lambert published in 1773 a treatise on Venus' moon in which he even calculated its orbit. Frederick the Great honored Jean Le Rond d'Alembert by naming the moon after him, although the great French mathematician politely refused the honor. Of course there never was such a moon or it would have been visible as a black speck when Venus crossed the sun's disk. The astronomers had either seen nearby stars or ghost images produced by lens refraction.

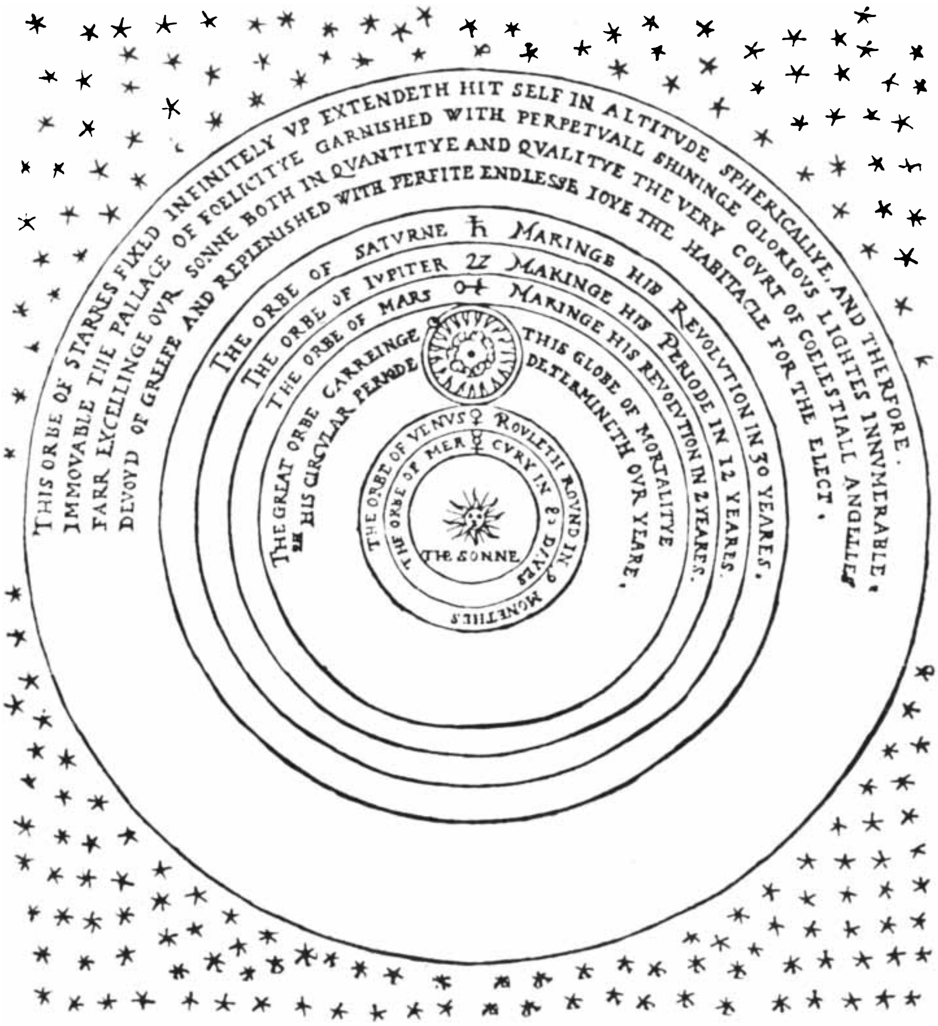
How did the solar system evolve? No one is sure. The most popular view at



Pre-Copernican universe in Peter Apian's **Cosmographia** *(1539)* present is the one first advanced by Immanuel Kant. Somehow the planets condensed from gases and dust particles in a whirling disklike cloud that once surrounded the sun. The counterclockwise spin of this cloud, when viewed from above north poles, would explain why all the planets and most of their moons revolve in the same direction. Why, though, are the ancient tracks spaced the way they are? Is it mere happenstance or are their distance ratios governed by a mathematical law?

It was Johannes Kepler who dreamed up the most fantastic explanation. He first tried inscribing and circumscribing regular polygons, then spheres and cubes, but he failed to hit on a pattern that gave the right ratios. Suddenly an inspiration struck him. There are six planets, therefore five spaces between them. Are there not five and only five regular convex solids? By nesting the five Platonic solids inside one another in a certain order, with shells between them to take care of eccentricities in the planets' elliptical paths, he arrived at a structure that corresponded roughly with what were then believed to be the maximum and minimum distances of each planet from the sun [*see illustration on page 108*]. It was a crazy theory, even in Kepler's time, but Kepler was a remarkable blend of stupendous scientific intuition and occult beliefs (including astrology) that led him to expect such geometric harmonies. "The intense pleasure I have received from this discovery," he wrote, "can never be told in words." Ironically, his correct convictions that the planets move in ellipses, not circles, and that tides are caused by the moon seemed so equally preposterous that even Galileo dismissed both views as more Keplerian fantasy.

In 1772 Johann Daniel Titius of Wittenberg announced a simple number sequence that seemed to fit the planetary orbits. It soon became known as "Bode's law" because four years later another German astronomer, Johann Elert Bode, published a celebrated paper on the series. To obtain the numbers start with 0, 3, 6, 12, 24, 48, 96, 192, ... Every number is half the next one except for 0, which really should be 1½. To each number add 4. The resulting sequence—4, 7, 10, 16, 28, 52, 100, 196, . . . —gives the ratios of the mean distances of the planets from the sun. If we take the earth's distance as our "astronomical unit," the third number, 10, becomes 1. Dividing the other numbers by 10 then gives the mean distances of the planets in astronomical units. The chart on page 109 shows these distances alongside the actual ones. Note that the mean distances of the first six planets, still the only planets known when Bode published his paper, are in remarkably close agreement with values given by the Bode series. Not only that but Bode's law succeeded in making two excellent predictions.



Copernican universe was depicted by Thomas Digges in 1576

The first prediction was that a planet should be at a distance of 19.6 astronomical units. When Uranus was discovered in 1781, it was found to have a distance of 19.2, a fact that convinced most astronomers of the soundness of Bode's law. The second prediction was that there ought to be a planet in the enormous gap between the orbits of Mars and Jupiter, at about 2.8 units from the sun. In 1801, on the first day of the new century, Ceres, the largest of the asteroids, was discovered at 2.77 units from the sun! Thousands of smaller planetoids were later observed in this region. Defenders of Bode's law argued plausibly that the planetoids were remnants of an exploded planet that had once orbited the sun at a spot close to where Bode's law said it should be.

Alas, the law failed for Neptune and Pluto, persuading many astronomers that the law's earlier successes had been accidental. Other astronomers have recently suggested that Pluto may be an escaped moon of Neptune and that before the two bodies separated Neptune could have been near the spot predicted by Bode's law. It has also been argued that Bode's law may apply to all planets except those at the inner and outer fringes of the solar system, where irregularities would be more likely. Since Mercury and Pluto have orbits much more eccentric and more inclined to the plane of the ecliptic than those of the other planets, it is not unreasonable to suppose fringe conditions would make them exceptions to a general rule.

Is Bode's law a numerological curiosity, as irrelevant as Kepler's nested polyhedrons, or does it say something of value that eventually will be explained by a theory of the solar system's origin? The question is still undecided. Defenders of the law usually cite the number sequence, announced in 1885 by the

Swiss mathematician Johann Jakob Balmer, that fitted the frequencies of the spectrum lines of hydrogen. This series was pure numerology until decades later, when Niels Bohr found the explanation for "Balmer's series" in quantum mechanics.

"The question is," writes Irving John Good, a mathematician now at Virginia Polytechnic Institute, in a recent paper on Bode's law that is listed in the bibliography at the back of this issue [*page 130*], "whether a piece of scientific numerology unsupported by a model is sufficiently striking to make us say that people ought to look for a scientific model in order to explain it." From my layman's seat I hesitate even to guess how Bode's law will fare in future years.

I conclude with a second tricky problem, both to be answered next month. As the earth goes around the sun its moon traces a wavy path with respect to the sun. How many sections of that wavy path, during 12 lunar orbits around the earth, are concave in the sense that their convex sides are toward the sun?

Readers were asked last month to investigate the cyclic properties of the period of the repeating decimal for 1/13. This period, 076,923, is not a true cyclic in the sense defined last month. It is cyclic, however, in the following double sense. If multiplied by any number from 1 through 12, half of the products are the six cyclic permutations of 076,923 and the other half are the six cyclic permutations of 153,846. Note that each of these two numbers (like the smallest order-1 cyclic, 142,857) can be split in half and added to get 999. Moreover, each can be trisected and added to get 99 ($07 + 69 + 23 = 99$; $15 + 38 + 46 = 99$; $14 + 28 + 57 = 99$).

When a number with n digits, multiplied by 1 through $2n$, yields products that are all the cyclic permutations of two n-digit numbers, we call it an order-2 cyclic. Disregarding the trivial case generated by 1/3, the lowest prime generating an order-2 cyclic is 13. Other primes under 100 that generate order-2 cyclics are 31, 43, 67, 71, 83 and 89.

Cyclic numbers can be of any order. The smallest prime generating an order-3 cyclic is 103. The repeating period of 1/103, multiplied by any integer from 1 through 102, gives products that fall into three sets, each containing 34 cyclic permutations of a 34-digit number. The smallest prime generating an order-4 cyclic is 53. In general, as H. J. A. Dartnall, a London correspondent, has pointed out, if the reciprocal of a prime p has a repeating decimal period with a length (number of digits) equal to $(p - 1)/n$, the period is an n-order cyclic. For example, 1/37 generates the three-digit period 027. Since $36/3 = 12$, the period is a 12-order cyclic. Eric Evans of Petts Wood, Kent, England, has supplied me with the lowest primes generating cyclics of orders 5 through 10. They are respectively 11, 79, 211, 41, 73 and 281. Note that the 10 products of the order-5 cyclic, 09 (the period of 1/11), are the first 10 multiples of 9.

A three-weighing solution of Ben Braude's problem of the six weights, three equally heavy and three equally light, follows. Call the weights A, B, C, D, E, F.

Weigh A against B. Assume one side, say B, goes down. Substitute C for B. If the scales balance, you know A and C are light, B is heavy. Therefore D, E, F must include two heavy, one light. For the third weighing pick any two of D, E, F and weigh them against each other. If they balance, you know both are heavy and the remaining one is light. Otherwise you know which is heavy, which light, and can infer the nature of the third.

Suppose the scales balance on the first weighing of A against B. Again substitute C for B. A balance of the scales tells you A, B, C are alike and D, E, F are alike; therefore a third weighing (say A against D) will identify all six. If one side goes down on the second weighing, you can label the first three weights (two light and one heavy, or two heavy and one light). As before, you know the combination of heavy and light for D, E, F, so that by weighing any two against each other you can identify all three.

Many experts on Chinese writing pointed out that in January's column on the abacus I reversed the positions of "hands" and "bamboo" in describing the Chinese character for "calculate." The hands are below, bamboo is above. Readers interested in the famous four-color map theorem of topology may wish to check an article by Joel Stemple and the late Oystein Ore, in the *Journal of Combinatorial Theory* (Academic Press), January, 1970, in which it is proved that a map requiring five colors must have at least 40 regions. This raises the figure of 36, previously established in 1940. There have been recent false rumors of higher bounds, and even rumors that the four-color theorem has been solved. As things now stand, if there is a counterexample to the still unproved four-color theorem, it must be a map with at least 40 regions.

Honeywell Radiation Center
Lexington, Mass.

Pointing and Tracking by Eye Control

A new device which measures the direction of vision should make eye control of systems feasible in environments ranging from aviation to production.

For centuries man's ability to point tools, weapons and machinery has been limited by his manual dexterity. The hand is both slower and less accurate than the eye; in the stressful conditions of a space capsule, an air traffic control center, or a reconnaissance plane, this disparity increases significantly. In an attempt to free the operator's hands and to harness the remarkable tracking ability of the human visual apparatus, Honeywell is developing a new method of measuring eye direction.

