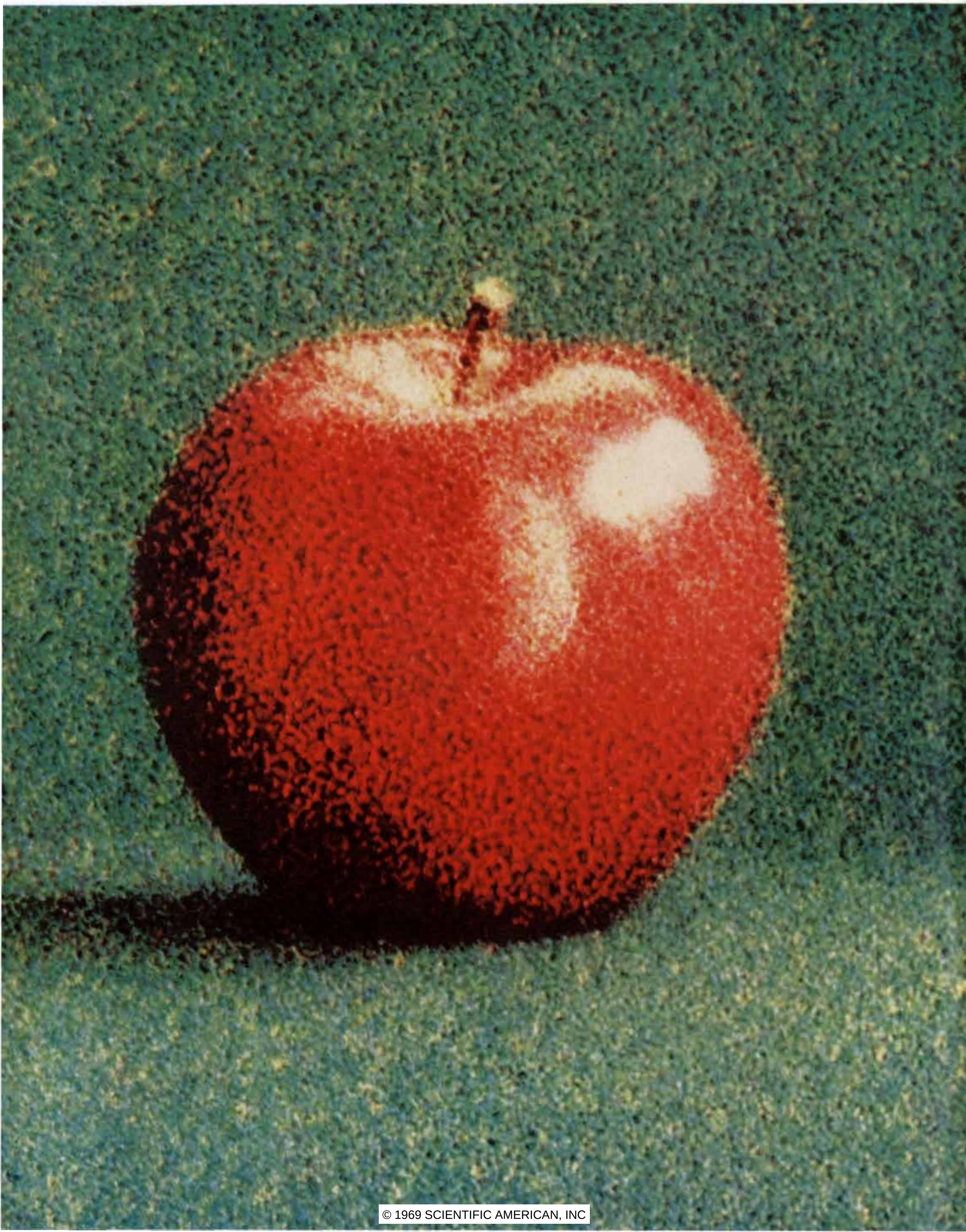
SCIENTIFIC AMERICAN

URBAN MONKEYS

SEVENTY-FIVE CENTS

July 1969



out of our coal mines.

We operate open pit coal mines in Illinois.

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GENERAL DYNAMICS

Established 1845 **SCIENTIFIC AMERICAN** July 1969 Volume 221 Number 1

ARTICLES

DEPARTMENTS

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THE COVER

The photograph on the cover shows a female rhesus monkey with her infant on the wall of a courtyard in Jaipur, a city in the Indian state of Rajasthan. They are among the large numbers of monkeys whose ancestors centuries ago left their natural habitat, the forests of northern India, and took up life with man in cities (see "Urban Monkeys," page 108). The question is: Have generations of urban life led to any detectable differences between these monkeys and their country cousins in terms of behavior and capacities?

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SCIENCE/SCOPE

The first five laser rangefinders for the M60 tank were delivered on schedule to the U.S. Army on April 30, and tests are now being conducted at Fort Knox and the Aberdeen Proving Grounds. When the commander selects his target and his gunner flashes the laser at it, the range appears on a readout and can also be fed automatically into the tank's fire-control system -- greatly enhancing the first-hit capability of the M60's 152-mm. gun.

A holographic technique for detecting flaws in honeycomb panels without destruction or contamination of the structure was demonstrated recently by Hughes Research Laboratory scientists. They stressed a fiberglass-aluminum panel and made a reflection interferogram of the strain pattern. The points where fiberglass and aluminum had failed to bond were easy to detect. They used a Hughes-developed stop-action holography system which provides images with photographic resolution, and can record dynamic strain patterns.

NASA's next Applications Technology Satellite, the Hughes-built ATS-5, has completed its environmental testing and is scheduled for launch in late summer. It will carry out a total of 13 experiments. One of the most significant will determine whether L-band frequencies will give better-quality radio communications between aircraft and between ships and shore stations. Another will test the feasibility of the gravity-gradient principle for stabilizing synchronous satellites.

Using heat pipes to cool high-density electronic packages and flatpack circuits is being studied at Hughes/Fullerton. Heat pipes are cooled by liquid evaporation, and can dissipate 1000 times more heat than solid metallic conductors of the same size. Hughes engineers are determining optimum structural geometry, operating fluid, and wick and shell materials for future applications.

More than 100 engineers from 10 nations met at Hughes recently to coordinate their efforts on the Intelsat 4 communications satellite program. They represented 10 companies which, with Hughes, are building four of the satellites under a $72-million contract awarded by Communications Satellite Corp. on behalf of the 68-member International Telecommunications Satellite consortium. A similar meeting of manufacturing executives is scheduled for September.

Hughes is hiring engineers: Radar Systems, Optical, Electro-optical System Analysis (IR, LLTV, Laser), Digital Systems, Spacecraft Systems, Circuit Design, Missile System & Vehicle Design, Ordnance Specialists (SAF Systems), Electromagnetics Test (EMI/EMC). Requirements: B.S. degree, two years related experience, U.S. citizenship. Please write: Mr. J.C. Cox, Hughes Aircraft Company, P.O. Box 90515, Los Angeles 90009. Hughes is an equal opportunity employer.

The high-reliability component selection programs which Hughes has used for its communications satellites since 1963 have contributed to a phenomenal record: no significant failures in more than 1.5 billion component-hours aboard the 10 Hughes-built satellites now in orbit for DOD, NASA, and Comsat. Programs use Hughes-developed electronic component screening and power aging techniques.

Creating a new world with electronics

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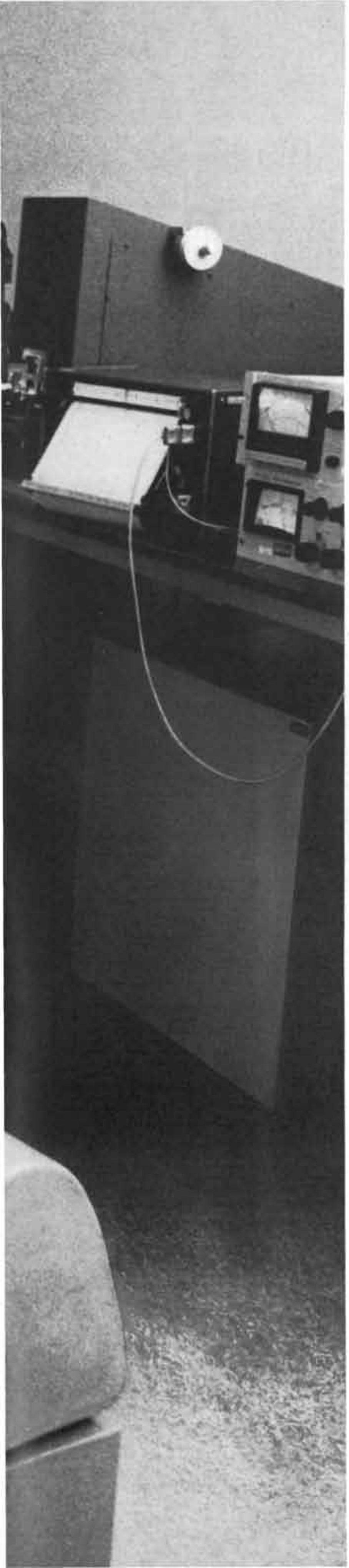

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LETTERS

Sirs:

I recently came across André Lwoff's review of James D. Watson's book *The Double Helix* [Scientific American, July, 1968]. I admired his brilliant analysis but was distressed by his interpretation of an episode that relates how I handed to Watson and Francis Crick an allegedly confidential Medical Research Council Committee report by Professor J. T. Randall with vital information about the X-ray diffraction pattern of DNA.

As I have pointed out in extensive detail in a letter to *Science,* the Watson description of the events was faulty in several regards. The committee of which I was a member did not exist to "look into the research activities of Randall's lab" but to bring the different M.R.C. units working in the field of biophysics in touch with one another. The report was not confidential and contained no data that Watson had not already heard about from Miss Franklin and Wilkins themselves.

I discarded the papers of the committee many years ago, but the Medical Research Council found them for me in its archives. In 1947 the Council set up the Biophysics Committee "to advise and assist the Council in promoting research work over the whole field of biophysics in relation to medicine." This committee consisted mainly of the heads of all the M.R.C. units related to biophysics and included Randall and myself. We visited each laboratory in turn; the director would tell the others about the research in his unit and circulate a report. His reports were not confidential. The committee served to exchange information but was not a review body: we were never asked for an opinion of the work we saw. The Medical Research Council dissolved it in 1954, in the words of the official letter because "the Committee has fulfilled the purpose for which it was set up, namely to establish contact between the groups of people working for the Council in this field."

M. F. Perutz

Cambridge, England

Sirs:

I am very sorry that by not pointing out that the Randall report was nonconfidential I portrayed Max Perutz in a way that allowed André Lwoff to badly misconstrue his action. As the report was not privileged, I should have made that point clear in my text. About the nature of the M.R.C. committee, I was led to believe by general lab gossip, now seen to be incorrect, that its real intention was to oversee the M.R.C.-King's effort, then its biggest venture into pure science.

It was my desire to reconstruct the story accurately, and so most people mentioned in the story, including Perutz, were given the manuscript, both in one of the first drafts and in the final revision, and asked for their detailed comments. I, of course, was responsible for the actual wording and apologize for the passage that so unfairly wrongs Perutz.

James D. Watson

The Biological Laboratories
Harvard University
Cambridge, Mass.

Sirs:

In his splendid article "The Atmospheres of Mars and Venus" in your March issue Von R. Eshleman attributed to me and to Charles E. Giffen the notion that the analysis of the chemical composition of a planetary atmosphere could constitute a life-detection experiment.

The very generosity of this tribute makes it necessary for me to straighten the record so that the substantial contributions of my colleague Mrs. Dian R. Hitchcock shall not go unrecognized. For the development of this notion and for the concomitant discovery that the atmosphere of the earth is an actively controlled component of its ecosystem, she is due at least half of the credit.

James E. Lovelock

Bowerchalke, England

Sirs:

In his interesting article on typesetting [Scientific American, May] Gerard O. Walter made reference to "the world's first papermaker, whose name is lost to history."

According to *Hou Han Shu* (*Book of the Second Han Dynasty*), in A.D. 105 a eunuch named Tsai Lun announced to the emperor, Ho Ti, that he had made sheets of paper from macerated tree bark, hemp waste, old rags and fishnets. Before this texts were either inscribed on bamboo slips or written on silk, the former being rather cumbersome and the latter costly.

Legend has it that in order to convince his fellow countrymen of the importance of his invention he staged a phony funeral and had his family burn square pieces of the paper he invented. Out he jumped from his coffin and proclaimed to the spectators that the imitation money destroyed by fire had been adapted as real currency in the spirit world.

The Chinese accepted both of his inventions, the material and the ceremonial. Even today the practice of burning the paper money is still common at funerals, and paper money instead of flowers is placed on the graves. The nature of such paper as manufactured by the traditional paper artisans still resembles the original: yellow, soft, porous and raw.