Eye control is possible because of the concentration of the sensory capacity of the retina on an extremely small central portion, the fovea. For maximum resolution, the eye must be physically pointed at the target with an accuracy of .25 inch at 5 feet in order to center the object on the fovea. By measuring the direction of the operator's eye as he looks at a target, precise target bearing coordinates can be obtained without manual action.

One laboratory method of measuring eye direction uses electrodes implanted in the skin around the eye to measure the basic potential between the front and back of the eye. However, this eye direction measurement is made relative to the head and does not provide an absolute indication of the bearing of the target detail. A more accurate method was provided by optical tracking. In these systems, electro-optical equipment tracks the displacement of some visible portion of the eye (such as the iris-white boundary) and from this measurement, the direction of vision can be determined. Although optical tracking itself is not difficult, most systems in use require an absolutely immobile subject, since they extrapolate vision direction from measurements of the position of eye detail within the skull. The tracking device is usually clamped to the skull by a dental "bite plate" to limit head movements to a thousandth of an inch. Obviously these are prohibitively restrictive for pilots or astronauts; they are also unsatisfactory in many psychological experiments because of the unnatural restraint of head movement.

Believing that an eye control system which would not confine the subject could make a whole new field of automation possible, Honeywell scientists began work over five years ago on a device to track and record eye movements. The instrument developed, the Oculometer, shines a beam of infrared radiation on the eye, and from the reflections off the retina and cornea, an electro-optic sensor records the actual movements of the eye.

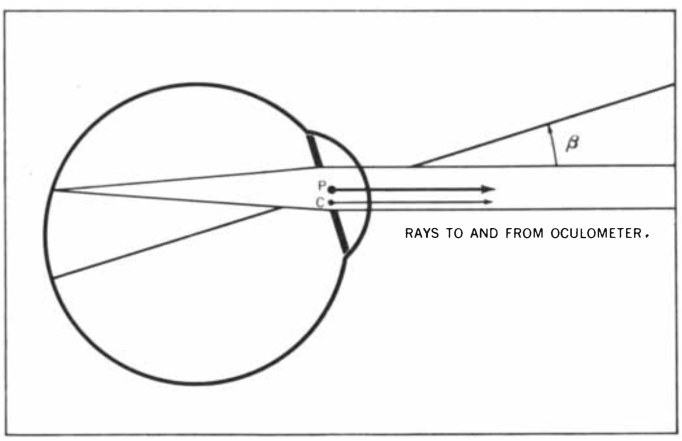
The Oculometer works in the following manner: If an infrared beam is directed on the eye, a reflection of that light off the cornea is produced approximately in the plane of the pupil. The direction of the illuminating radiation, which is along the optical axis of the Oculometer, is the reference direction. The direction of the eye relative to this reference is proportional to the displacement of the corneal reflection from the center of the pupil. Because the Oculometer determines the location of the reflection *within* the pupil itself, head movements do not affect the measurement.

The Oculometer images the pupil and corneal reflection on an electro-optical sensor. Using a raster scan, the Oculometer quickly locates the pupil and tracks its perimeter. It then scans the corneal reflection. The amount of additional electrical input needed to move from the pupillary center to the corneal scan gives the coordinates of the corneal reflection. Mathematically the displacement of the corneal reflection from the center is K sin β, where β is the angle between the geometric axis of the eye and the direction of the illuminating radiation. K is a dimensional constant of the eye. After completing the corneal scan, the image dissector repeats the pupillary scan, continually changing its diameter with changes in the pupil's diameter. The period of the repetitive scan is 2ms, fast enough to follow the fastest eye motion.

If the Oculometer output is connected to servo driven equipment, it could be used for many control applications normally done by hand. For example, the student's response in a teaching machine could be determined instantly by analyzing his eye movements.

The Oculometer could be used as part of an automated vision tester system measuring not only central but peripheral vision, speed and acceleration of the eye, and astigmatism and accommodation. Data on the changing diameters of the pupillary scan yield valuable information for both physiologists and psychologists, since pupil size may be correlated to the subject's interest in what he is looking at.

If you are working in the area of optical tracking of the eye, and want to know more about Honeywell's investigations, please contact John Merchant, Honeywell Radiation Center, 2 Forbes Rd., Lexington, Mass. 02173. If you are interested in applications for the Honeywell Oculometer, contact Peter Albertini, at this same address. If you have an advanced degree and are interested in a career in research at Honeywell, contact Dr. John Dempsey, Vice President Science and Engineering, Honeywell Inc., 2701 Fourth Ave. So., Minneapolis, Minn. 55408.



Apparent Displacement of Corneal Reflection C From Pupil Center P is Proportional to Eye Direction β

Honeywell
AUTOMATION

THE AMATEUR SCIENTIST

An ambitious observatory is built by father and son

Conducted by C. L. Stong

A few weeks ago one of the largest and most carefully made amateur astronomical observatories went into operation several miles north of Amherst, Va. The event happened to coincide with the 50th anniversary of telescope making as a popular avocation. The observatory and its telescope are the handiwork of John Wikswo, a chemist, and his son John, Jr., a senior at the University of Virginia who is majoring in physics.

The installation is remarkable in many respects. For example, the instrument embodies more scaled-down features of the 200-inch Hale telescope on Palomar Mountain than I have encountered heretofore. The two-story observatory building, made of masonry, has a motor-driven dome of reinforced fiber glass. The building includes a photographic darkroom, a machine shop and a study. All the functional elements are controlled electrically, including a system of remote dials that continuously monitor the telescope's position as it tracks an object across the sky.

The installation is the more remarkable because the older of the builders had no burning enthusiasm for either astronomy or telescope making when he began work on his first telescope. He was tricked into taking up telescope making by a friend, the late James H. Wyld, who was a pioneer in the design and construction of rocket engines. Wyld had become a telescope buff after reading in this department a report by the late Albert G. Ingalls on a group of amateurs in Springfield, Vt., who in 1920 had made a number of small reflecting telescopes.

Wikswo tended to look down his nose at telescope making. The deceptively simple appearance of a reflecting telescope rarely challenges the inexperienced eye. After much urging by Wyld, however, Wikswo reluctantly agreed to try his hand at a six-inch instrument. He spent almost a year on the project. Most amateurs would have finished it in 60 days. The difference was that Wikswo's telescope rivaled the excellence of a finely made watch. Wyld took one look through it and contrived a scheme for binding Wikswo forever to his avocation. Although Wyld was young and in perfect health at the time, he provided in his will for the purchase of two specially cast 16-inch disks of Pyrex as a bequest to Wikswo. In 1952 the disks were delivered. Wyld knew his man. The astonished Wikswo has been working on the telescope ever since. Recently he invited me to inspect the results.

To reach the observatory you turn left off Route 29 about 10 miles north of Amherst and follow the narrow road that winds northwest through the Blue Ridge mountains. Somewhere between the villages of Piney River and the Forks of Buffalo the road enters an oval valley. Atop a large knoll that rises in the valley you spot the dome of the observatory under a sky that is usually crystal clear. A breath of the fresh air almost justified the trip. "We were against pollution in these parts," Wikswo explained, "long before the idea caught on elsewhere. My neighbors on the crests of these mountains learned from skilled ancestors the art of firing a whiskey still without creating a telltale plume of smoke. That's one reason I'm here." Wikswo explained another of his reasons as we made our way along a footpath to the observatory. A vein of titanium ore runs for seven miles through a neighboring mountain. He heads a group of chemists that develops methods for processing the mineral.

The door of the observatory opens onto a landing from which a spiral staircase leads to the observing floor above and the darkroom below [*see illustration on opposite page*]. The cylindrical wall is made up of curved cement blocks. The overlapping dome is formed by two dozen curved trusses of fir overlain by a sandwich of Masonite and fiber-glass cloth cemented with polyester resin. The weight of the dome is carried by a base ring of laminated wood; the ring has flanged wheels that roll on a circular track of steel. The track was bent from bar stock two inches wide and half an inch thick. It is anchored to the rim of the concrete wall.

The telescope is supported at the center of the dome by a concrete pier that extends down through both floors to bedrock and is insulated against mechanical vibrations. You can jump on either floor without vibrating the instrument. The dome is rotated by frictional contact between the laminated base ring and a pneumatic tire on a motor-driven wheel. Access to the sky is through a pair of weatherproof shutters in the dome; they open to form a slit one yard wide from the horizon to the zenith. The shutters, which were built in an old farmhouse that came with the property, are also made of Masonite and fiber glass. They are operated with a hand wheel through a system of cables. This is one of the few features of the observatory that Wikswo has not mechanized.

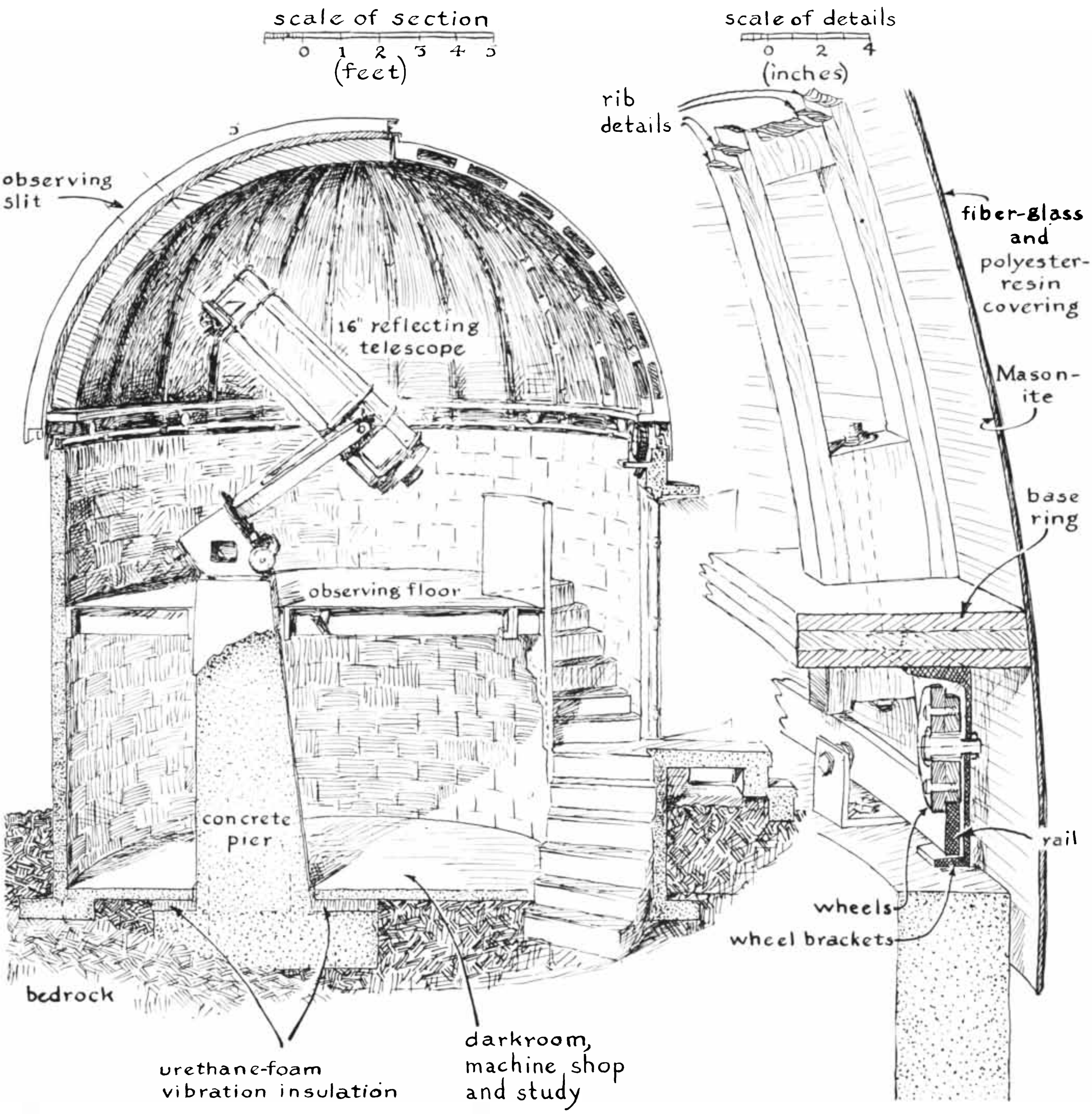
The fork that supports the tube of the telescope and rotates the instrument in right ascension, or celestial longitude, is of the welded box-girder type stiffened with internal partitions [*see illustration on page 117*]. The fork includes bolting plates an inch thick for attaching the shaft and the housings of the declination bearings. Although the instrument weighs more than 600 pounds, it moves easily in any direction.