Chau Hsiung Wu

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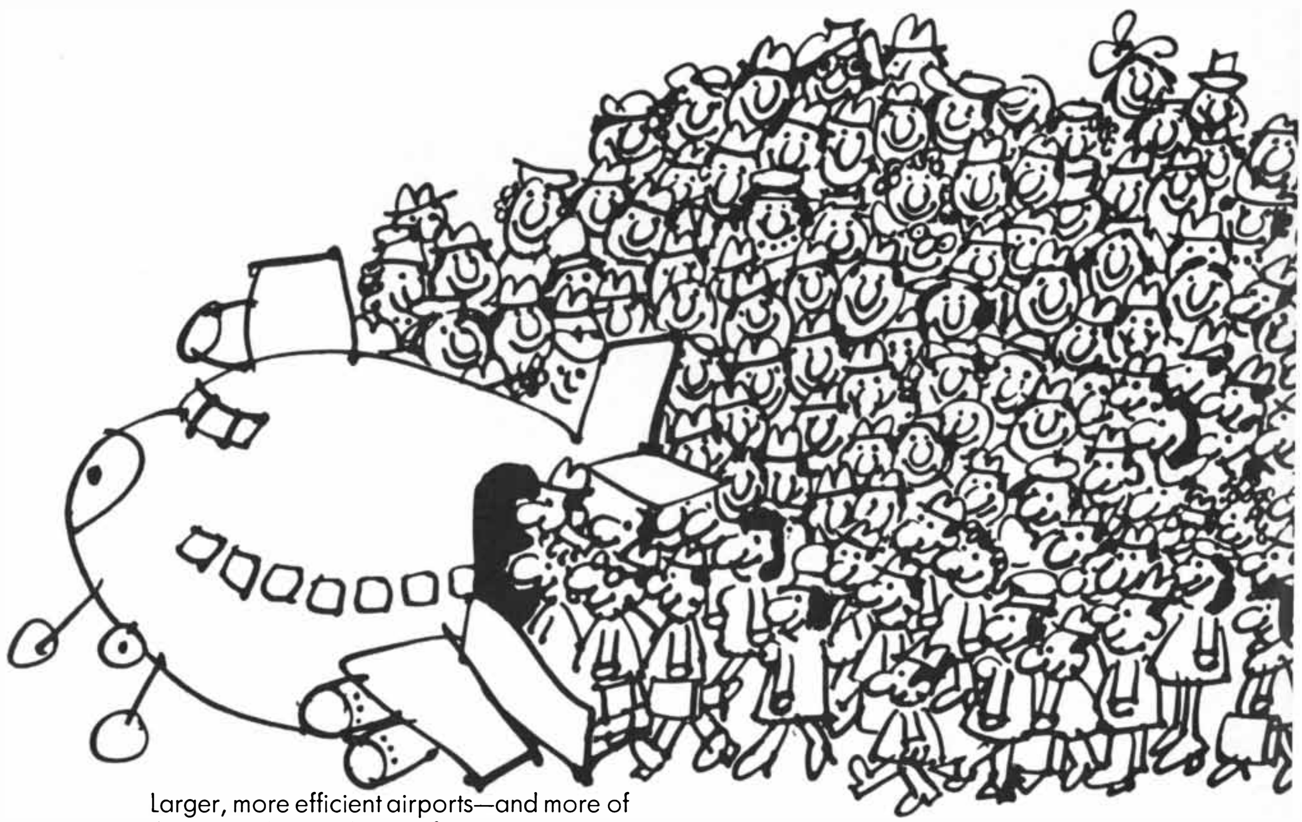
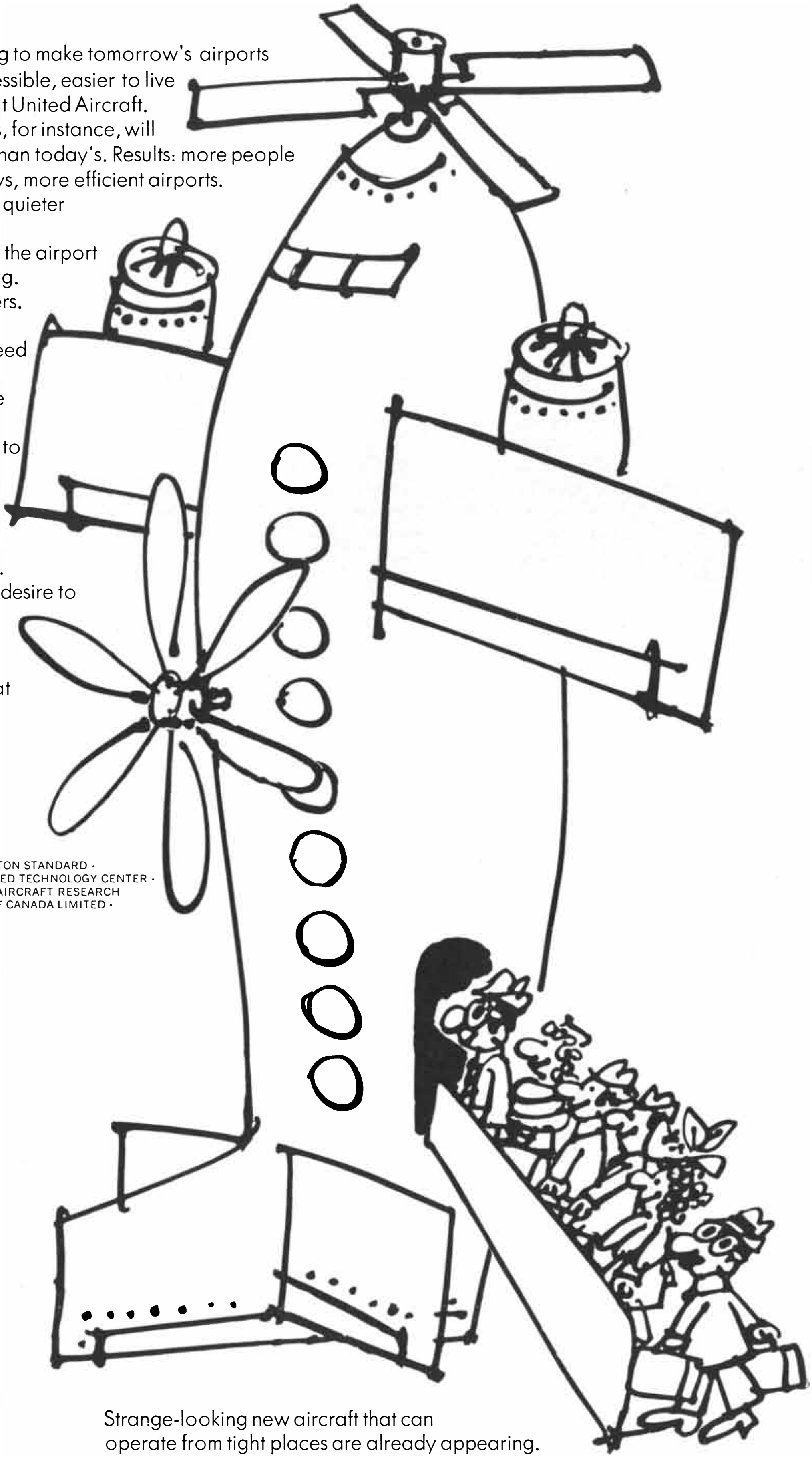


Larger, more efficient airports—and more of them—are being planned for tomorrow's giant jets.



50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

JULY, 1919: "The signing by Germany of the treaty of peace at Versailles brings to an end the war of arms begun by the Germans on the fields of Belgium. So long as Germany and the Allies abide by the terms of this momentous document the thunder of the guns and the tramp of armed peoples will never be heard. But the material peace that has come by the stroke of the pen at Versailles is, after all, only an outward and visible sign of a peace—secret, unwritten but eagerly hoped for—without which the Versailles document may prove to be only one more scrap of paper. If the vanquished nations who, by their accredited representatives, set their hand and seal to the covenant of peace did so with a hatred blind, unreasoning and implacable in their hearts, it will be merely a question of time and opportunity before the armed multitudes will be on the march and red ruin will stride again across the world. In respect of sincerity in carrying out the terms of the treaty, alas, Germany has made a very poor start. In her notification of acceptance she arrogantly stated she was signing, under compulsion, a treaty whose terms she never expected to fulfill, and in the same hour she placed the crowning mark of dishonor upon her unparalleled record by breaking her parole and sinking her interned fleet."

"Baron Rayleigh, who died on the evening of June 30th, was generally recognized as the foremost physicist of Great Britain, if not of the world. He possessed a rare combination of mathematical ability and experimental skill. Doubtless his most celebrated single achievement was the discovery in 1894 of argon, one of the inert gases in the atmosphere and the first known of these. But his less spectacular work was of far greater importance. A catalog of this work would look like the index to a text book in advanced physics; but of all the subjects with which he dealt, perhaps those in which he achieved the most lasting results were chemical physics, the theory of gases and the flow of liquids, photography and color vision as well as more general work in optics, the theory of wave motions, electric and magnetic problems and hydrodynamics."

"For the third time within two months the Atlantic has been crossed by intrepid airmen. The latest successful flight is that of the huge British dirigible R-34, which left the Royal Naval Air Station at East Fortune, near Edinburgh, at 2 o'clock on the morning of July 2nd, and after a more or less adventuresome journey arrived at Roosevelt Field, near Mineola, Long Island, at 8:45 o'clock on the morning of July 6th. The R-34 was commanded by Major G. H. Scott, and the crew comprised 30 officers and men, as well as one stowaway."

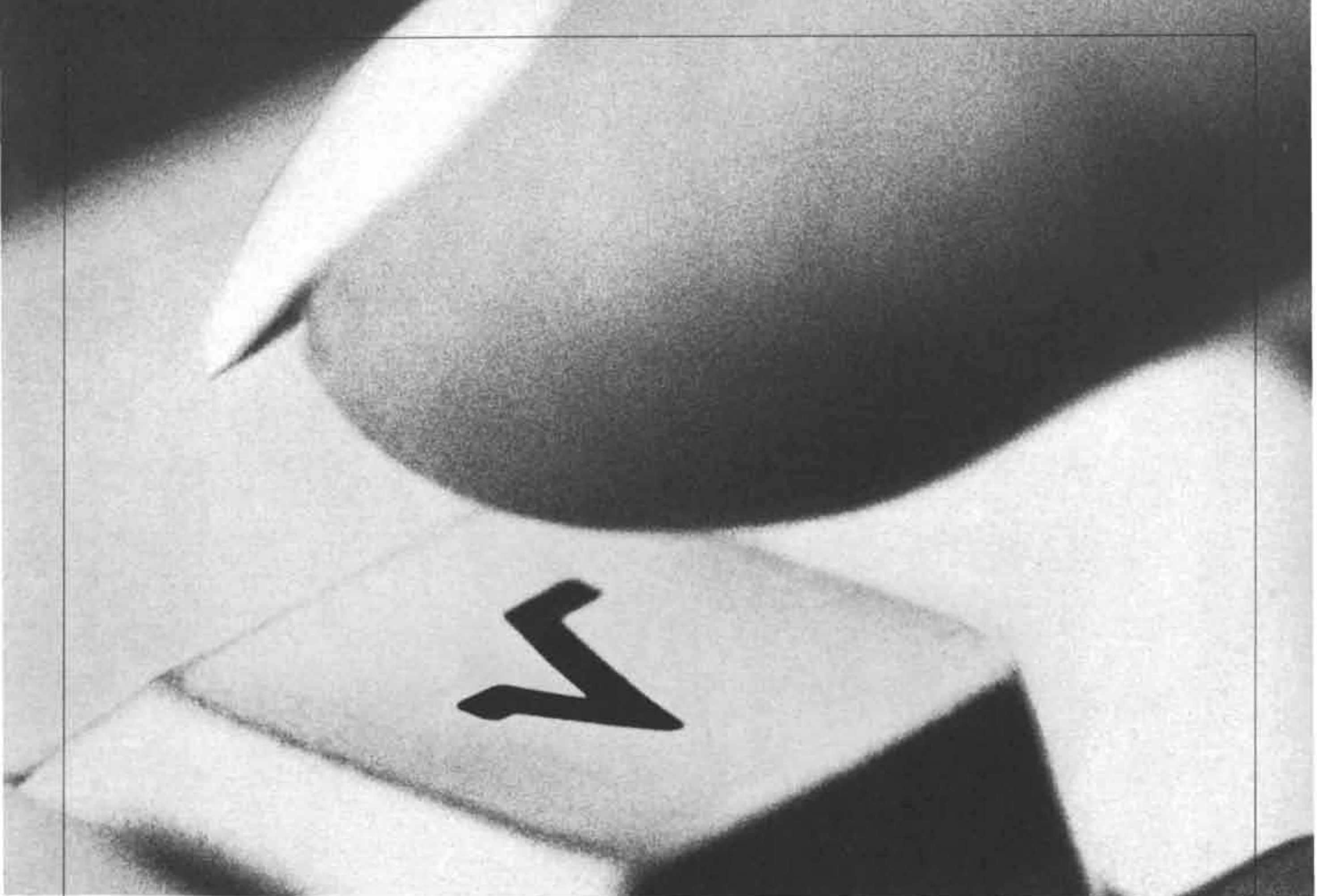
"The old-time autocracy was opposed, bitterly opposed, to the coming of political democracy—because it promised to interfere with the autocratic enjoyment of power. In the same way, present-day industrial and commercial autocrats often object to any suggestion for giving the employees a little voice in the running of the plant—because this would interfere with the autocratic enjoyment of power. But if political autocracy is not to be, there seems no very rational ground for tolerating any other kind of autocracy. Why should not every man have his voice in the things that concern him as a buyer and a seller of goods and of labor, as well as in those that concern him as a citizen? There is today a growing conviction that this suggestion should be carried out—even that it must be carried out. More and more we read of schemes looking toward the participation of the workers in the control and in the profits of the plant. More and more we are getting away from the theory that the plant should be run in the exclusive interest of the proprietors, just as 100 years ago we were getting away from the idea that the government should be run in the exclusive interests of the few who till then had been its proprietors."

SCIENTIFIC AMERICAN

JULY, 1869: "The public is watching with great interest the attempts making to promote industrial and scientific education in this country. Undoubtedly the most important effort of this kind is the Cornell University at Ithaca, N.Y. The tide of opinion has of late been rapidly setting toward a more practical kind of education than has for a long time prevailed. The applications of scientific discovery have revolutionized the arts, and success in any department of industry is getting to depend more and more upon knowledge of fundamental principles. It has therefore become necessary to provide for the special education of youth in order to fit them for anything like a high station in any industrial department. Such a conclusion could not long be entertained without attempts to put it into practice, and schools have been established in both America and Europe subordinating classical education to scientific instruction. The Cornell University is such an institution. As yet it has not got fully under way, and its ultimate success or failure is problematical. We believe it will prove a triumphant success, and we have had this faith from the outset."

"In a large hall near San Francisco a small steam balloon has lately been tried, with so much success as to excite enthusiasm among the stockholders, and to make them think that the great problem of aerial navigation has been solved. We are assured that the first packet of a regular line of aerial steamships will start from California for New York within a very few weeks. We should be glad if there were any reasonable basis for this expectation, but we find none whatever. Substantially the same forms of balloon and machinery have before been tried, always with apparent success on the small scale in still air; always with failure when subjected to atmospheric currents. Experience shows that the attachment of wings, tails and wheels to balloons tends more to impede than to assist their progress. Aerial navigation will never be reduced to a regular commercial system until some one shows us how to dispense with the unwieldy gas balloon and replace it with an effective method of generating the requisite buoyant power. The subject is one of great importance and worthy of diligent study on the part of all inventors."

"The steamship *Great Eastern* is now engaged for the second time in laying a cable across the Atlantic, this time, however, from the coast of France. The latest account represents that everything was proceeding favorably. The ship was 294 knots out of Brest and had paid out 310 knots of the cable, the signals to the shore continuing perfect. This affair is proceeding with all the quiet of a determined success, and we hope soon to learn of the safe accomplishment of the undertaking."



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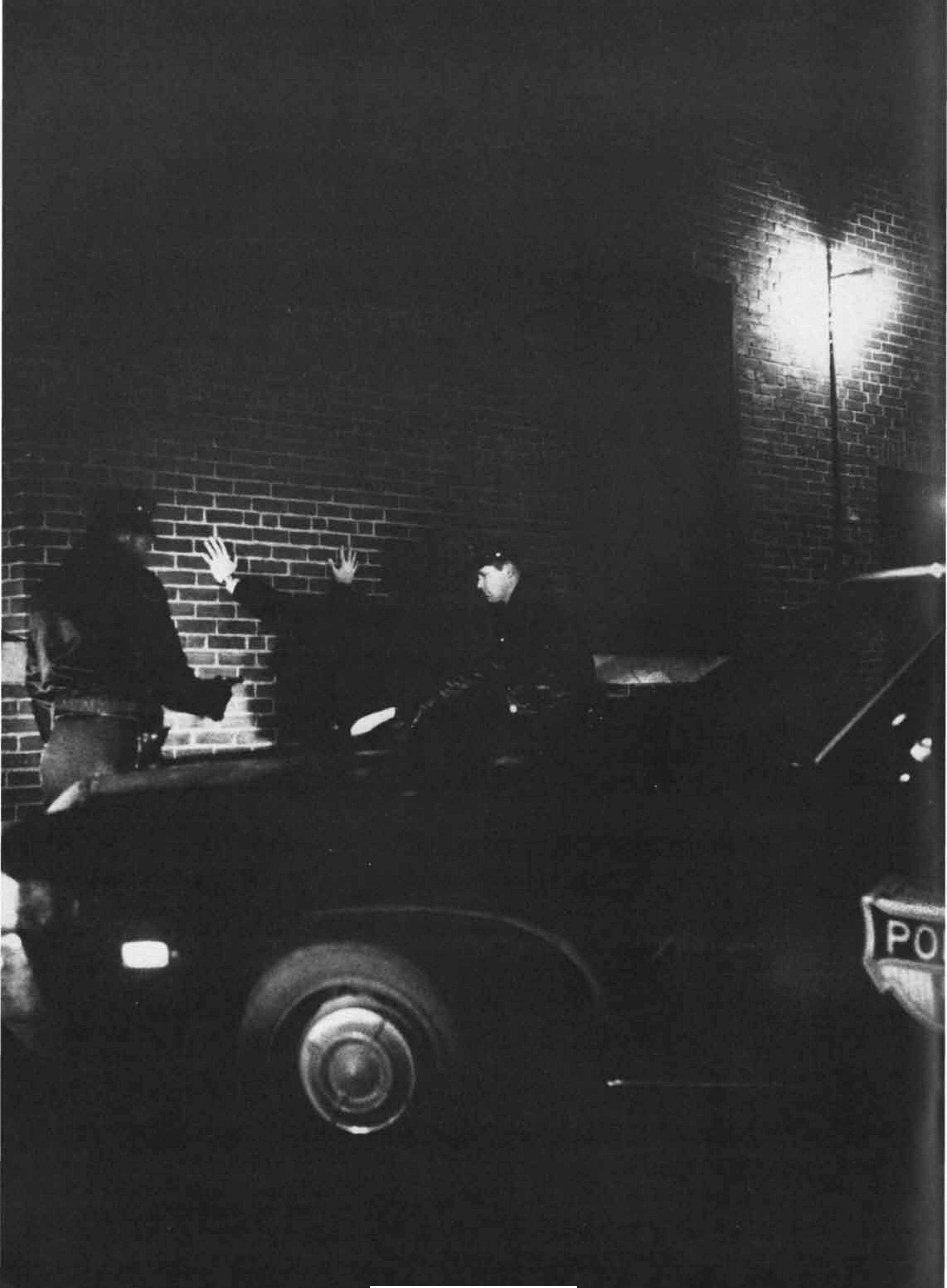
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THE AUTHORS

WILLIAM F. HAMILTON II and DANA K. NANCE ("Systems Analysis of Urban Transportation") are with the General Research Corporation in Santa Barbara, Calif.; Hamilton is director of the civil systems department and Nance is editorial director. Hamilton took his bachelor's degree in physics at Yale University and his master's degree in applied physics at Harvard University. After two years at the Instrumentation Laboratory of the Massachusetts Institute of Technology he moved to Santa Barbara, where he was with the General Electric Company until he joined his present firm in 1962. Nance was graduated from Vanderbilt University with a degree in English. He writes: "After an exposure to the fascination of electronic gadgetry during service in the Air Force I changed fields and studied physics and mathematics at Purdue University. For seven years I was a research engineer with General Motors, finally combining my two loves—words and gadgets—as a technical editor."