The tube is rotated in right ascension by a synchronous motor that operates at 1,800 revolutions per minute in combination with a gear system that includes a differential mechanism. A direct-current motor coupled to the differential is used for turning the tube to any part of the sky. The gearing in both declination (north-south direction) and right ascension includes selsyn (self-synchronous) transmitters that couple electrically to companion receivers operating dials for monitoring the position of the instrument. When the telescope is tracking a star automatically, a selsyn motor geared to the polar shaft communicates the rotation synchronously to a companion motor coupled to one input shaft of a differential in the dial mechanism that indicates right ascension. Concurrently rotation in the opposite sense is fed into the second input shaft of this differential by a clock motor that keeps sidereal, or star, time. The two inputs cancel. Accordingly the dial remains fixed and indicates the unchanging position of the telescope in right ascension.

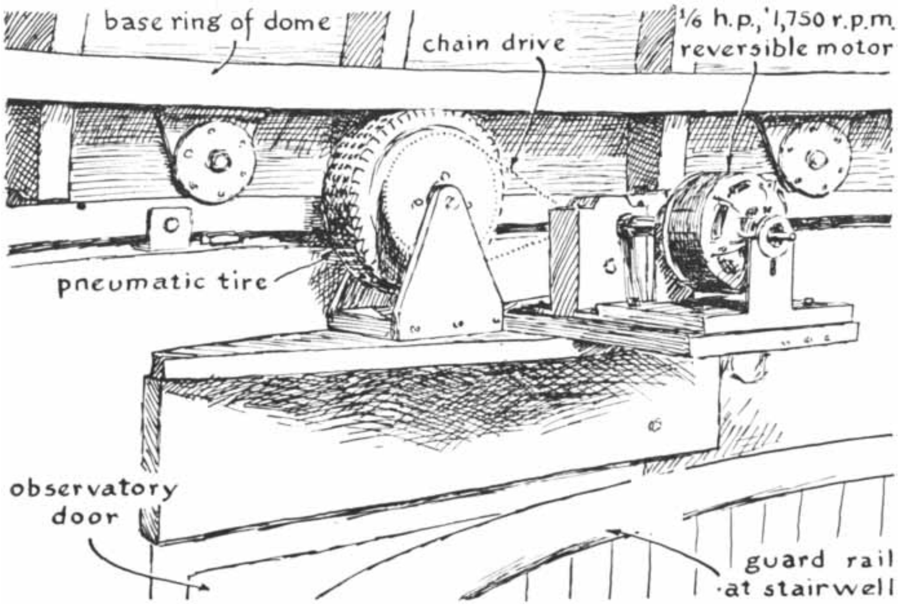
When the telescope is stopped, the clock takes over. The dial now advances at the sidereal rate, thus indicating the telescope's changing position with respect to the sky. To aim the instrument at a particular object, Wikswo consults a star chart for the celestial coordinates. By operating push buttons he directs the instrument onto the target as indicated by the dials.

The tube is of the open-cage type and consists of five rings of cast aluminum weighing 20 pounds each. They are supported axially by a series of tubular spacers held in compression by six steel tie rods [*see top illustration on page 120*]. The tube rotates in declination on hollow shafts of cast iron fixed to ribbed cast-aluminum plates that form part of the tube assembly. The shafts turn in ball bearings that are carried by the fork. A 4½-inch steel shaft, salvaged from an old ore mill, was fitted with ball bearings for rotating the fork in right ascension. The perforated objective mirror floats on a nine-point suspension mechanism inside a cell of cast aluminum that closes the back of the tube. Patterns for all castings were made in Wikswo's basement workshop.

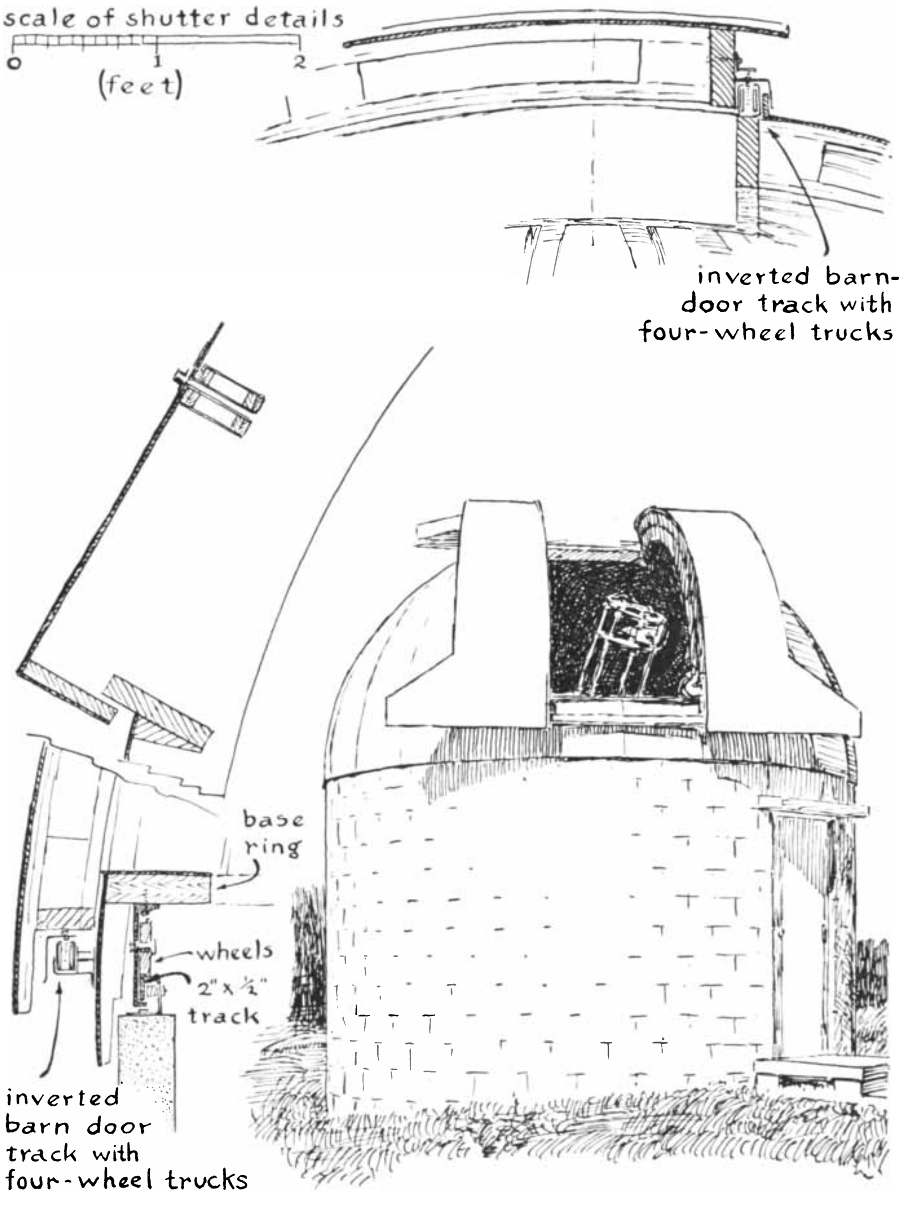
A paraboloidal mirror is the heart of



The Wikswo observatory, with details of the dome at right



The mechanism for rotating the dome



External and detailed views of the shutter

all reflecting telescopes. An instrument can be no better than its mirror, however much care the maker may lavish on the mounting. Wikswo kept careful notes as he made his 16-inch mirror, and from them he prepared the following account:

"The first thing you need when you undertake the construction of a telescope larger than about 10 inches is a machine for grinding and polishing glass. It is simple to make a small concave mirror by sandwiching a slurry of Carborundum grit between matching disks of glass and pushing the upper disk back and forth across the lower one by hand. During a portion of each stroke the upper disk overhangs the lower one; maximum pressure between the two develops in the central portion of the upper disk and around the edge of the lower one. The grit abrades the glass in proportion to the pressure. Hence the upper disk becomes concave; it eventually serves as the mirror. The lower disk, which becomes convex, functions as the grinding tool and is discarded when the job is finished.

"Stroking the upper disk back and forth by hand is possible, although not necessarily easy, with disks up to about 10 inches in diameter. The thickness of the disks must be at least a sixth of their diameter to prevent the mirror from flexing and thus grinding out of true. The thickness of a 16-inch Pyrex casting as it comes from the factory is more than three inches, and the glass weighs about 60 pounds. You do not push a disk of this size by hand.

"The machine I made was based on the design described in *Scientific American* [see "The Amateur Astronomer," by Albert G. Ingalls; SCIENTIFIC AMERICAN, May, 1950]. Essentially it consists of a rigid turntable 18 inches in diameter, mounted on the upper end of a motor-driven shaft, and a rigid bar that oscillates lengthwise above the turntable. The bar is driven by a crank that is coupled to the motor by a train of gears. Both the relative and the absolute speed of the crank and turntable can be altered.

"The disk of glass to be ground and polished is mounted face up on the turntable. Glass tools of appropriate diameter are pushed back and forth across the mirror by the oscillating bar. The grinding can be done with a slurry of grit, as in the hand technique. The machine lends itself to other grinding techniques, however, and even to other uses, as I learned from experience. For example, I adapted it for machining the mirror cell and other aluminum castings used for the tube.

"The Pyrex disk I chose for the mirror was slightly oval and wedge-shaped. Grinding it to within .005 inch of a true cylinder with parallel faces required 100 pounds of No. 54 Carborundum grit, which has particles about the size of the grains in granulated sugar. The rough glass was prepared for grinding by cementing a disk of 3/4-inch plywood 15 inches in diameter to the bottom of the casting with hot pitch. The wood disk was centered on the steel turntable of the machine and screwed in place. The top face of the glass was first ground parallel to the face of the turntable by a drill press provided with a tool made from an eight-inch length of heavy aluminum pipe eight inches in diameter. The tool was chucked in the press and rotated by a drill shank that projected from the center of a metal disk, which closed one end of the pipe. The open end of the pipe, which functioned as the cutting edge, was supported parallel to the top of the turntable. A slurry of bentonite clay and Carborundum was applied to the working edge of the tool. A teaspoon of clay mixed with three pounds of wet Carborundum forms an adhesive mud that speeds the rate of abrasion.