JOHN N. BAHCALL ("Neutrinos from the Sun") is associate professor of theoretical physics at the California Institute of Technology. He was graduated from the University of California at Berkeley in 1956 and received his Ph.D. from Harvard University in 1961. He was a research fellow at Indiana University for two years before going to Cal Tech. His wife, Neta, whom he married in Israel in 1966, will receive her Ph.D. in physics from the University of Tel Aviv in September. Bahcall writes: "I have had many able collaborators in the theoretical work described in this article. Everyone agrees, however, that my wife is the prettiest."

IDA MACALPINE and RICHARD HUNTER ("Porphyria and King George III") are mother and son. Dr. Macalpine, a physician who has retired from clinical work, served as psychiatrist at St. Bartholomew's Hospital in London. She has published papers on psychoanalysis and psychosomatic medicine. Hunter is physician in psychological medicine at National Hospital in London and lecturer in the history of psychiatry at the Institute of Psychiatry of the University of London. Dr. Macalpine writes: "Our common interest in the history of psychiatry is motivated by the belief that it helps to understand the complex and confused state of the specialty at the present time and will foster a development away from its preoccupation with treatments and toward investigative and causative research and so catch up with general medicine. We have published together the source book *Three Hundred Years of Psychiatry 1535–1860* and have edited a number of classic psychiatric texts."

STUART PATTON ("Milk") is Evan Pugh Research Professor of Agriculture at Pennsylvania State University. He writes that although his principal interest has been the chemistry and biology of milk, he is "easily distracted" and finds "the whole of nature intriguing." To allow for diversity he often spends vacations working in marine biology; his recent projects have included the study of red-tide organisms along the southern California coast and the investigation of spawning salmon in British Columbia. Patton was graduated from Penn State in 1943 and obtained his master's and doctor's degrees from Ohio State University. He writes: "I enjoy all kinds of things: my family, home, the outdoors, the ocean, the mountains, travel, all kinds of sports, reading, concerts, art, lectures, the university. We have a 2.5-acre place four miles outside of State College, and it has been a wonderful spot to live for 20 years and raise a family." The family, he says, "has rounded off at seven children."

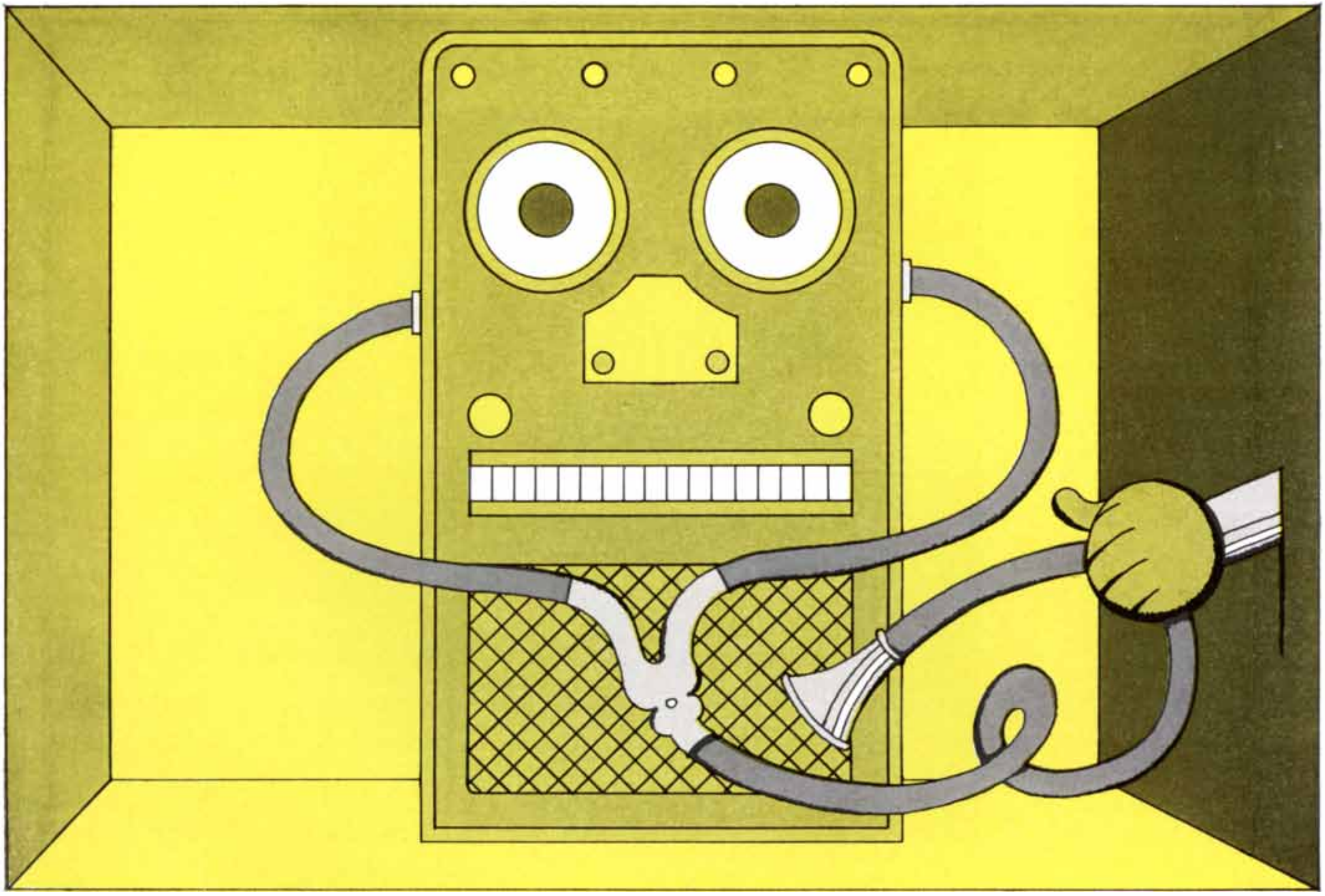
N. W. ASHCROFT ("Liquid Metals") is associate professor at Cornell University, working at the university's Laboratory of Atomic and Solid State Physics. He was born in England and raised in New Zealand. Educationally he traveled the reverse route, doing his undergraduate work at Victoria University in New Zealand and his graduate work at the Cavendish Laboratory of the University of Cambridge, where he obtained his Ph.D. in 1966. He went to Cornell after postdoctoral work at the University of Chicago. Ashcroft writes that his research interests are "theory of the metallic state" and "properties of disordered systems."

MARGARET OAKLEY DAYHOFF ("Computer Analysis of Protein Evolution") is head of the chemical biology department and associate director of research at the National Biomedical Research Foundation. She writes: "I received my B.A. from New York University in 1945 and my Ph.D. in chemistry from Columbia University in 1948. I then joined the staff of the Rockefeller Institute, where I remained for three years as a physical chemist. For the next few years my main interests centered around my husband, who is a physicist, and my two daughters. The development of the accurate programmed high-speed computer has paralleled and greatly influenced my scientific career. The recent accumulation of fundamental structural data in biochemistry has sparked my hope that the computer's memory, its capacity for handling details and its many features analogous to living systems would make possible a new level of human understanding of biological structure, evolution and function. As our contribution to the realization of this hope, my colleagues and I have set out to collect, organize and analyze protein and nucleic acid sequence data, and to publish this collection for the convenience of workers in biomedical research."

A. H. FRAZER ("High-Temperature Plastics") is research fellow in the pioneering research division of the textile fibers department of E. I. du Pont de Nemours & Company. He received bachelor's and master's degrees at Tulane University in 1944 and 1945 respectively and obtained his Ph.D. from Syracuse University in 1948. His work at Du Pont since 1948 has been in all phases of basic and applied research on polymers, with particular emphasis on fibers. He was the organizer of the first symposium on high-temperature fibers and is the author of the book *High Temperature Resistant Polymers.*

SHEO DAN SINGH ("Urban Monkeys") has just taken up an appointment as associate professor of psychology at the University of New Brunswick. After receiving his master's degree at Muslim University in Aligarh, India, he went to the University of London, where he obtained his Ph.D. in 1958. Until 1967 he taught at Indian universities. For the past two years he has been a visiting scientist at the Regional Primate Research Center of the University of Wisconsin. "At present," he writes, "I am studying the effects of cortical lesions and drugs on the social and learning behavior of monkeys and rats. I hope to establish a primate center in India but as yet do not know when the project will materialize."

P. C. MAHALANOBIS, who in this issue reviews *Asian Drama: An Inquiry into the Poverty of Nations,* by Gunnar Myrdal, is founder and director emeritus of the Indian Statistical Institute in Calcutta.



No time for downtime

A machine as complex as the Bell System's new Electronic Switching System (ESS) must help with its own maintenance. Consider, for example, that an ESS installation in a single Bell System central office can perform nearly a billion and a half switching, logic, and memory operations per second. And that we expect it to provide service for 99.999 percent of the next 40 years. Also, that the system employs a totally new concept: "stored program control." That is, each of the many actions in connecting one telephone with another is governed by a central digital data processor which draws upon program instructions and other stored data; new and revised features are incorporated by changing memory content rather than by rewiring.

All of this makes traditional servicing obsolete, and calls for advanced ideas in reliability and maintenance of electronic equipment.

Vital units such as the central data processor and the memories operate in pairs; if one unit ever falters, its twin maintains service. But, because there is no standby until the defect is repaired, ESS itself helps with the work. For instance, there are three principal fault-detection schemes:

"Match and Check Circuits" constantly compare critical information in duplicated units.

"Audit Programs" check that the system's temporary memory reflects what is actually going on.

"Exercise Programs" use the brief intervals between telephone calls to check all circuits, including those for maintenance.

If a fault is found, alarms operate and "fault recognition" programs take over. These automatically find the defective unit and reroute the information flow through its duplicate. Or, if the problem is simply a memory error, it is corrected. Such actions take less than a millisecond; office operation is unaffected.

Finally, "diagnostic programs" test any faulty unit, store the results, and print them out with a reference number. A craftsman looks the number up in his "ESS Troubleshooting Manual" and finds a list of possibly defective circuit packs. He replaces one or more of them to clear the problem.

Over half of ESS—circuits and stored program—is devoted to maintenance. But only with modern techniques can so complex a system meet today's communications needs.

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Systems Analysis of Urban Transportation

Computer models of cities suggest that in certain circumstances installing novel "personal transit" systems may already be more economic than building conventional systems such as subways

by William F. Hamilton II and Dana K. Nance

There is a growing recognition that many of the ills of U.S. cities stem from the problem of transportation within the metropolis. Although the automobile has endowed the American people with unprecedented mobility, the long-range trend toward movement by private automobile rather than by public transit has created a new complex of difficulties for urban living. The price being paid for the privacy and convenience provided by the automobile is enormous. It includes the engulfing of the city by vehicles and expressways, congestion, a high rate of accidents and air pollution. The automobile has brought another consequence that tends to be overlooked but is no less serious: by fostering "urban sprawl" it has in effect isolated much of the population. In the widely dispersed metropolis, much of which is not served by public transit, those who cannot afford a car or who cannot drive are denied the mobility needed for full access to the city's opportunities for employment and its cultural and social amenities.

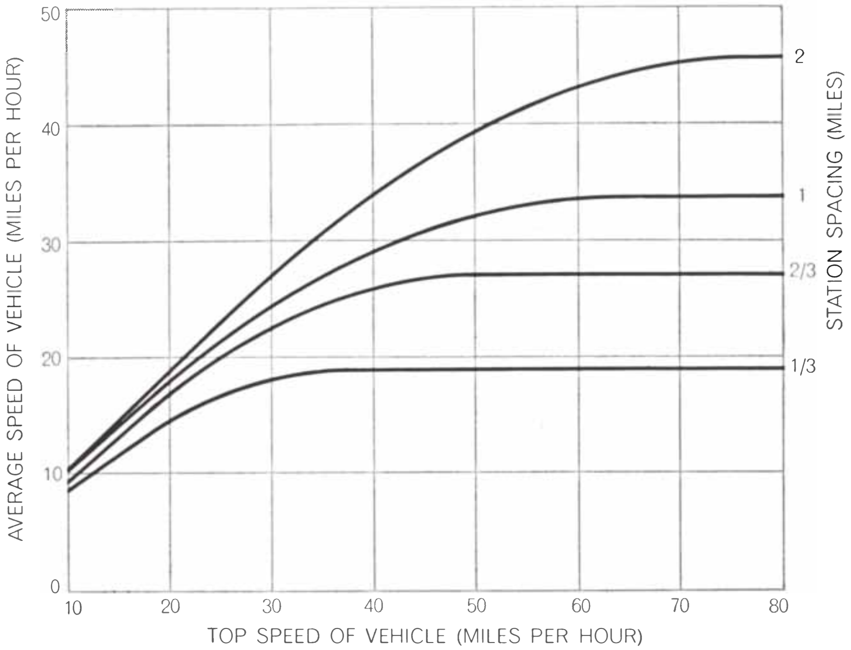
These "transportation poor" constitute a far larger proportion of the population than is generally realized. Half of all the U.S. families with incomes of less than $4,000, half of all Negro households and half of all households headed by persons over 65 own no automobile. Even in families that do own one it is often unavailable to the wife and children because the wage earner must drive it to work. The young, the old, the physically handicapped—all those who for one reason or another cannot drive must be counted among the transportation poor in the increasingly automobile-oriented city. The generalization concerning the mobility made possible by the private automobile must be qualified by the observation that 100 million Americans, half of the total population, do not have a driver's license, and the proportion of nondrivers in the big cities is higher than in the country at large.