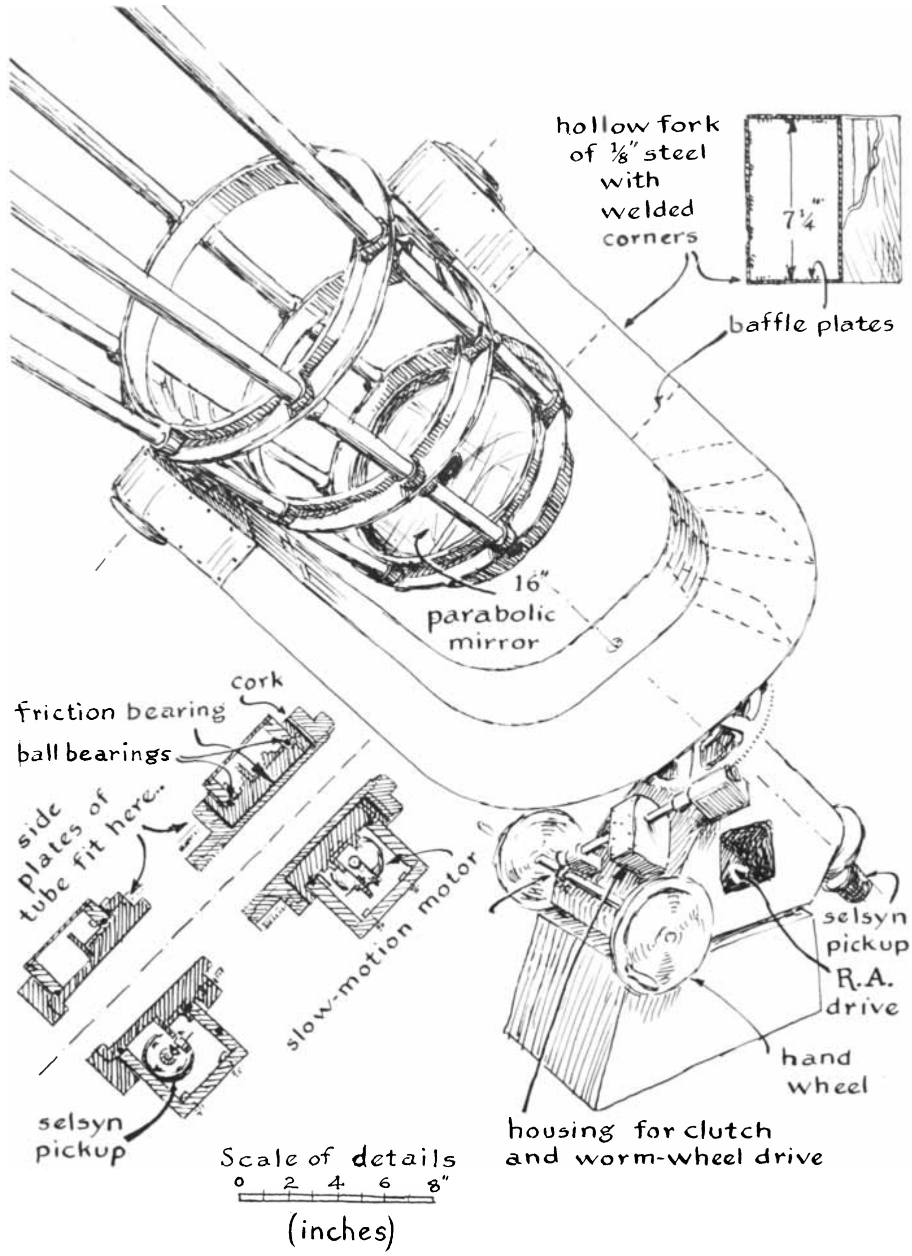
"Most amateurs grind the edge of a glass disk simply by wrapping a strap of sheet metal around the disk, rotating the disk and applying abrasive slurry. The technique wastes glass. The edge of my disk was ground true with abrasive slurry applied to a rotating brass cylinder, three inches in diameter, that was also chucked in the drill press. The turntable was rotated by hand until all high spots had been ground from the edge. The glass was then turned by the motor at 2½ revolutions per minute as successively finer grades of abrasive were applied to the tool in preparation for the polishing operation. The brass cylinder rotated 100 revolutions per minute. The finely ground edge was polished by wrapping around the disk a metal band lined with felt charged with rouge.

"After the edge reached full polish I detached the wood disk from the glass with a hammer blow that fractured the pitch. The turntable was covered with a disk of sheet plastic. The glass was turned over, centered on the plastic rough side up and clamped in place by three equally spaced blocks of maple bolted to the edge of the turntable. The unfinished side was ground parallel to the bottom with the eight-inch tool.

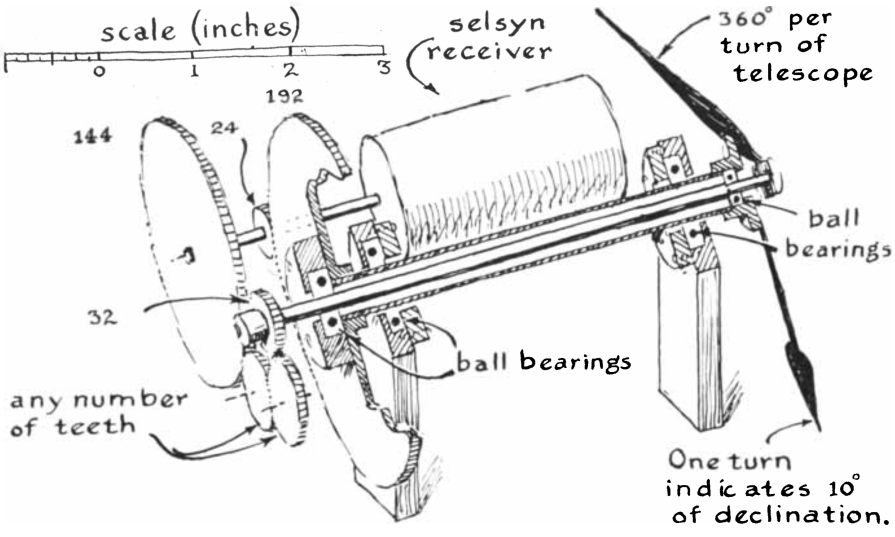
"The interior of the glass could be examined for defects by looking through the polished edge. I selected for the working face of the mirror the side that contained the fewest bubbles. This side was then ground to a concave spherical figure of 160-inch radius, twice the desired 80-inch focal length. To generate the curve, I canted the drill press by shimming up the outer end of the base to an angle that formed the 160-inch radius when the eight-inch tool abraded the glass. At this stage some 300 hours of work had been invested in the mirror.

"The telescope was designed to provide access to the focal plane at any of three locations: the distant end of the tube, called the Newtonian focus; through the hollow declination axis, or coudé focus, and at the rear of the objective mirror, known as the Cassegrainian focus. In the first two of these arrangements the converging rays are reflected outside the tube at right angles by plane mirrors. In the Cassegrainian arrangement they are reflected backward by a small convex mirror through a perforation in the center of the objective mirror.

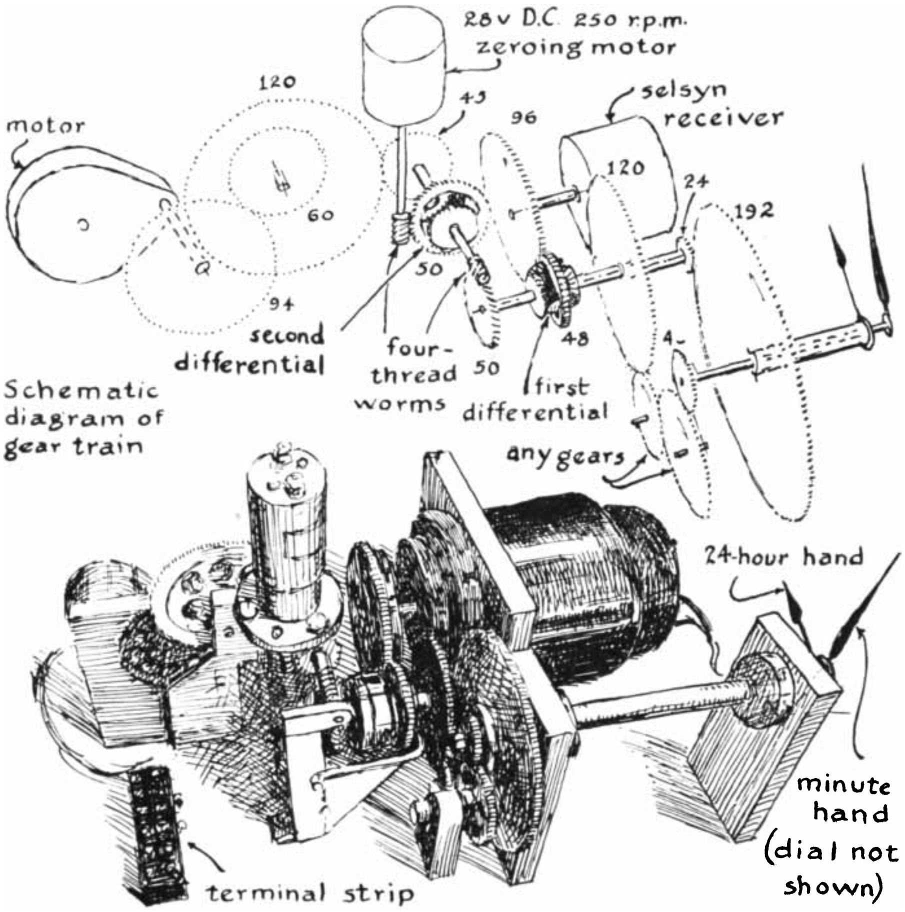
"The required perforation was trepanned in the disk with abrasive applied to a three-inch pipe chucked in the drill press. The cut was made halfway through the glass from both sides to avoid chipping the surfaces. After the inner surface of the perforation had been trued (by lapping the hole with fine abrasive applied with a cylindrical tool of brass) the glass plug was replaced and



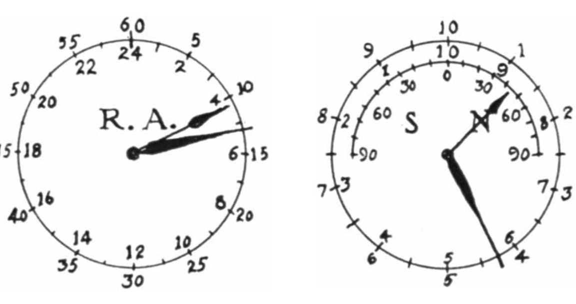
Base of the telescope mounting, with details at left



Readout mechanism for monitoring declination; numbers refer to gear teeth



Readout mechanism for monitoring right ascension



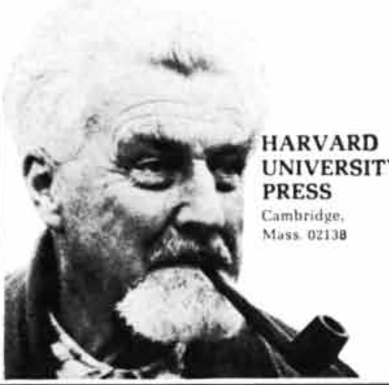
Dials registering right ascension (left) *and declination* (right)

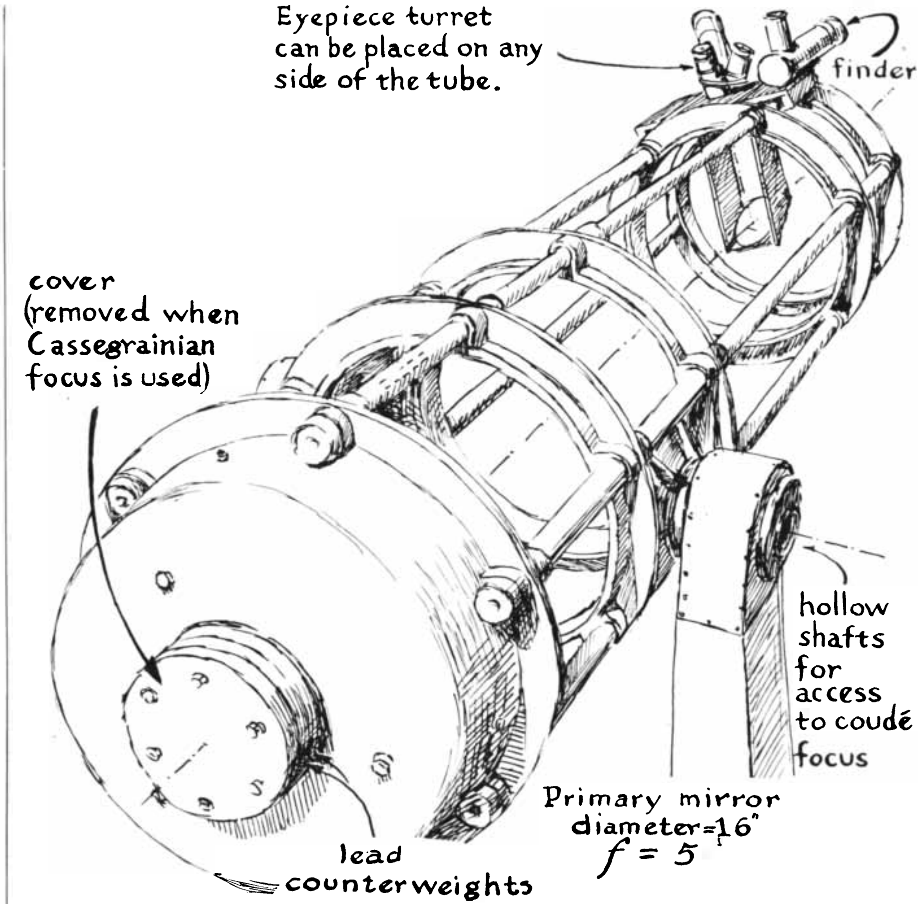
cemented with dental plaster as a mechanical support for the surface during the final grinding, polishing and figuring of the paraboloid. In this step I made use of a clever trick devised by Fred Cowan of the Lick Observatory optical shop. The glass plug was covered with a closely wound layer of No. 22 steel wire before the cement was applied. The plug was removed easily when the mirror was finished by unwinding the wire.