The gravity of the urban transportation problem prompted Congress three years ago to direct the Department of Housing and Urban Development (HUD) to look into the entire problem. HUD awarded 17 study contracts to a wide variety of groups: transportation experts, university laboratories, research institutes and industrial research organizations. Our group, the General Research Corporation of Santa Barbara, Calif., which is experienced in the discipline known as systems analysis, was assigned to apply such analysis to the transportation problem, considering the entire complex of transportation facilities for a city as an integrated system. In analytic method our study resembled a number of earlier ones devoted to this subject. It is nonetheless unique in that it weighed not only existing systems of transportation but also future systems. Furthermore, it carried cost-benefit accounting to a new breadth and depth of coverage.

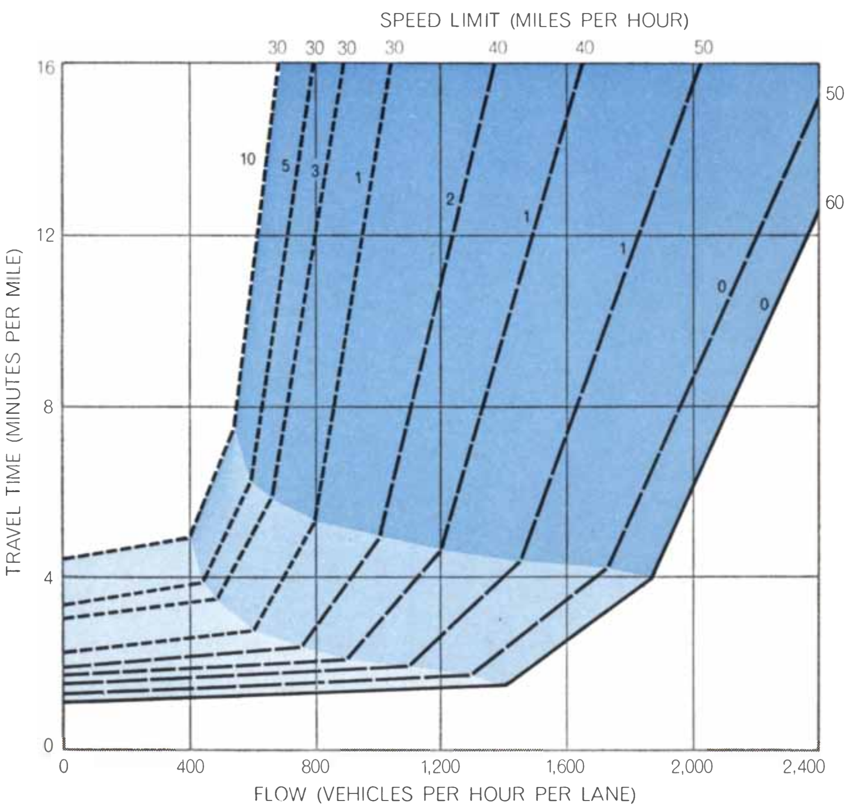
We set out to build a mathematical model of urban transportation and to test with the aid of a large computer the effectiveness and the costs of various possible networks. Systems analysis is a general approach that consists in examining a complex system by exploring the interactions of its many parts. One "wiggles" each part in order to see what will happen to the whole when all the parts are taken into account. When the system does not exist and would be too expensive or too risky to build for testing by direct experimentation, the analyst tries to construct a model representing it and does the experiments on the model. Most often the model turns out to be a set of equations that can be solved together. For a system of any complexity the model usually is so complicated that the experiments can only be performed with a high-speed computer.

Our goal was to model all the significant modes, actual and potential, of transporting people in an urban area. We were not trying to design a particular optimal system; rather, we undertook to examine various combinations of the possible modes to see how the system as a whole would work.

To make our model as realistic as possible it was plainly desirable to use data from actual cities rather than from a hypothetical average city. We therefore decided on a case-study approach, selecting four representative cities as models. On the basis of an elaborate factor



AVERAGE SPEED OF SUBWAY IS LIMITED by the spacing of stations and the acceleration that passengers can tolerate. It is assumed that the maximum tolerable acceleration is three miles per hour per second and that stops are 20 seconds long. Thus regardless of what the top speed of the train is, it can only average (if stations are a mile apart) 33 miles per hour. Improved equipment cannot overcome this limitation of conventional transit.



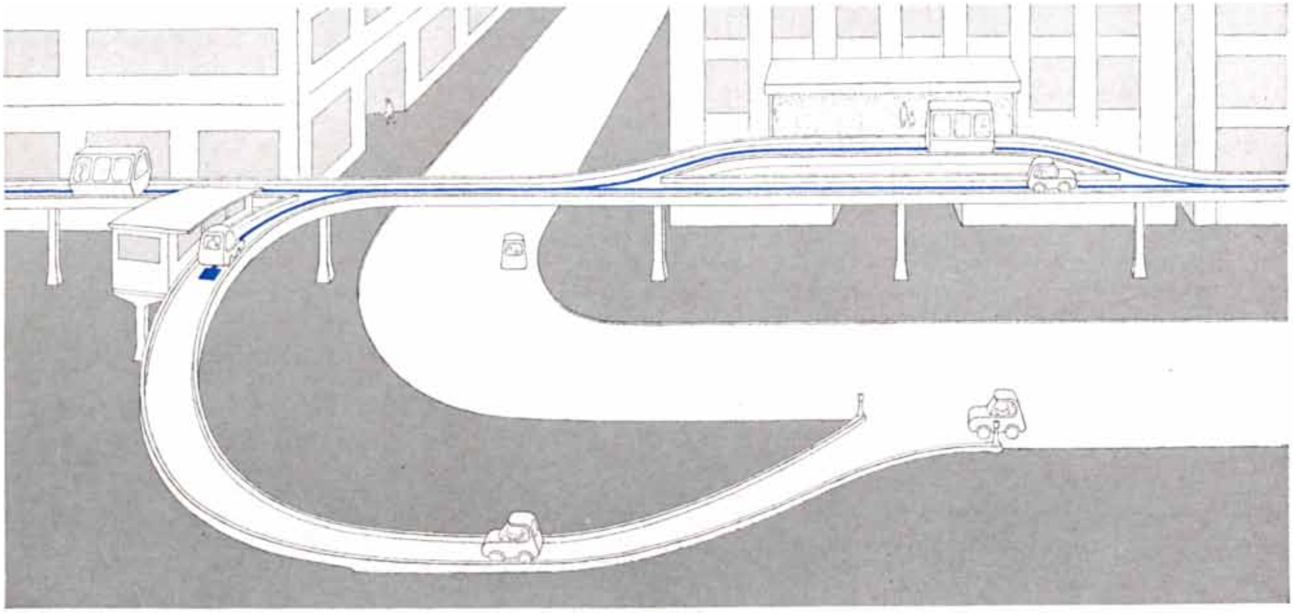
STREET CAPACITIES were represented in mathematical models of a city's transportation by the equations of these lines. At low traffic flow (*light color*) the speed and number of signal-marked intersections per mile (*numbers within grid*) are governing factors. The region above (*medium color*) is mainly governed by car density. Where flow exceeds street capacity (*dark color*) the slope was calculated from queuing theory. Data for particular streets are from city maps. The number of signal-marked intersections is an approximation.

analysis of census data we chose Boston as a typical example of a large city that was strongly oriented to public transit, Houston as a large city oriented to the private automobile and New Haven and Tucson as corresponding representatives of smaller cities (between 200,000 and 400,000 in population). These four cities offered the valuable advantage that detailed studies of their traffic flows had recently been made in each of them, so that they provided data not only for building our model but also for validating the results of experiments with the model.

The formulation of the model for each city started off with a description of present transportation facilities and considered the travel needs of its people both now and in the future. We described for the computer the streets, freeways, bus service and rail service (if any). For evaluation of the present system and of possible future improvements the model had to take into account a great deal of demographic and technical detail: the population density and the average family income in each area of the city, the location of residential and business areas, the traffic flows over the transportation routes at typical peak and off-peak hours, how the speed of flow over each route would be affected by the number of vehicles using it, the amount of air pollution that would be generated by each type of vehicle and a great many other factors that must enter into the measurement of the costs and benefits of a transportation system.

Starting with computer runs that evaluated how well the existing system performed, we went on to model progressively more advanced systems and compare their performance. All together we tested some 200 models, each loaded with a tremendous amount of detail and each taking about an hour for the run-through in our computer. The project occupied a large team of specialists: engineers, city planners, mathematicians, sociologists, economists and computer programmers. A measure of the amount of work entailed is the fact that our final report, written by 17 authors, ran to 500,000 words—and we tried hard to be brief!

As our study proceeded, the results of the experiments showed that the possible strategies for the improvement of urban transportation fell into two sharply different categories from the standpoint of effectiveness. One of these was an approach we called "gradualism." It consisted in building improvements into the existing methods of transporta-



HYPOTHETICAL PERSONAL-TRANSIT SYSTEM would combine the speed and privacy of the automobile with the advantages of rail transit. A passenger entering the automated guideway network at a station would be carried by a small vehicle nonstop to his destination at speeds of up to 60 miles per hour. Specially equipped automobiles could enter the guideway by ramp, affording the driver swift, safe and effortless transport. Such dual use would make it feasible to extend the system to urban fringe areas.

tion. These, for example, included modernizing and extending old subway lines and building new ones, redesigning buses to make them quieter and easier to enter and speeding up their movement, equipping automobiles with devices to minimize air pollution, and so forth. The other approach, which we labeled "new technology," consisted in a jump to entirely new modes of transport, involving the creation of new kinds of vehicles and interconnections. Our tests of models indicated, as we shall show, that the gradualistic approach could not meet the future transportation needs of the cities, whereas innovations already in sight promise to do so.

Let us briefly examine some of the most promising of these new concepts. Engineers have described a system called "personal transit" that will operate like a railroad but will transport individual passengers or small groups nonstop to stations of their own selection. Its cars will be small, electrically propelled vehicles, with a capacity of two to four passengers, running on an automated network of tracks called "guideways." All stations will be on sidetracks shunted off the through line [*see illustration above*]. A passenger will enter a waiting car at a station, punch his destination on a keyboard and then be carried to the designated station with no further action on his part—no transfers, no station stops, no waiting, no driving. It appears that such a system could take the passenger from starting point to destination at an average speed of 60 miles per hour, as against the present average speed of 20 miles per hour counting station stops in U.S. subways.

The guideways could be designed to carry private automobiles as well as the public-transit cars, so that a driver coming into the city could mount the guideway at a station and ride swiftly to a downtown destination. Transport of the automobile by the guideway could be arranged either by providing flatbed vehicles that carried ordinary automobiles "piggyback" or by building into automobiles special equipment that enabled them to be conveyed by the guideway itself. The dual-mode use of guideways—by automobiles as well as by passengers in the small public vehicles—could make it financially feasible to extend the guideway system to outlying districts of a metropolitan area.

In some of our models of transportation systems incorporating new technology we also postulated entirely new automobiles designed from scratch for maximum safety and minimum air pollution. Such steam-engine automobiles are a feasible alternative to vehicles that could be combined with a personal-transit system. In contrast to gradualistic improvements, such as the padded dashboard or the smog-control device added to an internal-combustion engine, all-new automobiles would dramatically reduce accident casualties and fatalities and essentially eliminate air pollution. On the other hand, these cars would not help to defray the cost of personal-transit facilities nor would they automate any part of the burdensome task of driving.

For the suburbs, to transport people between their homes and local guideway stations or ordinary railroad stations, a promising possibility is a system known as "Dial-A-Bus." It would employ small buses (for eight to 20 passengers) and provide door-to-door service at a cost substantially less than that for a taxi. A commuter preparing to go into town would simply dial the bus service and be picked up at his front door in a few minutes to be taken to the nearest rapid-transit station. As calls for the bus service came in, a computer would continuously optimize the routes of the buses in transit for speedy responses to the developing demand. The computer technology to make such a system work is already developed, and the system could be tried out on a large scale immediately in connection with present suburban railroads. The Dial-A-Bus system would be most effective, however, in conjunction with a guideway network for personal transit.

For short-distance travel in the dense central areas of cities something is needed that would be faster than buses and cheaper than taxis. One classic proposal is the moving sidewalk. Unless someone can think of a better way of getting on and off than any yet proposed, however, the moving-sidewalk idea would work only for those who are content to travel at about two miles per hour or for people with a certain amount of athletic agility. A small-scale version of the personal-transit guideway looks like a more practical solution to the problem. The tracks for this system would stand above street level, to avoid interference with other traffic. The passenger would enter a personal "capsule" (which might hold one or two people) at a siding, dial his destination and travel to it at a speed of about 15 miles per hour. Such a system could be very compact and quiet.

Engineers generally agree that these innovations, specifically the personal-transit and personal-capsule systems, are already within the realm of feasibility. There are problems of safety and reliability to be solved, and decisions have to be made as to the best methods for propulsion, suspension and control. There is little doubt, however, that a system based on the innovations here described could be operating within a few years.

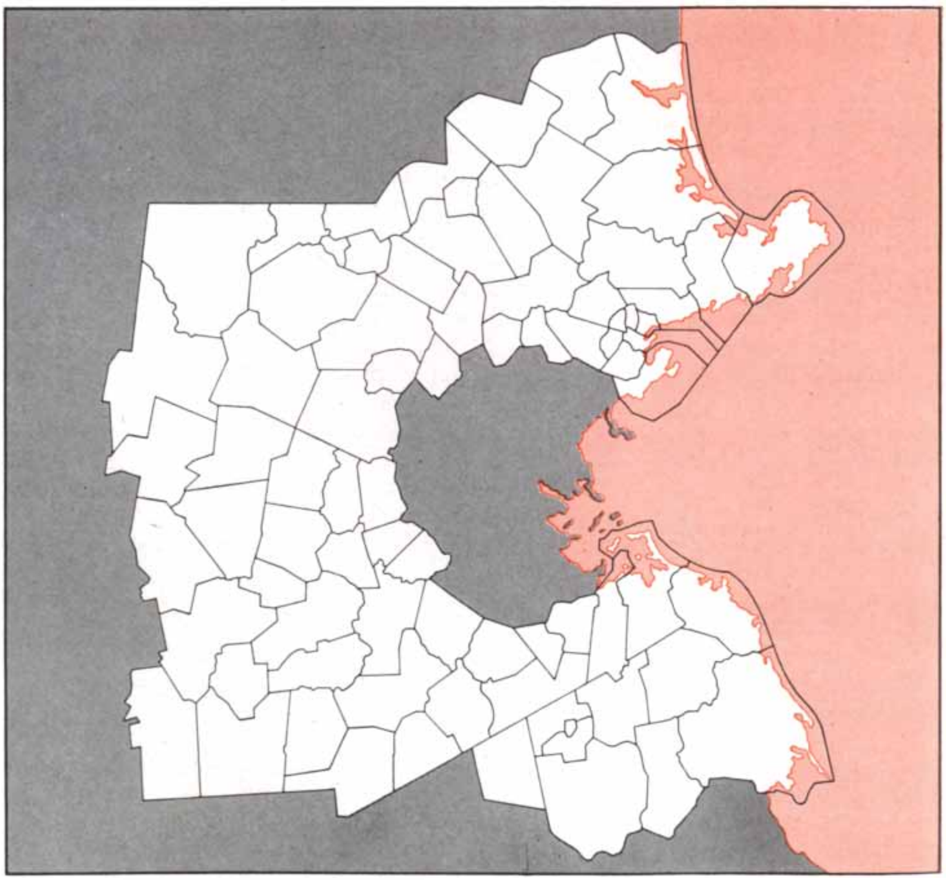
The big question is not whether such a system *could* be built but whether it *should*. The new system would take several years to develop, and there can be no guaranty that it would live up to its promise when it was completed. Meanwhile cities are hard-pressed for immediate relief from their transportation crisis. Would it not be wiser to adopt the gradualistic approach, to invest in improved buses, in better scheduling and perhaps in rapid-transit networks, than to invest millions of dollars in an untried system that in any case could not bring any help to our cities until years hence? This was the major question our computer tests of the various alternatives sought to answer. Our systems analysis attempted to compare the alternatives as fairly as possible in terms of the measurable costs and benefits—social as well as financial.

The heart of our model was a network representing a city's transportation. Network-flow analysis is an outgrowth of the mathematical theory of graphs. In the abstract, the question it deals with is this: Given a set of "nodes" (points) connected by a set of "arcs" (lines), with a specified cost associated with each arc, how can each shipment from node to node be routed at minimum cost, taking into account all other shipments? In our network each node represented a district, or "zone," in the city under study (for precision the node was defined as the center of population in the district) and each arc represented the capacity of the collection of streets that carried traffic from one node to the next. Besides the city streets we added separate arcs to represent expressways, rail lines, bus routes and walking and waiting for a conveyance, all of which had to be taken into account in order to calculate the minimum cost of travel from one node to another. Our basic measure of "cost" was the time required to traverse an arc, which depends not only on the length of the arc but also on how many other users are on the arc at the same time. We assumed, as could reasonably be done, that people usually take the fastest route (not necessarily the shortest in distance) between points.

A city's transportation system involves thousands of places to go, dozens of ways to get there and thousands of possible choices by an individual. As powerful as a large computer is, it can handle only so many calculations an hour. For our program the computer was limited to dealing with a maximum of 200 zones, 1,500 nodes and 5,000 arcs. Hence we had to divide each of our model cities into no more than 200 zones. We varied the zones in size from just a few blocks in the dense central city to substantially larger sections in areas away from the center. The criterion for zone size was that travel within a zone be negligible compared with travel among zones. We also had to make certain other simplifications.

The most crucial simplification had to do with the expected behavior of individuals in choosing their routes and means of travel. For a precise prediction of the traffic flows from zone to zone in the network we would have needed answers to a number of specific questions. Would a given resident going downtown take the bus, drive his car or have his wife drive him to the subway? How far would a $5,000-a-year male worker living in Zone 27 in Boston walk on an average winter day to save a 25-cent fare? How heavy would the traffic have to get before a person contemplating a nonessential trip decided not to go at all? If we had had detailed information such as this, we could have computed who went how by routing each person in the way that cost him the least in time, money and trouble—or, as economists say, "minimized the disutility to him."

Lacking sufficiently detailed data on such questions, we developed a general basis for predicting behavior that turned out to be reasonably reliable. First, we applied a simple formula, which had



TRAFFIC-ZONE BREAKDOWN of the Boston area formed the basis of a model (*see illustration on page 24*). Boston represents a typical example of a large city strongly oriented to

been developed by the Traffic Research Corporation and had been found valid in traffic studies in several cities, to determine what proportion of the people in any given home zone would choose public over private transportation. (The formula computes this "modal split" on the basis of the average family income in the home zone, the relative amounts of time needed to reach a target zone by the two transportation methods and the relative "nuisance time" spent in walking and waiting.) Second, we assumed that within either of the two modes, public or private, each traveler will simply choose the route that minimizes his total travel time.

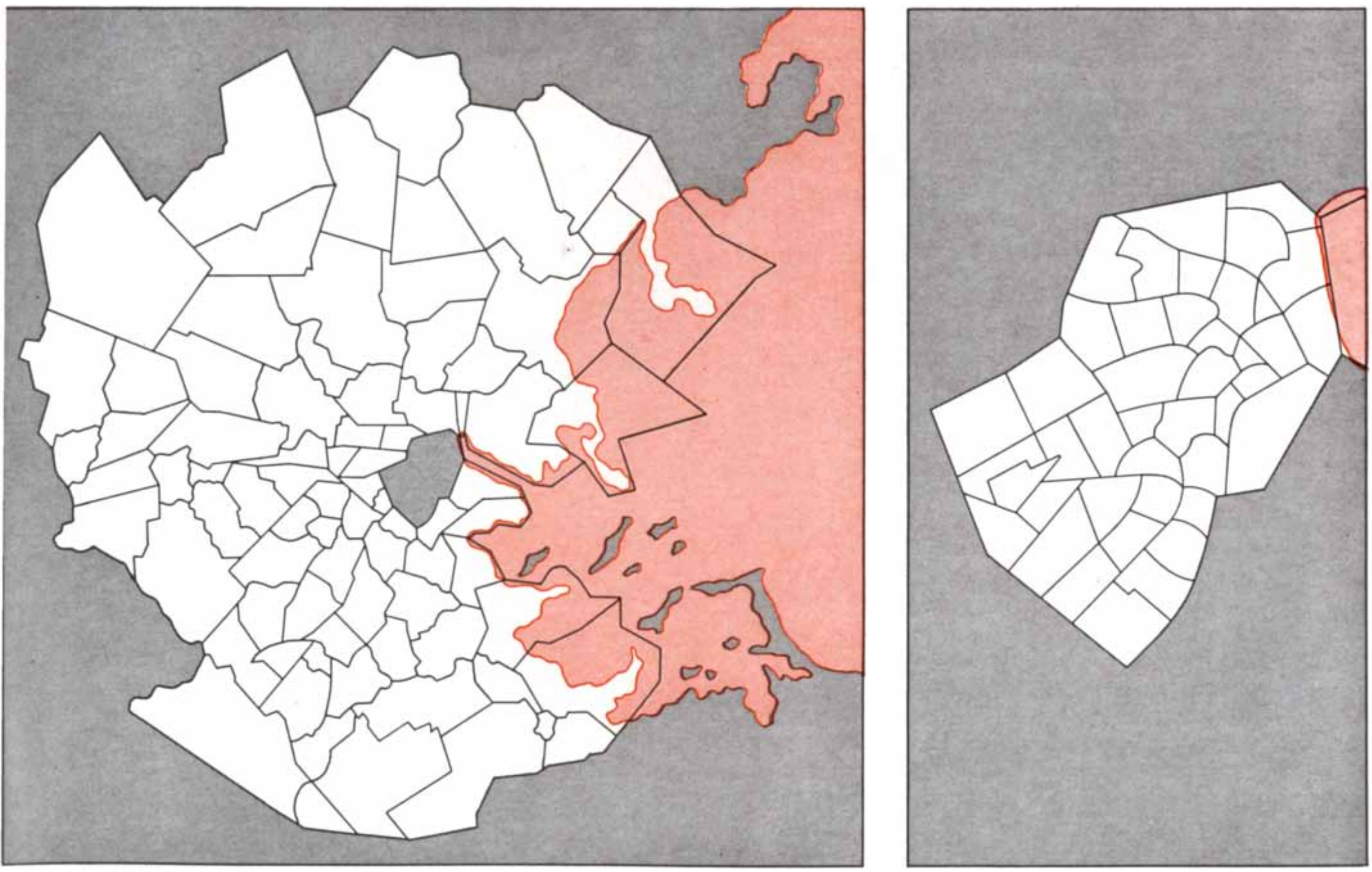
After thus working out a program for computing the expected zone-to-zone traffic flows in a city network under given conditions, we fed our data for each city into the computer to calculate the flow in the network with given demand for travel. The procedure was "iterative," employing a series of trials to arrive at the final allocation of flows. The program first calculated what the travel time for each arc would be if there were no congestion. Then it considered the destination zones one at a time and calculated the quickest route to each destination from all the other zones. Next it introduced, for each route, the complicating factor of the relative numbers of travelers who would use the public mode and the private mode respectively. When this had been done for all the arcs, the program went back to the beginning and recomputed the travel times on the basis of the traffic flows indicated by the foregoing trials. It took about five such iterations to produce a stable picture of traffic flow that did not change in further trials.

For a quantitative assessment of what benefits could be brought about by improvements of the system, we modeled not only the existing modes of transportation but also various possible future systems with entirely different flow characteristics. The program included a number of subroutines that measured the costs and benefits of each system, in social terms as well as in terms of travel speed and money. Among the factors we introduced into the calculation were air pollution, the intrusion of automobiles into the city, the accessibility of key areas and the mobility of ghetto residents. Thus the transportation system judged to be "best" was not necessarily the one that was simply the cheapest or the fastest.

Obviously no model or program is worth much if it overlooks crucial factors or if its key assumptions are wrong. How much confidence could we place in the general model we finally developed? Fortunately it passed every validation test we could apply.

In the first place, as the work proceeded we took a skeptical view of the model's basic assumptions, trying out different assumptions to see how they would affect the results and encouraging each expert to criticize the others' work. We had some lively conferences and threw away a lot of computer printouts before we settled on a model we felt we could trust.

As it happened, the representation of traffic flow that we developed on the basis of our experience in studying quite different systems turned out to be very similar to flow models that had been devised by transportation engineers for use in traffic planning. Since we had had no prior knowledge of the traffic engineers' ideas, the fact that we had arrived



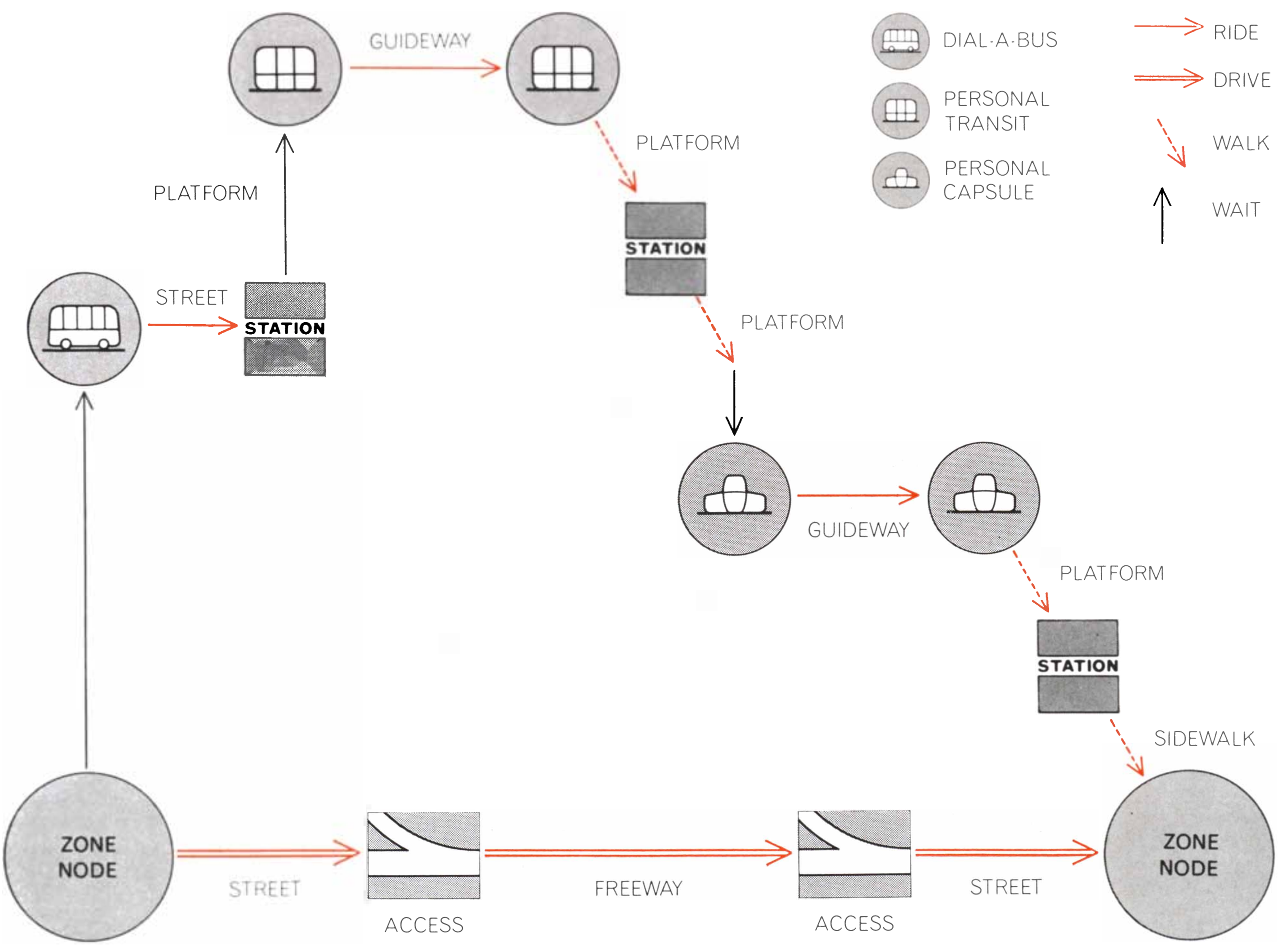
public transit. The size of a zone varies with population density and relative contribution to total traffic. In the dense core of the city (*right*) a zone often comprises only a few blocks. The total number of zones (200) represent an area of 2,300 square miles.

at much the same method of predicting traffic flow gave us considerable confidence that we were on the right track. Furthermore, we found that our network-flow program reproduced a faithful picture of the known flow in specific situations. As we have mentioned, each of the four cities we modeled had recently undergone a detailed traffic survey. These studies had recorded the average speed of traffic movement on the major streets, the numbers of people using public-transit facilities, the times for various trips in the city and so forth. To test the prediction ability of our network-flow program, we fed into the program the characteristics of the city's population and transportation network as of the time of the survey and let the program route the flow according to its own rules. In each case the results in the computer print-out corresponded so closely to the actual flow pattern as the direct, on-the-spot survey had described it that we were satisfied our model could do a realistic job of representing a city's traffic flows.

Further validation of the general usefulness of our model emerged when we came to testing the alternative approaches for dealing with the urban transportation problem. In all four of our model cities the results of the analysis pointed to the same major conclusion: the best hope of meeting the cities' future needs lies in developing new transportation systems rather than in merely improving or adding to present systems.

A summary of our tests of various systems in Boston will serve to illustrate our findings. The story begins with the situation in 1963 [*see illustration on page 26*]. In that year the average door-to-door speed of public-transit travelers in the peak hours was nine miles per hour; the average automobile traveler's speed in the city was 16.4 miles per hour; 32 percent of the people used public transit at peak hours, and the downtown streets were heavily burdened with automobile traffic. We next projected what the situation would be by 1975 if there were no change in the transportation facilities and traffic reached the level predicted by the Boston Regional Planning Project. Our calculations showed that public-transit travel would slow to 7.8 miles per hour and automobile travel to 15.7 miles per hour; the use of public transit would fall to 23 percent, and the intrusive concentration of automobile traffic downtown would rise by more than 15 percent. (One disastrous day in 1963 automobile traffic in downtown Boston reached a level of congestion that stopped all movement for several hours.)