"The coarse abrasive used for generating the curve left deep pits in the surface. These were ground away, in preparation for polishing the glass, with successively finer grades of abrasive applied with a tool in the form of a disk that was pushed back and forth by the oscillating arm of the machine. The tool moved at a rate of 1.5 inches per second. The mirror simultaneously rotated at a speed of 2½ revolutions per minute. The diameter of the tool was 13.3 inches, five-sixths of the diameter of the mirror. The tool was a ribbed disk of steel faced with an orthogonal mosaic of two-inch glass squares 3/8 inch thick cemented to the steel with epoxy. The edges of all the squares were beveled to an angle of 45 degrees by hand with a fine Carborundum stone and water. When shifting from each of the coarser grades of abrasive to a finer grade, I thoroughly washed and dried the mirror and the tool. The tool was also repainted each time, including the spaces between the glass squares. This precaution minimized the possibility that a grain of coarse grit might be carried into the succeeding stage of fine grinding and scar the glass. No scratches appeared. The mirror was ready for its final polish after 51 hours of fine grinding.

"The polishing tool was made by placing gummed paper dams around each of the glass facets and filling the cavities with tempered black pitch. Thirty-five hours of polishing with rouge eliminated all traces of the fine grinding and brought the surface to a polished spherical figure. The curve was then deepened into a paraboloid by altering the length of the strokes and displacing the tool laterally as necessary. Various optical tests were made during this stage for monitoring the changing shape of the curve. Work was stopped when tests indicated that the surface was within a millionth of an inch (approximately a twentieth of a wavelength of light) of the desired paraboloid. The complete job of converting the rough casting into the finished mirror required 440 hours of work.

"The telescope cost just a little less





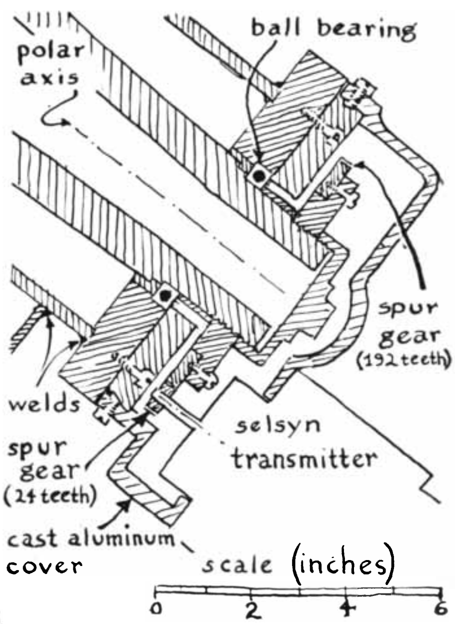
Tube of the telescope

than $500. The largest single item was $150 for foundry castings. The grinding machine, abrasives and evaporated aluminum coating of the mirror amounted to another $150, not counting $60 for express charges. Another $200 was spent on the shop and darkroom. The observatory cost $1,500.

"Occasionally I am asked why I made the observatory of cement blocks. Masonry structures leave something to be desired because they function as heat sinks that create convection currents in the cool night air and thus degrade seeing. I took this disadvantage into account when I decided on masonry for protection against speeding bullets. High-powered rifles are legal for hunting deer in this part of the country. Not all our city visitors have the skill of my neighbors at handling a gun."

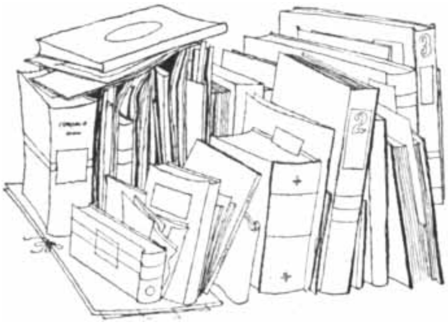
Wikswo's telescope performs beautifully, as you can see for yourself if you wish. Wikswo holds open house occasionally at night. Visitors who write for reservations are welcome. The address: John Wikswo, Route 4, Box 224-A, Amherst, Va. 24521.

The circuit diagram of the power supply for the tunable laser using organic dye, described in this department in February, shows a connection between the primary and secondary windings of the oscilloscope transformer. The connection invites the destruction of one of the diodes and should be omitted, as several readers have pointed out.



Details of main shaft

CHARLES HARBUTT / MAGNUM



BOOKS

On Erik Erikson's study of Gandhi

by S. Gopal

GANDHI'S TRUTH: ON THE ORIGINS OF MILITANT NONVIOLENCE, by Erik H. Erikson. W. W. Norton & Company, Inc. ($10).

Of all the great figures of modern history, Gandhi is the obvious choice for psychoanalytic dissection and explanation. He was successful; he demonstrated a new technique of revolution and change; he concealed nothing from the world; he had no private life in any sense after he had attained middle age, and he provided such detailed, firsthand testimony of his political reflexes, personal passions and private emotions that he could be described as having a strong streak of exhibitionism. He bared his soul as much as he did his body. His method of nonviolence was, Erik Erikson tells us, an extension of the ethical principle of psychoanalysis to the arena of social and political action. In the method of psychoanalysis, says Erikson, Freud "replaced moral suppression with the belief that truth has enough force to make the patient reveal what he had suppressed." So does the method of *Satyagraha*—the Sanskritic combination of "truth" and "force" that Gandhi chose as a name for his way of life and action—confront the enemy nonviolently and, by forcing him to recognize the truth, reconcile the two sides. There is something natural, therefore, in psychoanalyzing Gandhi, in applying Freudian techniques to the individual who was the master of social psychoanalysis, in putting his spiritual truth to the test of psychological truth, and in complementing the Gandhian results with psychoanalytic insights.

Yet what makes Gandhi a worthwhile subject for such attention is, above all, the fact that he was a success. He more than any other individual raised the pressures that led to the British withdrawal from India and thereby changed the face of Asia and the world. It was Gandhi who demonstrated the moratoriums and fasts, the civil disobedience and passive resistance that are now being utilized, and with effect, on every continent. Doubtless in the centuries before him there were many unknown Gandhis in India if not elsewhere. They are not heard of, however, because they did not quite bring it off. If his life is of interest, it is primarily because his life was of consequence.

Gandhi himself had no illusions about his chief objective. He was interested in perfecting his character and personality not so much for self-sufficient spiritual ends as to make himself an effective instrument of political and social change in India—"Indian leadership, Indian style." He was above all a man of action, of enormous restlessness and energy, with a will to power and a touch of ruthlessness; he functioned with a shrewd grasp of whatever context he found himself in. At the age of 25 in South Africa he acquired a sense of his destiny; neither at that time nor thereafter did he display any arrogance or false humility in his acceptance of it. Regarding discrimination against Indians in South Africa he wrote in 1894: "I am the only available person who can handle the question." In the same matter-of-fact way he could declare 25 years later: "I am the one man who can today preserve the peace in India." On his return to India in 1915 he was convinced that all the former leaders had failed the Indian people. He began at once to travel far and wide all over India, seeking information about grievances in various regions and planning to draw new tides of men, until then unaware of politics, into his hands.

Erikson recognizes that Gandhi's attitudes and beliefs were more subtle and complicated than many of his followers realize; he offers no simplistic explanations. It is well known that there was a strong feminine strand in Gandhi's nature. Many other interpreters have made the all too easy jump from this knowledge to the contention that Gandhi mobilized weakness and inertia, that he directed the masses of India to sit down and suffer in protest because he was not equipped to get them to do anything else. Erikson shows that on the contrary there was a strength in Gandhi's womanliness, that his identification with his mother was a large part of his rock-like purpose. Motherhood can be fiercely protective; in Gandhi's nature these impulses expanded from a diffuse tenderness to a guardianship of his people and of all mankind sharing their plight.

Of no other political leader of our time can one imagine a book being written with the title *Bapu, My Mother*. Certainly of no other leader could such a book have been written without detracting from his heroic stature. Erikson strains too hard in suggesting that Indians held this kind of esteem for Gandhi because the mother-goddess cult has given India basic bisexuality. Rather, no one could mistake Gandhi's gentleness for frailty. Indeed, the title *Bapu, My Mother* is in itself significant. *Bapu* means father; it was the term of affection by which Gandhi was addressed by many of his close followers, including Jawaharlal Nehru, later to be prime minister. The total image, as Erikson says of Gandhi's father, is one in which it is difficult to allocate masculine and feminine identifications.

In fact, Gandhi's image was the image of a new kind of leadership. There were abler men in Indian politics, and many who had suffered more in India's cause. Lokamanya Tilak, one of the first protagonists of "home rule," had spent six years in solitary confinement in Burma; the health of Subhas Bose, a militant leader of the Congress party just before World War II, was broken in prison. Yet none could contest the hold Gandhi had on the hearts of the common people. Him alone they regarded as one of themselves, a leader whose sole objective was to serve them. It is not, as Gandhi (and Lenin) understood, necessary to indoctrinate the masses in order to inspire and rouse them; to evoke their latent consciousness it is only necessary to be absorbed by them, to live and work among them.

Gandhi had no clear social and eco-

nomic ideas. His frequent resort to the line from the hymn, "one step enough for me," while evidence of his faith, was also an escape from systematic thinking. All of this baffled his more intellectual followers. As an exasperated Nehru once wrote to him, "Who can argue with a magician?" Gandhi knew, however, that the devotion of the masses had to be spearheaded by an elite. He built up a band of chosen apostles who in most cases had nothing in common but their acceptance of Gandhi. He was Christ-like in his seizure of men, in the way he tore them from their families and made them follow him. As Erikson shows, Gandhi's authority rested on one-to-one relationships with his community of followers, to each of whom he revealed the relevant aspect of his personality so that they were indissolubly chained to him. Erikson mentions a few of these followers, but the roll is long and the association of names incongruous. No simple explanation can enfold the man who could captivate such diverse figures as Madeleine Slade, the British admiral's daughter; Nehru, the Cambridge graduate and sophisticated intellectual; Gaffar Khan, the roughhewn Pathan, and Vinoba Bhave, in the line of Indian ascetics with a social purpose.

Nor was the impact of Gandhi's leadership restricted to his committed followers. He knew how to make use of men such as the world-famous poet Rabindranath Tagore and the philosopher (later president of India) Sarvepalli Radhakrishnan; although they were not wholly his disciples and were often severe critics of his actions, they were still stirred by his life and his example. The penumbra of Gandhi spread far beyond his *ashram* and the Congress party. His influence stretched even to those whom Erikson has happily termed his "counter-players." His spontaneity and goodwill, his genuine concern to put himself in the other man's position and see the problem from that viewpoint, his total honesty with himself and with others, his eagerness to release tension and his refusal to violate the other's personality—all struck responses in opponents who were sufficiently humane and civilized. There was Jan Christian Smuts in South Africa, who always regarded Gandhi as a prince among men, and Lord Irwin (later Lord Halifax) in India. In the Gandhi archives there is a private letter from Irwin, written toward the end of his five years as Viceroy of India, after months of tussle and conflict with Gandhi: "It has been a great privilege to me to be given this opportunity of meeting and knowing you; and I hope that either before I leave India or in England, you will give me the pleasure of seeing you again. I do pray—as I believe—that history may say you and I were permitted to be instruments in doing something big for India and for humanity."