We then proceeded to consider the effects of improvements in the transportation network. Addition of the costly freeways and extensions of rapid transit

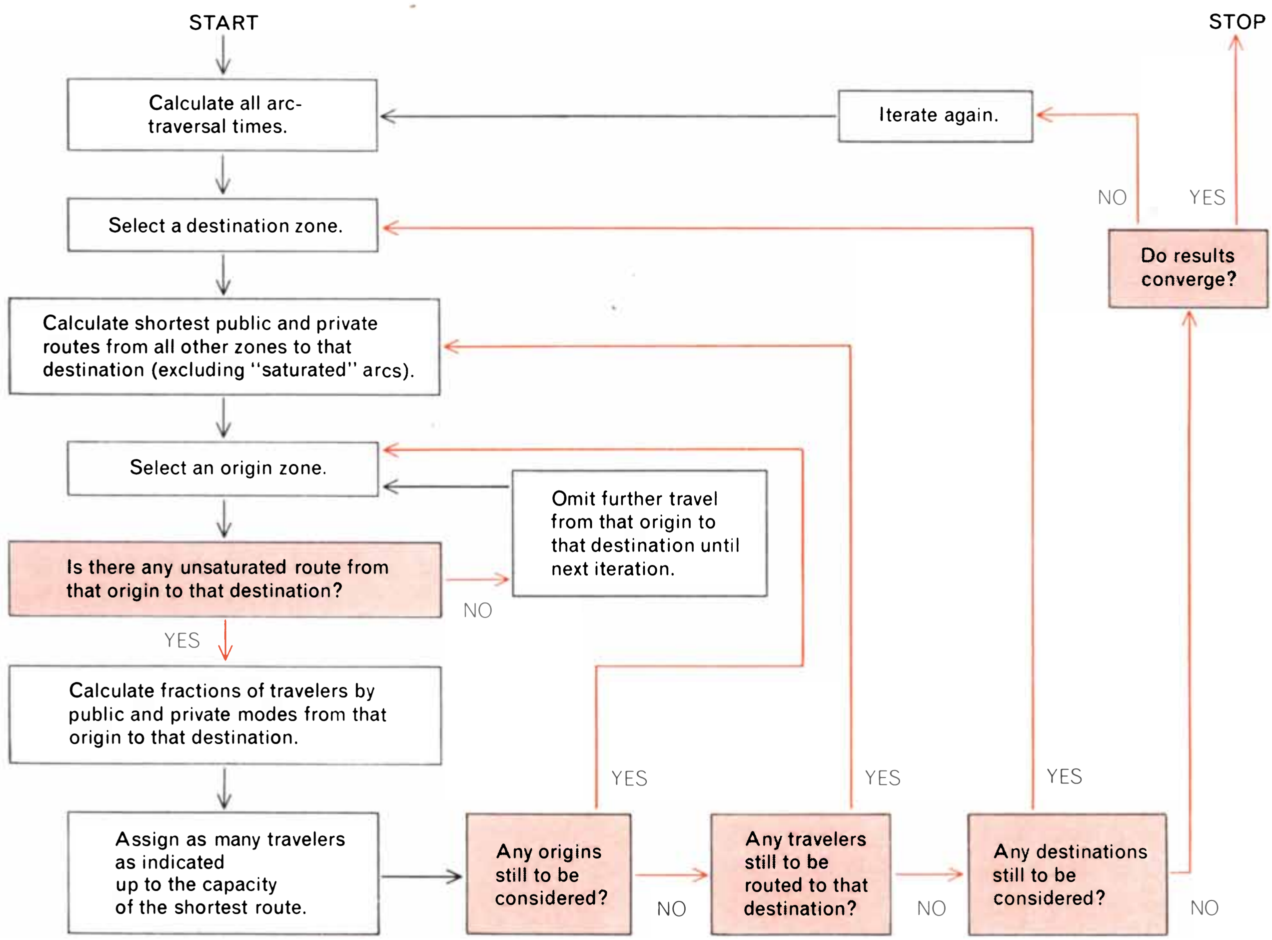


NETWORK simulates a city's transportation in terms of nodes (points) and arcs (lines). A zone node represents the center of population of a traffic zone and the point at which any trip begins or ends. Other nodes represent transfer points. Here two trips are represented in diagrammatic form, both beginning at the zone node at left and ending at the zone node at right. One trip utilizes transport by "Dial-A-Bus" (a hypothetical door-to-door system where the bus is routed by telephone calls of prospective passengers), personal transit and personal capsule, a version of the personal-transit guideway that could serve a central urban area, traveling at a speed of about 15 miles per hour. The second trip is by automobile. The parking and walking time at the end of this trip are not indicated. The relative lengths of the lines are not significant. Boston's transportation was modeled in terms of network flow.

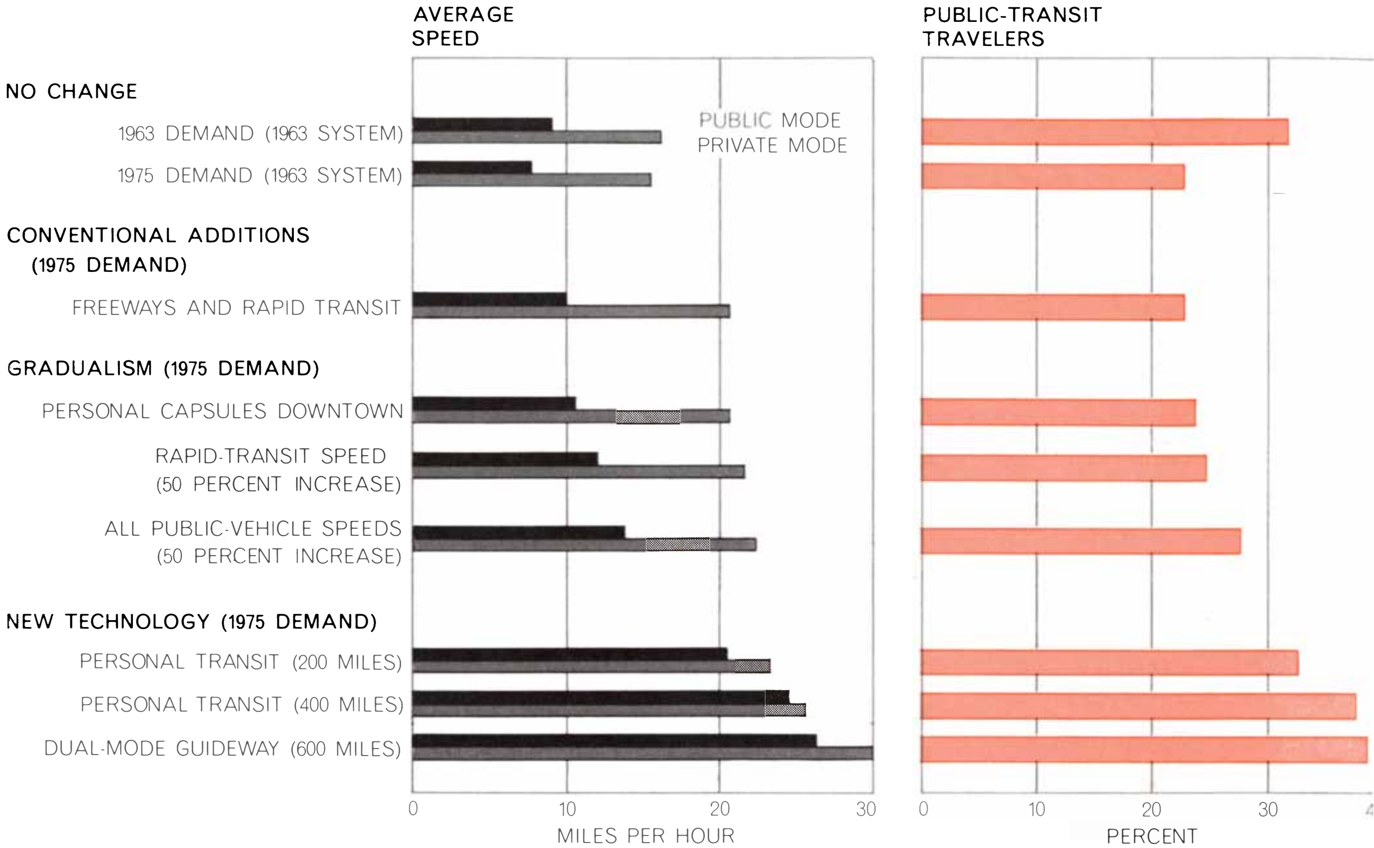
that metropolitan Boston planned to build by 1975, it turned out, would bring about some improvement in speed over 1963 (to 10 miles per hour for public transit and 20.7 miles per hour for private automobiles) and somewhat reduce the crush of automobile traffic in the downtown streets. Replacement of buses by personal capsules for short-distance travel downtown would produce modest additional improvements, at a small net reduction in transit cost. In order to see what effects might result if public transit were considerably speeded up by improvements in the conventional system, we fed into the program an arbitrary assumption of a 50 percent rise in speed (disregarding the cost). On this assumption (which represents the maximum speedup that is likely to be attained on the basis of any current proposal) we found that automobile travel also would speed up substantially, because more people would be drawn to public transportation and congestion on the freeways and in the streets would be relieved. The percentage increase in the use of public transit was only moderate, however, which suggests that an investment in speeding up conventional public facilities will not pay for itself unless it can be done very cheaply.

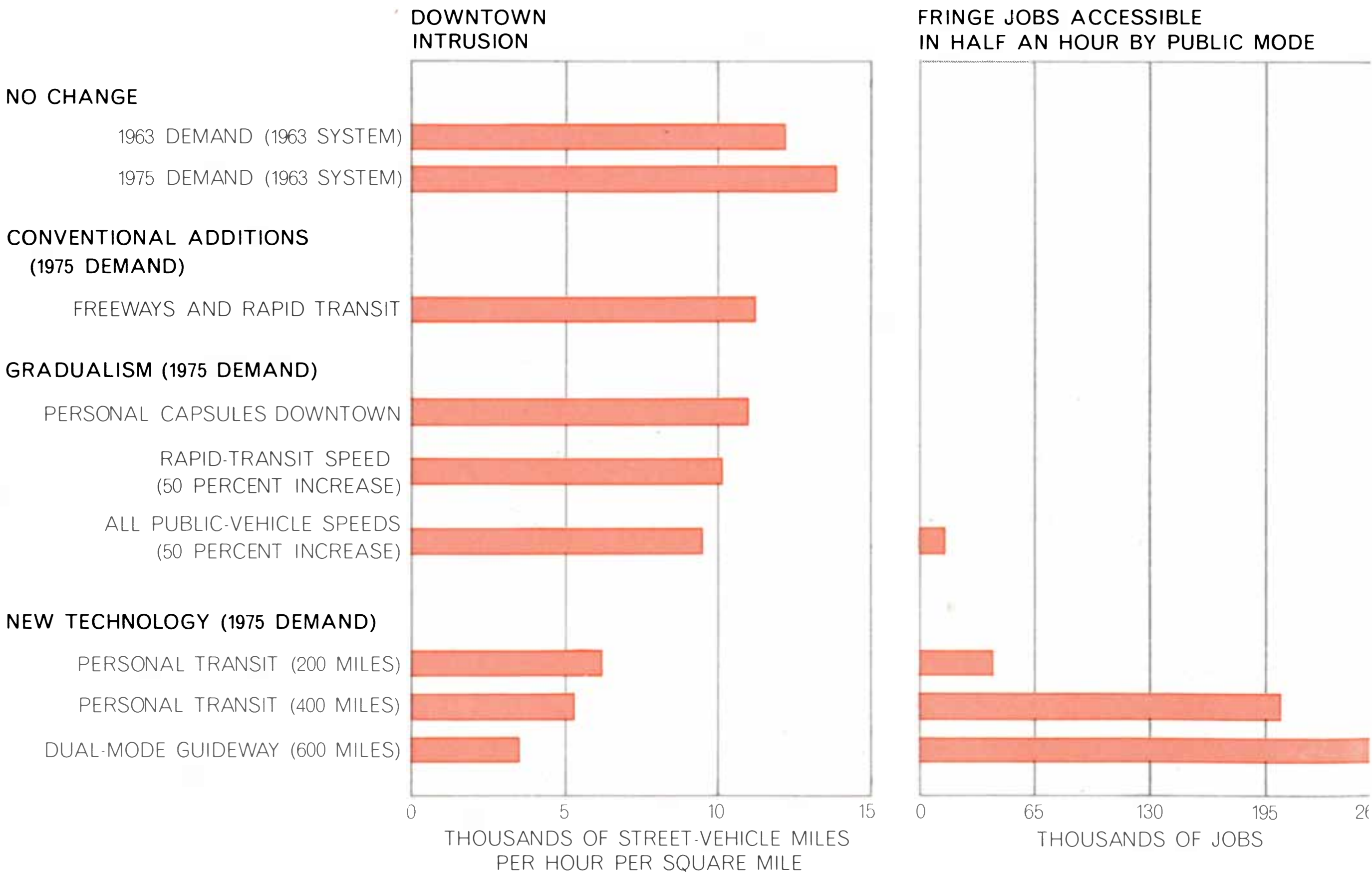
When we came to testing systems incorporating a network of personal transit by means of guideways, we saw really striking improvements in service. Speeds took a jump, particularly in the public mode, and more riders were attracted to public transportation. Had our calculations taken into account the comfort and privacy that personal transit offers in relation to conventional transit, the fraction of public-mode travelers would doubtless have been considerably higher. Furthermore, the introduction of a guideway network reduced the intrusion of vehicles and congestion in the downtown streets to less than half the 1963 level. Installation of a 400-mile network for personal transit in the Boston area would speed up travel to an average of 24.6 miles per hour in public facilities and 25.7 miles per hour in private automobiles, and 38 percent of the city's travelers (in 1975) would use public transit. If the network were extended to 600 miles and provided for the transport of automobiles as well as transit cars on the guideways, the average speeds of travel and the use of public transit would increase still further.

More important than these gains is the great improvement a personal-transit system would provide in mobility for the transportation poor or disadvantaged populations in the city. The 400-mile network we postulated for 1975 would make some 204,000 jobs in outlying areas of the metropolis accessible within half an hour's travel to people living in the city center; at present these



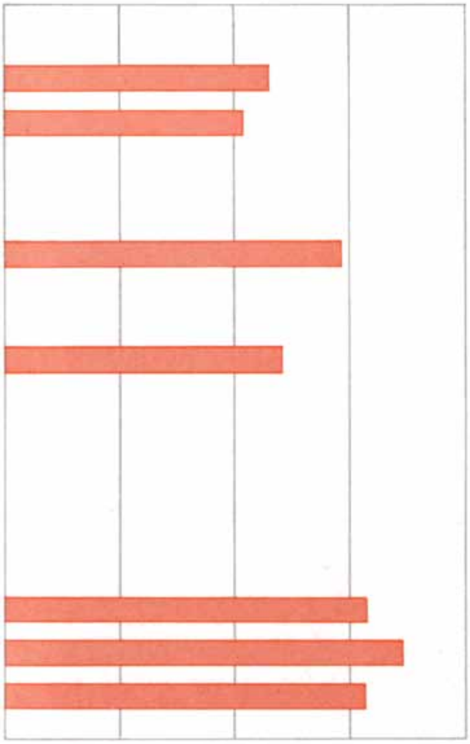
CALCULATION OF NETWORK PERFORMANCE utilized a computer program that employs a series of trials, or iterations, to compute the flow in the network. The program first calculates what the travel time for each arc would be if there were no traffic congestion. After the quickest route to each zone from all the others is calculated, the program introduces, for each route, the complicating factor of "modal split," namely the proportion of people traveling by public mode. If these numbers cannot be handled within the capacities of the shortest routes, the program goes back and computes the next-shortest routes. After the first iteration the program computes travel times as they are influenced by the flow assigned on earlier iterations. The exclusion of "saturated" arcs is an artifice to keep all the flow from following a few routes on early iterations. It speeds the convergence of the iteration process.



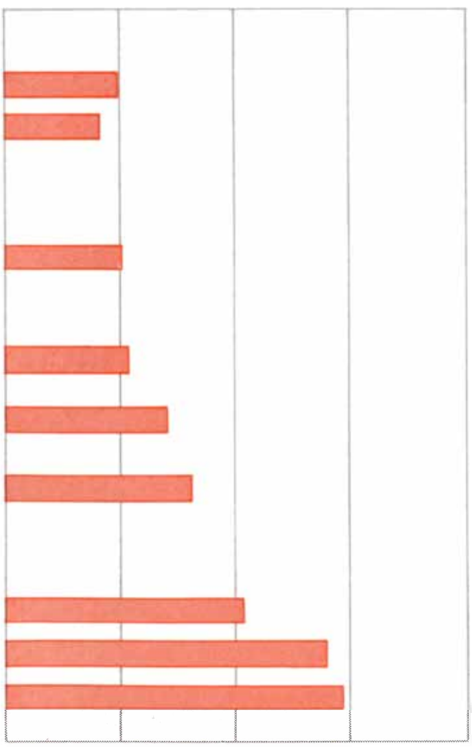


PERFORMANCE MEASURES from the authors' cost-benefit summary show how different transportation systems behaved in the case of the Boston model. All figures except public-mode cost refer to travel at a peak hour. In the full cost-benefit summary there

PUBLIC-MODE COST



DOWNTOWN ACCESS IN HALF AN HOUR BY PUBLIC MODE



were 229 performance measures. The term "downtown intrusion" refers to automobiles.

job areas are beyond that range of accessibility. The system would also make the downtown area, the airport, universities and hospitals quickly accessible even in peak hours to millions of people in the suburbs. Our full "cost-benefit" survey of the system indicated other benefits such as reductions of traffic accidents and air pollution.