Gandhi's leadership, which not only enthralled his followers but also elevated opponents to levels unknown to them until they grappled with him, was novel and obviously of the highest quality. Erikson analyzes its genesis in a detailed case study of Gandhi's intervention in a labor dispute in Ahmedabad in 1918. This was only one of Gandhi's efforts to reach out beyond the small groups of educated men who at that time monopolized Indian politics, to stir the rank and file and test his leadership of the various elements of Indian society. In the five years between his return from South Africa in 1915 and the launching of civil disobedience on an all-India scale in 1919, Gandhi was constantly engaged in pilot experiments. In 1917 he traveled to Bihar to take up the case of the cultivators against the indigo planters. Later, while he was still engaged in the dispute at Ahmedabad, he involved himself in a rural campaign in Gujarat for the suspension of revenue collections. Hence Ahmedabad was only one step in a general plan to awaken a wide political consciousness, one of the many preludes to the national campaign and not the most important one at that. Erikson would seem to be asserting too much when he terms the strike at Ahmedabad "The Event." There could be no mass movement in India that did not include the peasants, and Gandhi's hold was on them rather than on the factory workers. The Ahmedabad episode nonetheless lends itself to fruitful study, because it displays various facets of the Gandhian technique in operation, some of them for the first time.

To the student of industrial relations there is a touch of unreality about this strike and Gandhi's role in it. The leader of the millowners, Ambalal Sarabhai, was a personal friend of Gandhi's; he was probably also the anonymous donor who gave Gandhi considerable financial assistance on his repatriation in 1915. The leader of the workers, who sought Gandhi's intervention, was Sarabhai's sister. Throughout the three weeks of the agitation Sarabhai, his sister and Gandhi met every day and often had lunch together. When the workers demanded a rise in wages, the employers staged a lockout; then, when the workers went on strike, the millowners ended the lockout and sought to break the strike. Gandhi, by daily addresses and leaflets, exhorted the workers to stand firm and stressed the need for truth and courage. He helped them to formulate and put forward minimum demands, so that there was no room for retreat; this to him was always an important essence of *Satyagraha*. Finally, when the workers began to grow despondent and critical of their leaders, he undertook a public fast as a sign of solidarity with them. The employers thereupon agreed to the demands of the workers. Gandhi, however, was reduced almost to shame at the realization that, because of his special relationship with the employer group, his fast had served as a kind of blackmail of them.

In keeping with the unreality of the episode, Gandhi was able to express at every stage his satisfaction that the lock-out and the strike were being conducted with mutual regard and cordial relations: "That action alone is just which does not harm either party to a dispute." This, of course, is easier done in political and social reform movements than in the settlement of economic problems. Gandhi's abhorrence of class warfare; his pledge that he would promote the interest of the workers only "while safeguarding the employers"; his condemnation of the "Western, or the modern Satanic, notion of justice" that could benefit one party only at the expense of the other—all this idealization could rapidly be reduced to mere rationalization in favor of the employers. Gandhi's approach to economic matters had a touch of Moral Rearmament, with its invocation of ethical tenets to stabilize iniquitous economic relationships. "Workers," he wrote, "have no money, but they possess a wealth superior to money. They have their hands, their courage and their fear of God." Gandhi believed it was the *dharma*, the ethical duty, of capitalists and industrialists to make profits. The personal decency of a rich millowner such as Sarabhai further blinded him to the injustice of the system.

Marxists would say that Gandhi was the representative of the upper bourgeoisie, that he needed the support of the wealthy and that nothing better could be expected of him. Gandhi himself acknowledged that he had a predilection for Ahmedabad not merely because it was in his native Gujarat and had been an ancient center of handloom weaving but also because of his expectation that monetary help from wealthy citizens would be more available there than elsewhere. Erikson finds in Gandhi's attachment to Ahmedabad the unconscious resolution of unresolved conflicts in his past: he had abandoned his caste, his father's memory and his brother's legal work, and now perhaps Sarabhai had become the true brother. Such considerations blurred Gandhi's perception of the economic realities, to say the least.

Erikson does well to remind the reader that Gandhi was never a total pacifist. There were many shades and nuances to his belief in nonviolence. His commitment to this principle had nothing to do with religion, Hindu or Jain. The fact that he often expressed himself in Hindu terms and proclaimed that he stood in the mainstream of the Hindu tradition should not obscure the truth. Gandhi was a pragmatic revolutionary to whom nonviolence was a political expedient and not a doctrinal value. Civil disobedience seemed to him, and proved to be, the best way to bring the South African government to its knees; its use as a militant weapon in a number of campaigns in India ultimately made the British position there untenable. Gandhi was not bent on eliminating force from politics. He sought to generate that form of force which would be the most irresistible in the contexts in which he was operating. He did not discard the possibility of certain situations in which violence might be required. Not only had he served as a noncombatant in the Boer and Zulu campaigns; in 1918 he conducted a vigorous recruiting drive for the British army.

In Gandhi's view, as Erikson shows, there could be no real nonviolence unless there was the power of violence: "Immediately you cease to fear, you are ready for your choice—to strike or to refrain.... The ability to strike should be present when the power of the soul is demonstrated." His campaigns of militant nonviolence were rooted not in fear but in courage. There was also, much to the interest of Erikson as psychoanalyst, a considerable amount of hidden, subdued violence in Gandhi's nonviolence, in the pressure and coercion he applied to his opponents and in the moralism he inflicted on his disciples. And after the British had left India he approved of the action taken by Indian troops in Kashmir. On all these seeming contradictions Gandhi himself said the last word as far back as 1918: "One cannot climb the Himalayas in a straight line. Can it be that, in like fashion, the path of nonviolence, too, is difficult? May God protect us, may He indeed!"

Gandhi repeatedly stressed that God appears not in person but in action. Throughout his life he functioned primarily in the political context. Curious about his body and his spirit, he experimented constantly. The results make a fascinating record. He was a saint who placed his halo at the service of his secular aspirations; it was from "experiments in the spiritual field that I derived such power as I possess for working in the political field." What makes Gandhi important as well as interesting is that he was a leader of men comparable, in his time, only to Lenin. He used men with decisive effect, and in the process he often ennobled them.

Searching for the Mahatma can never be a wholly successful pursuit. It is the merit of Erikson that he casts new light on this extraordinary man. Discarding the veils of myth, he discloses the attachment to the mother that was sublimated into strength; the assumption of moral responsibility on behalf of the father that later extended to all fellow men; the return from Europe as an augmented Indian; the primacy of political commitment; the rejection of both procreation and killing; the care for the superior adversary, and, toward the end, the need to be mothered himself, in the bitter disillusion of the communal massacres that attended the liberation and partition of the Indian subcontinent. Erikson's book furthers our understanding by clarifying the humanity of the man to whom lesser men were so eager to ascribe godlike qualities.

Shorter Reviews

by Philip Morrison

Bats of America, by Roger W. Barbour and Wayne H. Davis. The University Press of Kentucky ($17.50). The World of Bats, photographs by Nina Leen, text by Alvin Novick. Holt, Rinehart and Winston ($23.95). In the dusk of a New England summer's night a householder enjoying his garden is apt to notice the darting, ticking habitual flight of a little brown bat around the house and under the trees. *Myotis lucifugus*, taking one flying insect every few seconds by frequency-modulated sonar, is a member of the most abundant of the 40 species of bats in the U.S. During the summer little *lucifugus* lives huddled in colonies behind the white clapboards of the still, hot church and mansion attics of a thousand New England towns; telltale spattered droppings usually mark the dawn entryway of these colonists. ("The postmistress of a small town always seems to know who has bats.") By September the animals have congregated in winter quarters; the total population of *M. lucifugus* from Cape Cod to Lake Champlain, a band of 300,000 bats that in season hunt over more than 8,000 square miles, huddle in a single cave on the wild slopes of Mount Aeolus in southern Vermont. These five-gram cousins of ours fly far and fast on their delicate wings of eight-inch span. They bear live single young, fast-growing little things that seem to stay in the roost during the mother's feeding flights, although the newborn cling to a nipple for some days. These bats thrive at temperatures above 125 degrees Fahrenheit, but they are not irreversibly harmed (although they are dormant) when they are cooled to well below freezing.

In the wider spaces of Texas and Arizona there are great flights of millions of *Tadarida brasiliensis*, the free-tailed bat. ("Leaving a cave [they] sound like the roar of a white-water river and appear as a dark cloud visible for miles.") One cave near San Antonio supports 20 million individuals, and you can reckon a few grams of small moths per bat per night as the average intake. The column leaves the cave mouth at 35 miles per hour; in the open sky they easily outspeed a helicopter following the column at 40 m.p.h. They are flying at perhaps 60 m.p.h., yet flow calculations suggest that not all the bats from the biggest colonies can find air space to leave the cave every night! Hear the eloquent traveler to inner-city batdom: "A visit to one of the huge colonies... is a memorable experience. [The] intruder's light causes them to peel off from the great clusters ... until the cave is filled with milling bats. The floor and the walls... soon seem to be crawling with them.... They collide with the observer..., cling to him and crawl upward.... A writhing mound... quickly accumulates, and although they make no effort to bite, one gets the feeling that he may be smothered... as he sinks deeper into the... soggy guano which covers the cave floor. The caves are oppressively hot. [The] humidity is very high, and there is almost no air movement. Ammonia is sufficiently concentrated to cause irritation. ... Mites... seem to cover every available surface. [They] quickly move... to cover the additional surface presented by a human visitor.... Carnivorous beetles are abundant. [They] can skeletonize a bat within hours. [They] rarely bother a person on the move. Venomous snakes... are an additional concern.... No one should enter... unless he has been immunized against rabies."

The bats almost never bite; the virus in the bat-packed cave is airborne. In spite of repeated scare stories the bats have proved no menace whatever to public health. Bats are "exceptionally sanitary." They carefully arrange it so that their urinary stream does not soil themselves or their neighbors. Healthy bats are always clean and fluffy. They are as colorful as most furry mammals; many species sport marvelous large sonar ears, and nose leaves of bizarre and intricate form surrounding the nostrils are found in those species that emit the sonar pulses through the nose rather than orally. The bamboo bat, weighing about a gram and a half, is probably the smallest of all living mammals: "When I placed one with its wings folded on the terminal joint of my thumb, it was framed on all sides by a substantial margin of my skin."

Bats are numerous, subtle and beneficial, yet they remain largely unknown because they are so different from us. Our night is their day; our eyes are their ultrasonic ears; the ground under our feet they replace by the thin air; even when they touch the solid earth, they live inverted, head-down lives. They are "dynamic insecticides." In the Tropics many plants are designed for seed dispersal and pollination by bats. Such tropical fruit is often an obscure green or brown, since it is taken not by daylight vision but by its musty smell. The seeds are large and inedible or else small and slippery—bat-proofed. Some bats fish, although how they find their prey is still unclear. They can pick up by sonar a small needle that breaks the surface, but not a submerged fish. How they can work in the clutter of ripples and waves is unclear; perhaps they do not. Children can often hear the sonar cries, but sluggish older ear membranes make out only the fierce transient onset click. There are "whispering" species that hunt insects close to walls, tree trunks and leaves with weak pulses and slow, deliberate flight with quick maneuvers, employing the short-range returns to make manageable the complexity of their echo world.

So far I have spoken of the bats and not the books. These are two remarkable volumes. *Bats of America* is really a lavish key to American bat species. It is local, particular, a bit technical, giving the life history and territory species by species, almost cave by cave. It tells about skins and skulls, about netting bats with the nearly invisible (inaudible?) mist-net bird snares of Japanese make. The photographs, made by Roger Barbour out of 30 years of wildlife photographic experience, are guides to recognition. The bats are arrayed, live and engaging, their color true, resting on natural backgrounds, so that the species can be named from the bat one sees in nature. There is a clear index and a large annotated list of references, with many maps.

The World of Bats has a wider sweep and a less specific intention, but its text (by a Yale expert) is no less personal and precise, telling anecdotes bat by bat. It covers the world of bats, as it asserts, with less anatomy and much more evolution, although with neither index nor references. Its pictures are bravura photographs, often spread proudly over gatefolds, with montages and multiple images. Many bear the blue highlights of the strobe flash lamp; they show the bats in full flight, looking like parachutes or gliders as often as birds. Both inverted combat and upside-down amity can be seen. The photographer is a well-known professional who has spent three years and much devotion on bats.