In general, the results of our analysis made clear that, even with the most optimistic view of what might be achieved through improvement of the existing methods of transportation, such improvement could not satisfy the real needs of our cities in terms of service. Automobiles, even if totally redesigned for safety and smog-free steam propulsion, have the irremediable drawbacks that they must be driven by the user and are unavailable to a substantial percentage of the population. Buses and trains, however fast, comfortable and well scheduled, are unavoidably limited in average speed by the necessity of making frequent stops along the line to let riders on or off. All in all, our study suggested strongly that the course of gradualism is not enough: at best it is merely an expensive palliative for the transportation ailments of the cities.

On the other hand, our tests of the new-technology approach, particularly the personal-transit type of system, showed that it could provide really dramatic improvements in service. The personal-transit system would offer city dwellers a degree of convenience that is not now available even to those who drive their own cars. The city and its suburbs could be linked together in a way that would bring new freedoms and amenities to urban living—for the ghetto dweller now trapped in the city's deteriorating core as well as for the automobile-enslaved suburban housewife.

One must take account of the probability that drastic alteration of a city's transportation will bring about changes in the structural pattern of the city itself. We tested certain structural variations, such as concentration of the city population in a few dense nuclei, and found that the personal-transit system still offered striking advantages.

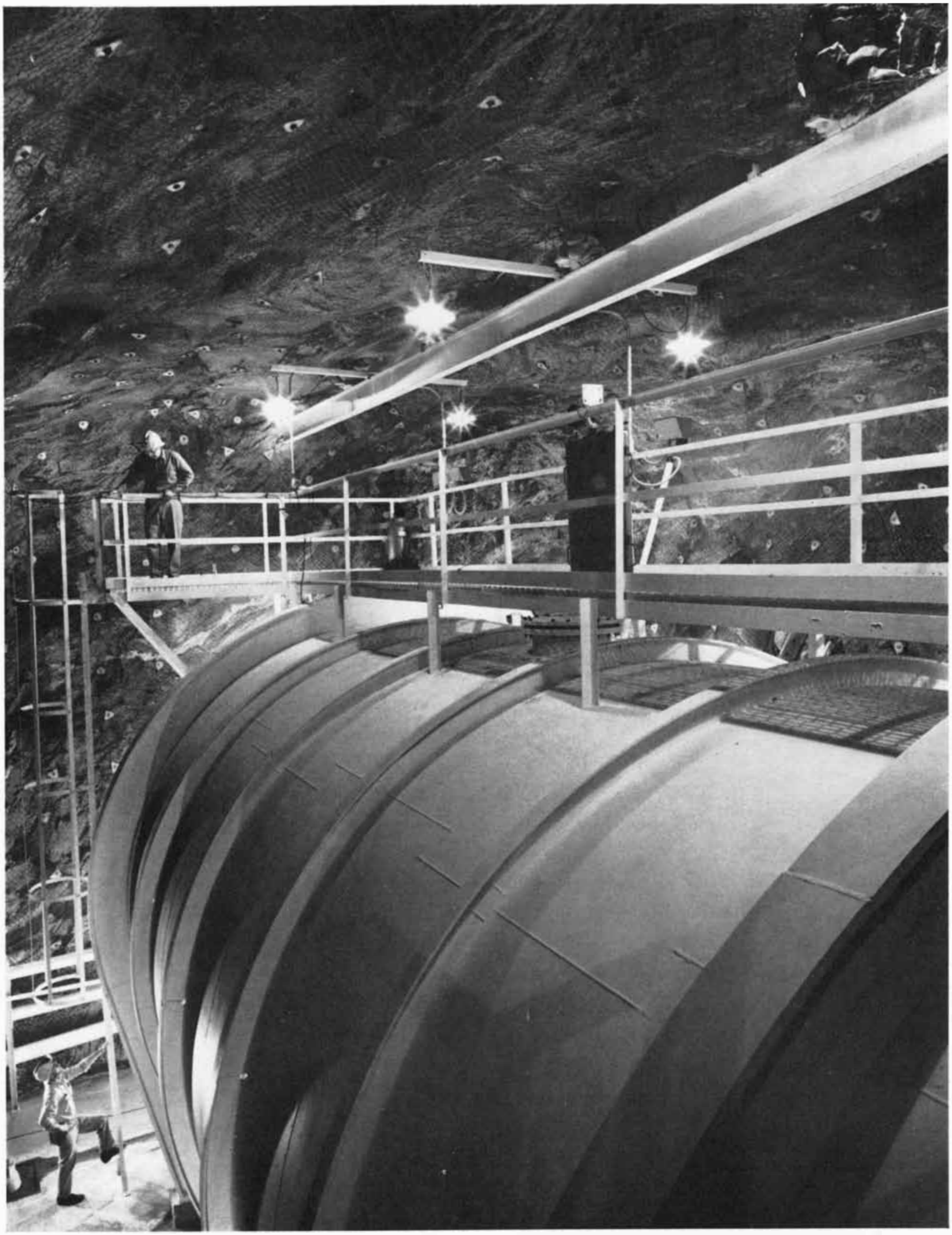
How would a personal-transit system compare with improvement of the existing system in the matter of financial cost? In Boston the cost of building and operating a personal-transit system would be somewhat more expensive per passenger-mile than a conventional rapid transit even if the city built an entirely new subway system from scratch. Remember, however, that we are talking about a personal-transit network of 400 miles, whereas Boston's rail system with its planned extensions by 1975 will consist of only 62 route-miles. Nevertheless, Boston and other cities that already have rather extensive rail rapid-transit systems may well think twice before scrapping the existing system to replace it with personal transit, even though personal transit offers benefits that rail rapid transit cannot approach.

For most of our large cities, now lacking rapid transit, personal transit looks like a much better bet than a subway. In automobile-oriented Houston, for example, personal transit in our calculations came out far cheaper than rail rapid transit, as well as far more effective. In such a city personal transit is clearly a best buy.

For smaller cities such as Tucson or New Haven personal transit looks less attractive. Because of their limited extent and lower density of population (and consequently smaller use of the system) the cost of personal transit per passenger-mile would be about three times the cost for a large city. It appears that a personal-transit system (as well as rail rapid transit, for that matter) would be too costly for cities with a population of less than half a million. Such cities, however, do not have to contend with the congestion that is overwhelming large cities.

To sum up, the installation of a personal-transit system, perhaps serviced by Dial-A-Bus feeders (the performance of such vehicles is not yet predictable), and designed from the start for eventual expansion to dual-mode service, seems well worth considering for the immediate future of many U.S. cities. We estimate that a personal-transit system could be developed and tested on a fairly large scale within five years at a cost of about $100 million. Compared with the cost of any sizable subway this development cost is insignificant. (A rail rapid-transit system recently proposed for Los Angeles, and rejected by the voters, would have cost about $2.5 billion.)

On the basis of the reports HUD has received from the groups it commissioned to study the urban transportation problem the department has submitted a number of recommendations to Congress, giving prominence to the proposed systems for personal transit, dual-mode transit and Dial-A-Bus. If the funds for development of these systems were made available immediately, the systems could be ready for installation in cities five years hence. Our study has convinced us that no time should be lost in proceeding with these developments.



NEUTRINO TRAP is a tank filled with 100,000 gallons of a common cleaning fluid, tetrachloroethylene. It is located in a rock cavity 4,850 feet below the surface in the Homestake Mine in the town of Lead, S.D. The experiment is being run by Raymond Davis, Jr., Kenneth C. Hoffman and Don S. Harmer of Brookhaven National Laboratory. Suggested in 1964 by Davis and the author, the experiment was begun last year. The first results showed that the sun's output of neutrinos from the isotope boron 8 was less than expected.

NEUTRINOS FROM THE SUN

A giant trap has been set deep underground to catch a few of the neutrinos that theory predicts should be pouring out of the sun. Their capture would prove that the sun runs on thermonuclear power

by John N. Bahcall

Most physicists and astronomers believe that the sun's heat is produced by thermonuclear reactions that fuse light elements into heavier ones, thereby converting mass into energy. To demonstrate the truth of this hypothesis, however, is still not easy, nearly 50 years after it was suggested by Sir Arthur Eddington. The difficulty is that the sun's thermonuclear furnace is deep in the interior, where it is hidden by an enormous mass of cooler material. Hence conventional astronomical instruments, even when placed in orbit above the earth, can do no more than record the particles, chiefly photons, emitted by the outermost layers of the sun.

Of the particles released by the hypothetical thermonuclear reactions in the solar interior, only one species has the ability to penetrate from the center of the sun to the surface (a distance of some 400,000 miles) and escape into space: the neutrino. This massless particle, which travels with the speed of light, is so unreactive that only one in every 100 billion created in the solar furnace is stopped or deflected on its flight to the sun's surface. Thus neutrinos offer us the possibility of "seeing" into the solar interior because they alone escape directly into space. About 3 percent of the total energy radiated by the sun is in the form of neutrinos. The flux of solar neutrinos at the earth's surface is on the order of 10^{11} per square centimeter per second. Unfortunately the fact that neutrinos escape so easily from the sun implies that they are difficult to capture.

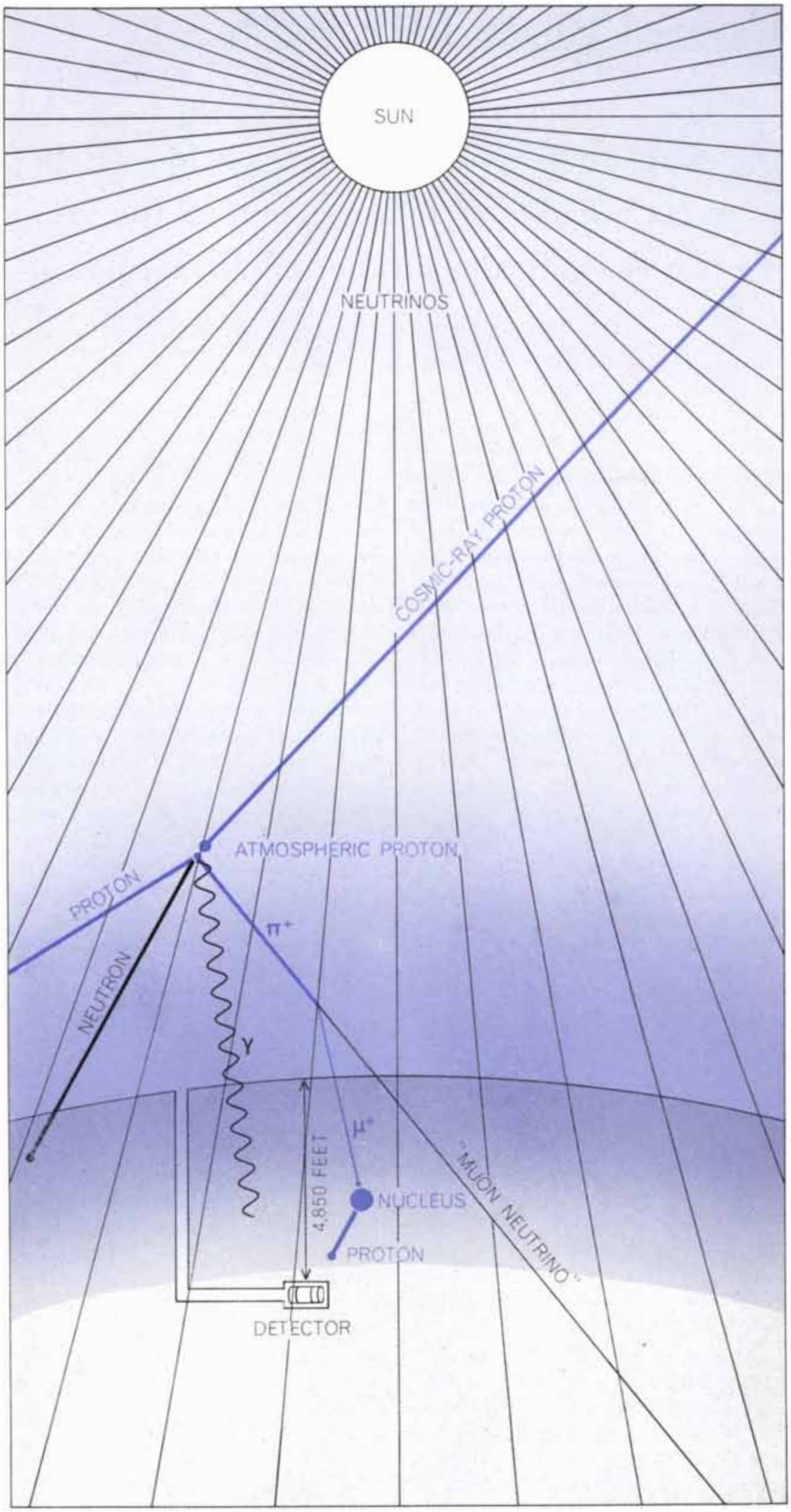
Nevertheless, within the past year a giant neutrino trap has begun operating in a rock cavity deep below the surface in the Homestake Mine in Lead, S.D. The neutrino trap is a tank filled with 100,000 gallons of tetrachloroethylene (C_2Cl_4), an ordinary cleaning fluid. The experiment is being conducted by Raymond Davis, Jr., of the Brookhaven National Laboratory, with the assistance of Kenneth C. Hoffman and Don S. Harmer. In 1964 Davis and I showed that such an experimental test of the hypothesis of nuclear burning in stars was feasible. The idea was strongly supported by, among others, William A. Fowler of the California Institute of Technology, Richard W. Dodson, chairman of the Brookhaven chemistry department, and Maurice Goldhaber, the director of Brookhaven. Subsequently the Homestake Mining Company contributed valuable technical help.

The initial results published by Davis and his co-workers have left astronomers and astrophysicists somewhat puzzled because the neutrino flux rate seems low. It is less than half the theoretical value one obtains by assuming certain "standard" values for quantities used in constructing theoretical models of the solar interior. I shall discuss the range of theoretical predictions later. The important initial fact is that one can now use the results of the experiment to improve our knowledge of the sun's thermonuclear furnace.

Neutrinos were first suggested as hypothetical entities in 1931 after it was noted that small amounts of mass seemingly vanish in the radioactive decay of certain nuclei. Wolfgang Pauli suggested that the mass was spirited away in the form of energy by massless particles, for which Enrico Fermi proposed the name neutrino ("little neutral one"). Fermi also provided a quantitative theory of processes involving neutrinos. In 1956 Frederick Reines and Clyde L. Cowan, Jr., succeeded in detecting neutrinos by installing an elaborate apparatus near a large nuclear reactor. Such a reactor emits a prodigious flux of antineutrinos produced by the radioactive decay of fission products. For purposes of demonstrating a particle's existence, of course, an antiparticle is as good as a particle.