SIPRI YEARBOOK OF WORLD ARMAMENTS AND DISARMAMENT 1968/69, by the Stockholm International Peace Research Institute. Humanities Press, Inc. ($13). THE MILITARY BALANCE 1969–1970, by the Institute for Strategic Studies, London ($2). The seismologist Charles F. Richter devised the logarithmic scale of intensities widely used to measure earthquake energy release; a similar kind of scale was proposed long ago by Lewis F. Richardson for the social seismology of human conflict. Richardson intensity 6 means the order of magnitude of 10^6 deaths, and since the end of World War II (which reached intensity 7.5 or more) there have been six such shocks: the wars in Korea and Vietnam, of course, the insurgencies in Indonesia and Colombia, the partition struggles in India and Pakistan, and (probably) the attempted secession of the Eastern Region of Nigeria. The Chinese civil war and the Algerian war of independence fall just short. All these conflicts are listed and categorized in the Stockholm yearbook, the first of an intended annual series, a substantial volume that treats the military issues of our time in a wide-ranging way. It outlines world military expenditures, the technological arms race, disarmament efforts and the history of recent conflict—all on two levels. The first 40 percent of the work is a well-documented set of essays on those topics centering on the years 1968 and 1969; the rest of the book is a valuable tabular presentation of data and chronologies of events connected with the same topics. Nuclear tests are exhaustively and critically listed and examined, as one might expect from the great interest Sweden has shown in this subject. It is made very plain that underground testing has become commonplace; there have been more tests since the test-ban treaty than there were before! The partial test ban is a contribution not to arms control but to public health. There are five similar recent treaties, widely ratified by the nations, that regulate arms: the agreements to disarm the Antarctic; to ban nuclear-weapons tests in the air, in the sea and in space; to neutralize the moon and earth orbits; to make Latin America nuclear-weapons-free, and to inhibit nuclear-weapons proliferation. We here in the U.S. have signed them all, albeit with some reservations about the one concerning Latin America.

A second solid part of this useful book is the tabular listing of military expenditures, by scores of nations, on all continents, in real and current prices. There is a detailed study of the international flow of arms on a similar scale. The technological picture, which is derived mainly from U.S. Congressional hearings and from the trade journals of the U.S. aerospace industry, is somewhat marred by retouching with the corporate hot-air brush in many of these sources. Nonetheless, the *SIPRI Yearbook*, fallible though it may be, meticulously lists all its sources. Altogether it is an admirable start on what will surely be an indispensable reference series.

The Military Balance is no first: it is the 11th in a paperback annual series. Where the *SIPRI Yearbook* is wide-ranging and carefully documented, even a little padded with chronologies of forgotten daily events, *The Military Balance* is cool, taut, narrow, compact. It is professional staff work, not academic scholarship. Its sources are suppressed, perhaps even somewhat covert, rising out of the international attaché community of diplomatic London. No treaties or diplomacy or news events fill its 63 pages; rather it gives, in a few paragraphs to a few pages, its own estimate of the armed forces of the powers, from the Big Five down to Albania (but not this year Latin America or Africa). In a few succinct tabular pages, a bit like the tablets from Mount Sinai, it tells off the names and numbers of the nuclear-weapons systems, the costs, the strength of armies and the agreements to transfer arms. It is a very good buy for him who would know that most of our 450 active B-52's now carry two AGM-28B Hound Dog cruise missiles with thermonuclear warheads and a standoff range of 700 miles. A tenth of our B-52's are engaged in Vietnam bombing missions; a third of the force is this year being given supersonic AGM-69's that have a short-

er range but may be more deliverable against opposition.

The orderly structure of the military world is spanned by these two works; the disorder and death implied are muted. The concerned reader will find more need for such guidance as the political decade moves on.

EARTH RESOURCES, by Brian J. Skinner. Prentice-Hall, Inc. ($5.95; paperbound, $2.50). RESOURCES AND MAN: A STUDY AND RECOMMENDATIONS, by the Committee on Resources and Man of the Division of Earth Sciences of the National Academy of Sciences–National Research Council. W. H. Freeman and Company ($5.95; paperbound, $2.95). Up-to-date and written both expertly and readably, these two brief books are texts for our times. The Skinner book (he is a leading economic geologist at Yale) takes the form of a single-topic partial text written for college students of introductory geology. It will gain a wider audience. Its aim is the detailing of the uses of the mineral kingdom that gives life to modern man. The book does not stop at the well-described graphs, charts and tables that make up the statistical story; it goes into minute particulars to bring reality and some insight into the numbers and the projections. Mapped here are the buried pillars of salt that float up, eight miles high and 1,000 feet across, through denser rock layers out of the deeply buried strata of ancient seas to reach almost to the fresh air of Louisiana. So are the deeply buried conglomerates of the Rand of South Africa. Those Rand ores look for all the world like ancient placer deposits: rounded pebbles in a cementing matrix, buried miles deep. But the billion-year-old placers of the Rand, source of most of the world's gold for 85 years, form a unique nearly continuous set of gold-bearing stream channels 250 miles long—the mother lode of the dreams of the forty-niners. Of course, it is not gold we humans really need and seek; it is iron, salt, nitrogen from the air, potash, phosphates, rock and sand, fuels and clean fresh water.

The Academy book, whose authors are eight American and Canadian government experts or professors, takes a wider view of resources (the living kingdom as well as the inanimate one) in a set of essays estimating the human population now and in the future, and its means and hopes for winning food, raw materials and energy from land and sea. The book is not at all introductory in nature, but it is accessible to any scientific reader with some tolerance for algebra. The picture is a practical one, aimed at estimating potentials and limits, and it is not much embellished with the marvels of geology and agriculture.

The consensus is plain: We shall need to feed about six billion of us by the turn of the century. We might well do it, but by that time we must begin to approach a zero net rate of population growth; otherwise we shall lose the hope of happiness. Ten billion of us could live in "an *intensively managed* world . . . with some degree of comfort," and 30 billion might find food at a "level of chronic near-starvation." It is plain to all these writers that the great growth of mankind has reached its last power of 10.

If we look at man's use of energy, the future of fossil fuels or fission is measured in centuries; only deuterium or sunlight can carry us through a long history of industrial life. Our history is now marked on a time axis by one single pulse of fossil energy, rising from the axis and falling back to it again in about a millennium. We are in the first fourth of that pulse today. Right now men add as much heat to the earth's surface as the natural flow of heat by convection and conduction from the earth's hot interior does, and we face a tenfold rise in man's activities. For the first time in so central a parameter as energy men will have worked on a geologic scale. (Of course, the sun sends 1,000 times more heat to the earth's surface; we shall not cook ourselves that way!) Still, our myriad stacks and tailpipes aggregate to more heat than Krakatoa, Etna and the Valley of Ten Thousand Smokes.

THE STRUCTURE AND ACTION OF PROTEINS, by Richard E. Dickerson and Irving Geis. Harper & Row, Publishers ($9.95; paperbound, $4.95). STEREO SUPPLEMENT TO THE STRUCTURE AND ACTION OF PROTEINS, by Richard E. Dickerson and Irving Geis. Harper & Row, Publishers ($6.50). The intricate jigs and fixtures that give form to the work of the power tools in the factory are made of steel. So too are the columns of the factory wall and the tension cables in the roof. In living matter the enzymatic molecular jigs and the strong fibers and sheets that enclose and frame the working molecular machinery are more evidently digital: their common material is the discrete peptide monomers of protein, not the apparently continuous metal with which we must build on a gross scale.

This introductory account, in which the text is intimately related to a rich collection of illustrations, is a look at the protein structural chemistry of the past two decades. It was in 1951 that Linus Pauling and his colleagues outlined and Max Perutz demonstrated the most stable three-dimensional array of polypeptide linkwork, the celebrated alpha helix.

After a chapter explaining the inventory of molecular standard parts, the geometry of peptide links is given description by the versatile map named after G. N. Ramachandran of Madras. It is a graph plotting on each axis one of the two angles of free rotation possible in a link between two amino acid units. Each link is a point in that plane. Careful model and computer studies have shown the regions of minimum strain and maximum stability in such a plot, using the somewhat oversimplified atomic models of differing spherical diameters. These regions reveal, however, what turns out to be adhered to in nature: three kinds of helix (handedness matters in the living world, since the asymmetrical amino acids are not present in both left- and right-handed forms), a pleated sheet and a ribbony ladder. They are drawn here in many ways, and the electron micrographs echo the models.

About a dozen globular proteins are treated: the carrier and the receiver of molecular oxygen in vertebrates (hemoglobin and myoglobin), the electron carrier (cytochrome *c*) and five real catalysts. The amino acid sequences are known for a couple of hundred links in each case, and the twists and turns of the folded chain are mapped point by point in space and on the Ramachandran plot. The molecule is really a tightly packed puff of electron orbits, although the link-and-ball diagram is often of great help for description. Most of the individual twists and turns cluster near the stable regions of the diagram, but here and there are special shapes that have meaning. They define the working surface of the catalytic jig. These shapes are mainly still uncertain, although in lysozyme we seem to have a working understanding of how the jig works. The chemists can tell what charges are brought up to just what bent portion of the sugar linkage to be attacked by hydroxyl ion, once the polysaccharide is held securely in the active crevice of the enzyme. Combine this kind of molecular-tool study with comparative molecular zoology down the evolutionary sequence, and the present state of the subject emerges, groping but powerful, and irresistibly cumulative.

The authors are a protein crystallographer and a scientific illustrator. The text and its intricate drawings are an amalgam. The stereo supplement gives spatial (if rather abstract) reality, in link-and-ball line drawings, to nine proteins shown in 55 stereo pairs from different viewpoints. Not everyone will be pleased by the particular blue that is the single added color in the main text, but the indispensable nature of the visual material is clear all the same. Form is function, although one feels that this frozen world of the crystallographer is unnaturally static. Form plus interaction forces plus Brownian motion is function!

The Grand Titration: Science and Society in China and the West, by Joseph Needham. George Allen and Unwin Ltd. (63 shillings). The sixth of the 12 great books of Dr. Needham's *Science and Civilization in China* will soon be at hand. There must be many readers who will welcome a learned, witty, brief surface cruise over that still unrevealed ocean of deep knowledge. This book presents eight overlapping essays, representing the author's work and thought since the early 1940's, all of them aimed at titrating the great civilizations East and West, to assay just what components in each have given rise to the present state of science. Even the photographs are a revelation: the oldest form of magnetic compass, an instrument of divination; the first form of stirrup; the first crank; the first segmented-arch bridge, and much more. There is a long piece with real insight into time and Eastern man, making a strong case against the cliché view of Chinese thought as past-bound, timeless or cyclical. Perhaps the strongest essay is one from 1964, setting forth a view that the overall social and economic circumstances will in the end make coherent the "early predominance of science and technology in China and the later rise of modern science in Europe alone."

One fascinating theme is the effect of gunpowder in Europe and in China. In Europe it broke the feudal strongholds in the land—quite literally. In China the landlord class never had armor proof against the peasant's crossbow. The Chinese made rockets and cannon, but these merely entered the arsenal of warfare without a social transformation. (It was not quite so in Japan.) Chinese sovereign power derived from consent, custom and cooperation; it was not brittle because the rulers never held the mere military ascendancy that in Europe was based on horse, fortress and armor.

Needham raises a noble banner. He holds that what scientists share in all lands is the legacy of Galileo, not of Greece or of Neoplatonism or of the Christian view of law. "Modern universal science, yes; Western science, no!"

INDEX OF ADVERTISERS

APRIL 1970

BIBLIOGRAPHY

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

THE DELIVERY OF MEDICAL CARE

REPORT OF THE NATIONAL ADVISORY COMMISSION ON HEALTH MANPOWER: VOL. I. U.S. Government Printing Office, 1967.

PRINCIPLES AND PRACTICE OF SCREENING FOR DISEASE. J. M. G. Wilson and G. Jungner. World Health Organization, 1968.

THE RECOGNITION OF SYSTEMS IN HEALTH SERVICES: PROCEEDINGS OF THE SYMPOSIUM ON HEALTH OF HEALTH APPLICATIONS SECTION, OPERATIONS RESEARCH SOCIETY OF AMERICA, MAY 14–16, 1969, WASHINGTON, D.C. Edited by George K. Chacko. Operations Research Society of America, 1969.

COST ANALYSIS OF A MULTIPHASIC SCREENING PROGRAM. Morris F. Collen, Prentis H. Kidd, Robert Feldman and John L. Cutler in *The New England Journal of Medicine*, Vol. 280, No. 19, pages 1043–1045; May 8, 1969.

THE HEALTH OF THE NATION'S HEALTH CARE SYSTEMS. Robert H. Finch and Roger O. Egeberg in *California Medicine*, Vol. 111, No. 3, pages 217–219; September, 1969.

REPORT OF ADVISORY COMMITTEE: AUTOMATED MULTIPHASIC HEALTH TESTING. C. D. Flagle. U.S. Government Printing Office, in press.

REPEATED SEGMENTS OF DNA

A MOLECULAR APPROACH IN THE SYSTEMATICS OF HIGHER ORGANISMS. B. H. Hoyer, B. J. McCarthy and E. T. Bolton in *Science*, Vol. 144, No. 3621, pages 959–967; May 22, 1964.

NUCLEOTIDE SEQUENCE REPETITION: A RAPIDLY REASSOCIATING FRACTION OF MOUSE DNA. Michael Waring and Roy J. Britten in *Science*, Vol. 154, No. 3750, pages 791–794; November 11, 1966.

REPEATED SEQUENCES IN DNA. R. J. Britten and D. E. Kohne in *Science*, Vol. 161, No. 3841, pages 529–540; August 9, 1968.

HIGHLY REPETITIVE DNA IN RODENTS. P. M. B. Walker, W. G. Flamm and A. McClaren in *Handbook of Molecular Cytology*, edited by A. Lima-De-Faria. North-Holland Publishing, 1969.

THE RED SEA HOT BRINES

ISOTOPIC COMPOSITION AND ORIGIN OF THE RED SEA AND SALTON SEA GEOTHERMAL BRINES. H. Craig in *Science*, Vol. 154, No. 3756, pages 1544–1548; December 23, 1966.

HOT BRINES AND RECENT HEAVY METAL DEPOSITS IN THE RED SEA. Edited by Egon T. Degens and David A. Ross. Springer-Verlag New York Inc., 1969.

CHEMISTRY BY COMPUTER

MOLECULAR THEORY OF GASES AND LIQUIDS. Joseph O. Hirschfelder, Charles F. Curtiss and R. Byron Bird. John Wiley and Sons, Incorporated, 1954.

VALENCE. Charles A. Coulson. Oxford University Press, 1961.

CHEMISTRY FROM COMPUTERS. A. C. Wahl in *Argonne National Laboratory Reviews*, Vol. 5, No. 1, pages 43–69; April, 1969.

BISON: A NEW INSTRUMENT FOR THE EXPERIMENTALIST. Arnold C. Wahl, P. Bertoncini, K. Kaiser and P. Land in *International Journal of Quantum Chemistry*, Symposium No. 3, Part 2, pages 499–512; 1970.

PESTICIDES AND THE REPRODUCTION OF BIRDS

PESTICIDES AND THE LIVING LANDSCAPE. Robert L. Rudd. The University of Wisconsin Press, 1964.

PESTICIDE-INDUCED ENZYME BREAKDOWN OF STEROIDS IN BIRDS. D. B. Peakall in *Nature*, Vol. 216, No. 5114, pages 505–506; November 4, 1967.

PEREGRINE FALCON POPULATIONS: THEIR BIOLOGY AND DECLINE. Edited by Joseph J. Hickey. The University of Wisconsin Press, 1969.

MARKED DDE IMPAIRMENT OF MALLARD REPRODUCTION IN CONTROLLED STUDIES. Robert G. Heath, James W. Spann and J. F. Kreitzer in *Nature*, Vol. 224, No. 5214, pages 47–48; October 4, 1969.

HOW IS MUSCLE TURNED ON AND OFF?

NEUROMUSCULAR PHYSIOLOGY OF GIANT MUSCLE FIBERS OF A BARNACLE, *BALANUS NUBILUS* DARWIN. Graham Hoyle and Thomas Smyth, Jr., in *Comparative Biochemistry and Physiology*, Vol. 10, No. 4, pages 291–314; December, 1963.

EXCITATION-CONTRACTION COUPLING IN SKELETAL MUSCLE. Alexander Sandow in *Pharmacological Reviews*, Vol. 17, No. 3, pages 265–320; September, 1965.

THE ROLE OF CELL CALCIUM IN THE CONTRACTION OF SINGLE CANNULATED MUSCLE FIBERS. Christopher C. Ashley in *American Zoologist*, Vol. 7, No. 3, pages 647–659; August, 1967.

INTRACELLULAR CALCIUM MOVEMENTS OF FROG SKELETAL MUSCLE DURING RECOVERY FROM TETANUS. Saul Winegrad in *The Journal of General Physiology*, Vol. 51, No. 1, pages 65–83; January, 1968.

HYPERACTIVE CHILDREN

A DEVELOPMENTAL STUDY OF THE BEHAVIOR PROBLEMS OF NORMAL CHILDREN BETWEEN 21 MONTHS AND 14 YEARS. J. W. Macfarlane, L. Allen and M. P. Honzik. University of California Press, 1954.

THE HYPERACTIVE CHILD SYNDROME. Mark A. Stewart, Ferris N. Pitts, Jr., Alan G. Craig and William Dieruf in *American Journal of Orthopsychiatry*, Vol. 36, No. 5, pages 861–867; October, 1966.

LIQUID-CRYSTAL DISPLAY DEVICES

DYNAMIC SCATTERING: A NEW ELECTROOPTIC EFFECT IN CERTAIN CLASSES OF NEMATIC LIQUID CRYSTALS. George H. Heilmeier, Louis A. Zanoni and Lucian A. Barton in *Proceedings of the IEEE*, Vol. 56, No. 7, pages 1162–1171; July, 1968.

REFLECTIVE LIQUID CRYSTAL TELEVISION DISPLAY. John A. van Raalte in *Proceedings of the IEEE*, Vol. 56, No. 12, pages 2146–2149; December, 1968.

MATHEMATICAL GAMES

THEORIES OF THE UNIVERSE: FROM BABYLONIAN MYTH TO MODERN SCIENCE. Edited by Milton K. Munitz. The Free Press, 1957.

A SUBJECTIVE EVALUATION OF BODE'S LAW AND AN "OBJECTIVE" TEST FOR APPROXIMATE NUMERICAL RATIONALITY. I. J. Good in *Journal of the American Statistical Association*, Vol. 64, No. 325, pages 23–49; March, 1969.

THE AMATEUR SCIENTIST

AMATEUR TELESCOPE MAKING (BOOK THREE). Edited by Albert G. Ingalls. Scientific American, Inc., 1953.

The do-it-yourself

You won't find it in a hobby shop. But if you like, we'll make one up for you. It's easy for us to do, because we make every single part ourselves. When you're through, you'll have your own MAC 16 control computer.

Since very few people would be tempted to assemble a computer, core stringing being a bit tricky and all that, there must be another point to our offer.

It's this. No other manufacturer of mini computers makes as many parts that go into the computer. With that kind of capability, it's natural that we also make a lot of parts that go into other peoples' computers.

We've shipped more bits of high speed—one microsecond or faster—core memory than

computer kit.

all other independent manufacturers combined. And we're probably the largest supplier of complex printed circuits in the world.

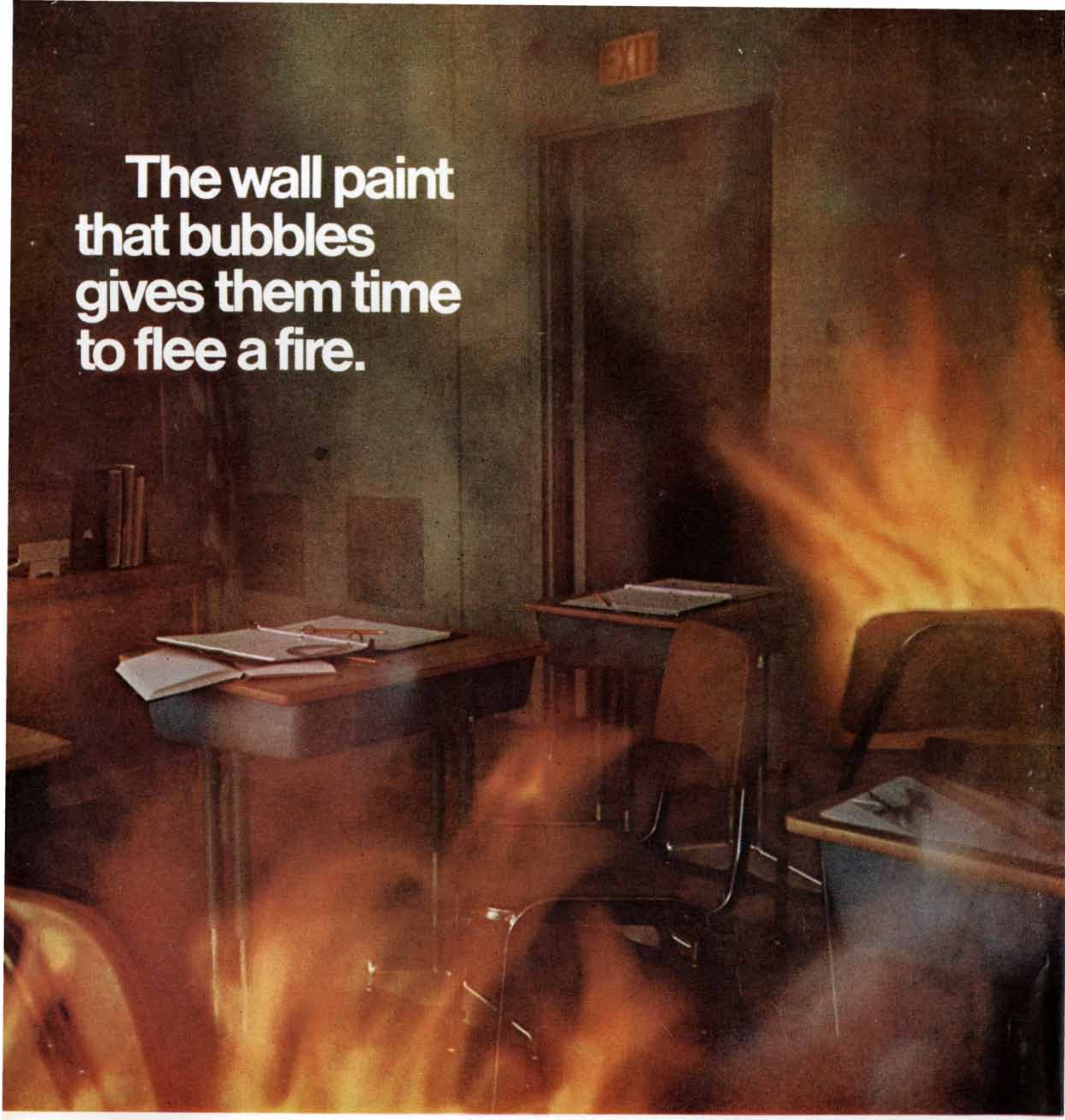
We're the champ at producing double-sided and multilayer boards with plated-through holes.

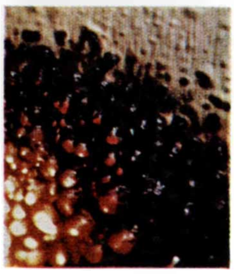
Now, we're manufacturing flexible printed circuit boards and plated-wire memories.

Our customer list is rich with big names. But there's always room for more. Yours, whenever you'd like to stop by and pick up your pre-assembled kit.

Lockheed Electronics

Data Products Division
A Division of Lockheed Aircraft Corporation,
6201 E. Randolph St., Los Angeles, California 90022





These bubbles come from a special paint that looks like any other paint until things get hot. Then it bubbles up to insulate walls against fire for a few precious extra minutes —minutes that can be used to put the fire out or to escape from it.

Phosphorus formulations from Monsanto give ordinary smooth-flowing latex paints and solvent-type interior paints this fire-fighting ability. Even if walls painted with these special fire-resistant paints are washed again and again, they're always on guard to slow down a fire.

We're developing new ways to control other types of fires, too. From air-dropped chemicals for forest fires, to fire-retardants for paper clothing. These new developments are coming from Monsanto—where science and research are working for people.

Monsanto Company, 800 N. Lindbergh Blvd., St. Louis, Missouri 63166

Monsanto