In the late 1930's Hans A. Bethe of Cornell University followed up Eddington's 1920 suggestion of the nuclear origin of the sun's energy and outlined how the fusion of atomic nuclei might enable the sun and other stars to shine for the billions of years required by the age of meteorites and terrestrial rocks. Since the 1930's the birth, evolution and death of stars have been widely studied. It is generally assumed that the original main constituent of the universe was hydrogen. Under certain conditions hydrogen atoms presumably assemble into clouds, or protostars, dense enough to contract by their own gravitational force. The contraction continues until the pressure and temperature at the center of the protostar ignite thermonuclear reactions in which hydrogen nuclei combine to form helium nuclei. After most of the hydrogen has been consumed, the star contracts again gravitationally until its center becomes hot enough to fuse helium nuclei into still heavier elements. The process of fuel exhaustion and contraction continues through a number of cycles.

The sun is thought to be in the first stage of nuclear burning. In this stage four hydrogen nuclei (protons) are fused to create a helium nucleus, consisting of two protons and two neutrons. In the process two positive charges (originally carried by two of the four protons) emerge as two positive electrons (antiparticles of the familiar electron). The



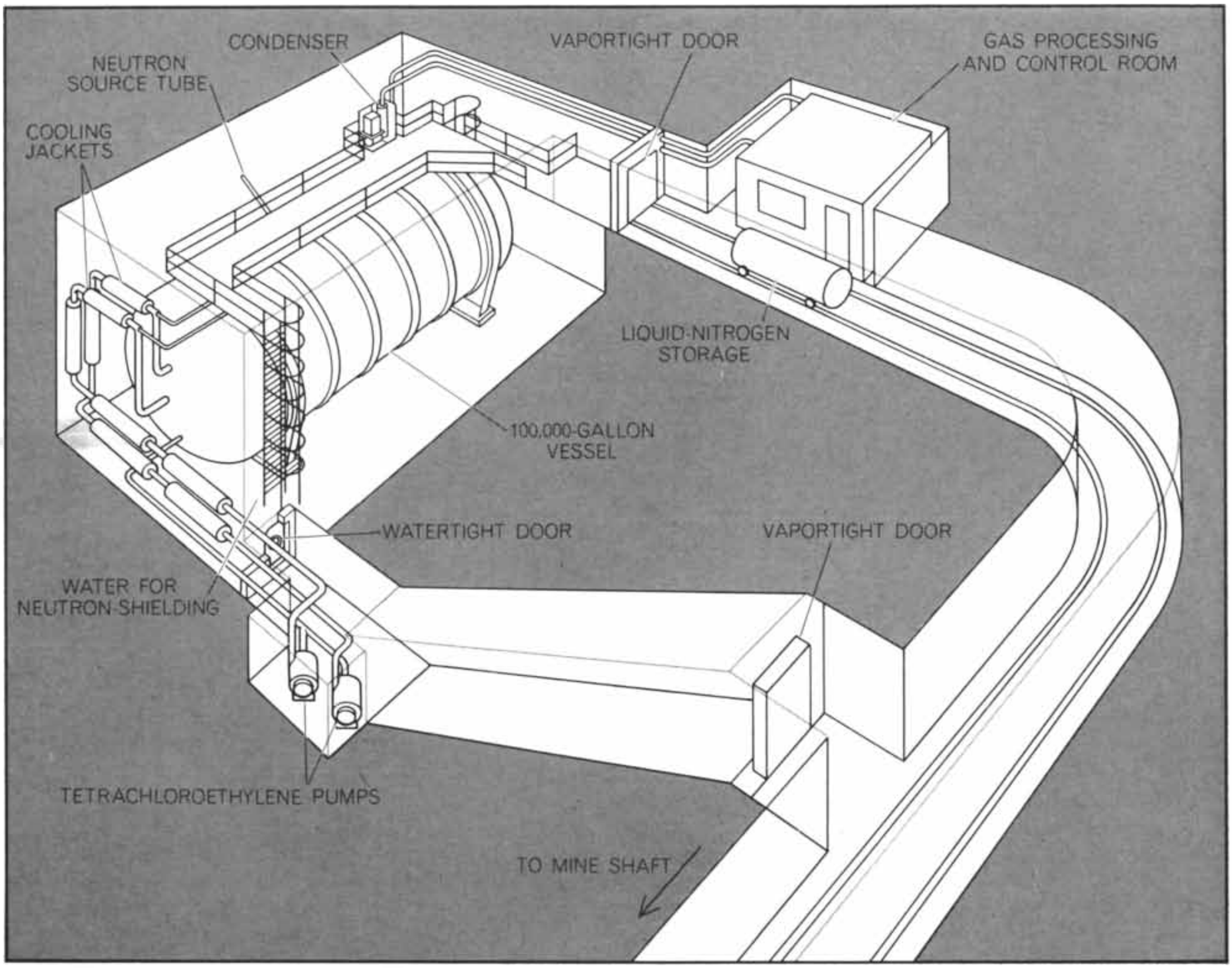
DEEP-MINE LOCATION shields the solar-neutrino detector from the intense flux of energetic particles produced when cosmic ray protons collide with atomic nuclei in the atmosphere or in the solid earth. Here a positive pion (π^+) generated in an atmospheric collision decays into a positive muon (μ^+) and a "muon neutrino." High-energy muons are very penetrating and can knock protons out of atomic nuclei well below the earth's surface. If such a proton entered the neutrino detector, it could mimic the entry of a solar neutrino by converting an atom of chlorine 37 (^{37}Cl) into an atom of radioactive argon 37 (^{37}Ar).

fusion also releases two neutrinos and some excess energy, about 25 million electron volts (MeV). This energy corresponds to the amount of mass lost in the overall reaction, which is to say that a helium nucleus and two electrons weigh slightly less than four protons. The 25 MeV of energy so released appears as energy of motion in the gas of the solar furnace and as photons (particles of radiant energy). This energy ultimately diffuses to the surface of the sun and escapes in the form of sunlight and other radiation.

Bethe and C. F. von Weizsäcker of Germany independently proposed one mechanism for assembling four protons into a helium nucleus. Because it involved nuclei of carbon, nitrogen and oxygen it became known as the CNO cycle [*see illustration on page 33*]. The cycle starts with a nucleus of ordinary carbon, $^{12}_{6}C$. (The symbol specifies a nucleus containing a total of 12 nucleons, of which six are protons and the rest neutrons.) Three protons are added one at a time, culminating in a nitrogen nucleus containing eight neutrons and seven protons ($^{15}_{7}N$). With the addition of another proton a reaction occurs in which two nuclei are produced: $^{12}_{6}C$ (the original nucleus) and $^{4}_{2}He$, which is ordinary helium.

In each cycle two neutrinos are emitted whose maximum energies are greater than 1 MeV. One comes from the radioactive decay of ^{13}N and the other from the decay of ^{15}O. (For simplicity I shall start omitting the subscripts indicating the number of protons in the nucleus.) The rates at which nuclear reactions in the CNO cycle occur in stars have been carefully studied over the past 20 years at the California Institute of Technology in the W. K. Kellogg Radiation Laboratory, first under the leadership of Charles C. Lauritsen and now of Fowler.

An altogether different series of nuclear reactions known as the proton-proton chain, also investigated 30 years ago by Bethe, can accomplish the same fusion of helium from four protons [*see illustration on page 34*]. In the first step of the chain two protons combine to form a deuteron, ^{2}H, the nucleus of heavy hydrogen. The deuteron then combines with a proton to form a light helium nucleus, ^{3}He. The next reaction can go in one of three directions. We estimate that in the sun's interior two nuclei of ^{3}He combine to form an ordinary helium nucleus, ^{4}He, with the release of two protons in about 91 percent of the cases. The other two possible



SOLAR-NEUTRINO DETECTOR is a tank 20 feet in diameter and 48 feet long, holding 100,000 gallons of tetrachloroethylene (C_2Cl_4). On the average each molecule of C_2Cl_4 contains one atom of the desired isotope, $^{37}_{17}Cl$, an atom with 17 protons and 20 neutrons. The other three chlorine atoms contain two less neutrons and are designated $^{35}_{17}Cl$. When a neutrino of the right energy reacts with an atom of $^{37}_{17}Cl$, it produces an atom of $^{37}_{18}Ar$ and an electron. The radioactive argon 37 is allowed to build up for several months, then is removed by purging the tank with helium gas. The argon is adsorbed in a cold trap and assayed for radioactivity.

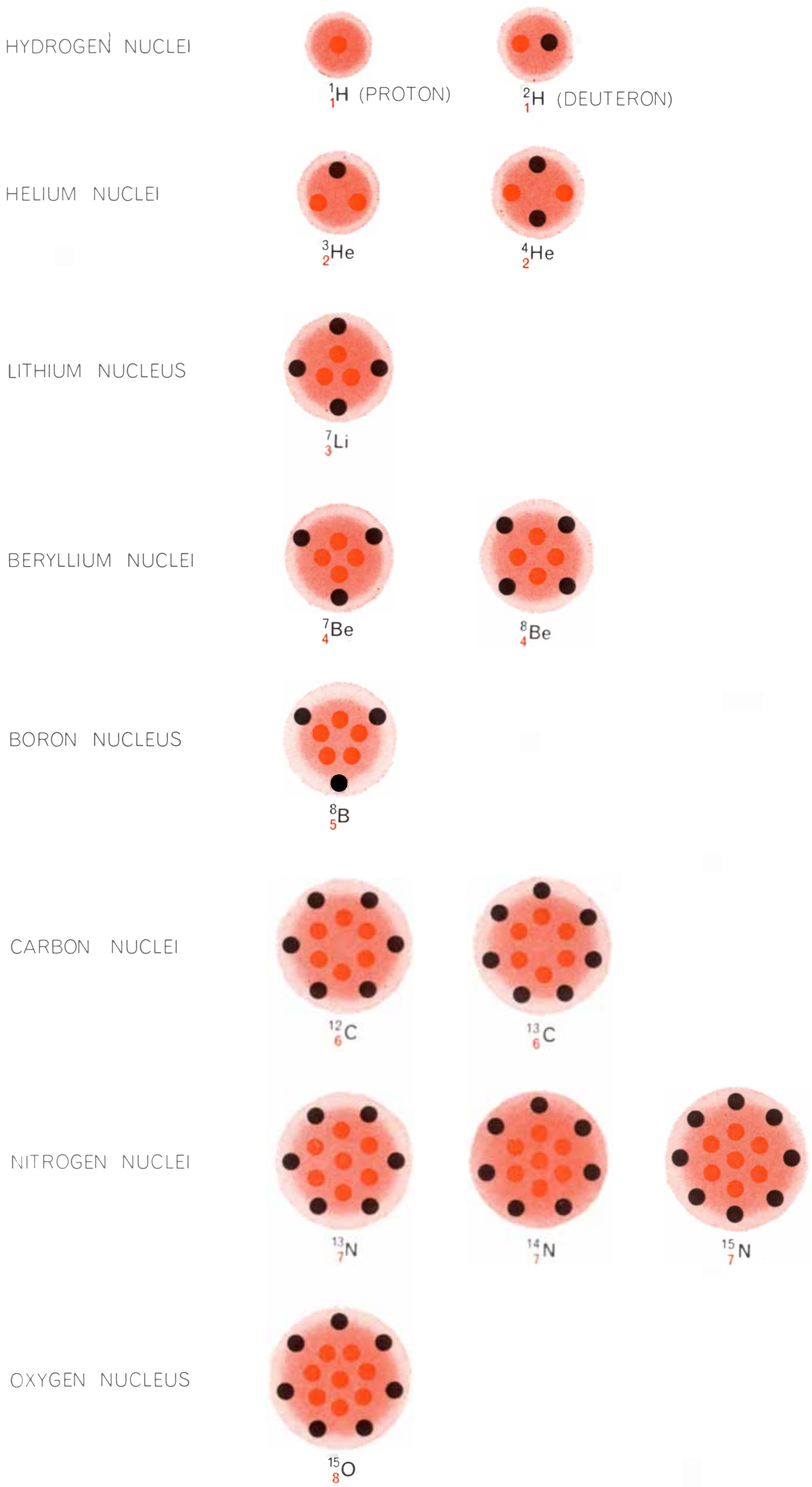
branches, or routes, involve the formation of nuclei of lithium, beryllium and boron (^7Li, ^7Be, ^8Be and ^8B), which give rise eventually to two helium nuclei.

At the time Bethe first investigated the proton-proton chain there was little experimental information on the rates of the relevant nuclear reactions. Since then laboratories all over the world have provided the data for a detailed understanding of the chain and its several branches. At the low energies believed to exist in the solar furnace (a few thousand electron volts) the probability of the occurrence of any given reaction in the proton-proton chain is low and hence difficult to measure. Nevertheless, the experimental group at the Kellogg Laboratory, aided by a succession of able graduate students, has refined the difficult experiments to the point where most of the information necessary for predicting the rates of reactions in the proton-proton chain is now available.

Three of the reactions in the proton-proton chain are of special importance for solar-neutrino experiments. Referring again to the illustration on page 34, these are the basic proton-proton reaction [*Reaction 1*], the proton-electron-proton, or "pep," reaction [2] and the decay of a radioactive isotope of boron, ^8B [*10*]. All produce neutrinos but only the second and third produce neutrinos energetic enough to trigger a reaction in the tetrachloroethylene detector.

The proton-proton reaction is the slowest in the proton-proton chain, and hence it determines the overall rate at which energy is produced. Unfortunately the rate of the reaction is so slow that it cannot be measured in the laboratory; the "weak" force that governs this reaction is the same force that determines the interaction of neutrinos with matter. Over the years the rate of the reaction under stellar conditions has been estimated by a number of theorists. Last year I collaborated with Robert M. May of the University of Sydney in making a new estimate that we believe is accurate to within 5 percent.

The pep reaction differs from the basic proton-proton reaction only in that it has a negative electron present initially rather than a positive electron present after the reaction. Its rate at solar densities and temperatures is even slower than the proton-proton reaction. May and I estimate that the pep reaction occurs 1/400th as often as the proton-proton reaction under solar conditions. The pep neutrinos, which are 3½ times more en-



SOURCES OF SUN'S ENERGY are believed to be the atomic nuclei symbolized here, which may be present either as reactants or as products in the sun's thermonuclear furnace. The basic fuel is ordinary hydrogen, $^1_1$H, whose nucleus consists of a single proton. Four protons can be fused into a helium nucleus, $^4_2$He, by two principal mechanisms, one called the CNO cycle because it involves carbon, nitrogen and oxygen nuclei (*see illustration on opposite page*) and the other known as the proton-proton chain, which involves nuclei of helium, lithium, beryllium and boron (*see illustration on page 34*). Protons are represented by colored dots, neutrons by black dots, arranged in arbitrary patterns. Other particles involved in the reactions are electrons (positive and negative), photons and neutrinos.

ergetic than the most energetic proton-proton neutrinos, should be barely detectable. As we shall see, their capture rate establishes the minimum rate compatible with the hypothesis that the sun has a thermonuclear furnace.

The third reaction of special importance, the decay of radioactive boron, ^{8}B, produces the most energetic neutrinos of all: they have a maximum of 14.06 MeV, or nearly 10 times the maximum energy of the pep neutrinos. The ^{8}B is formed when beryllium, ^{7}Be, adds a proton, a reaction [9] that occurs in a rare branch of the proton-proton chain. This branch begins with the fusion of light and heavy helium nuclei, ^{3}He and ^{4}He, which form ^{7}Be. In 1958 Harry D. Holmgren and R. L. Johnson of the Naval Research Laboratory discovered that this reaction is significantly faster than had been thought. It proceeds at a rate of about once for every 1,000 occurrences in the sun of the more probable ^{3}He-plus-^{3}He reaction. Immediately following this discovery Fowler and A. G. W. Cameron suggested that the decay of ^{8}B might produce a detectable flux of solar neutrinos. I subsequently made some calculations that showed that the capture probability for the energetic neutrinos emitted by ^{8}B was 18 times larger than had been previously estimated. On the basis of this calculation Davis suggested in 1964 the experiment eventually located at the Homestake mine.

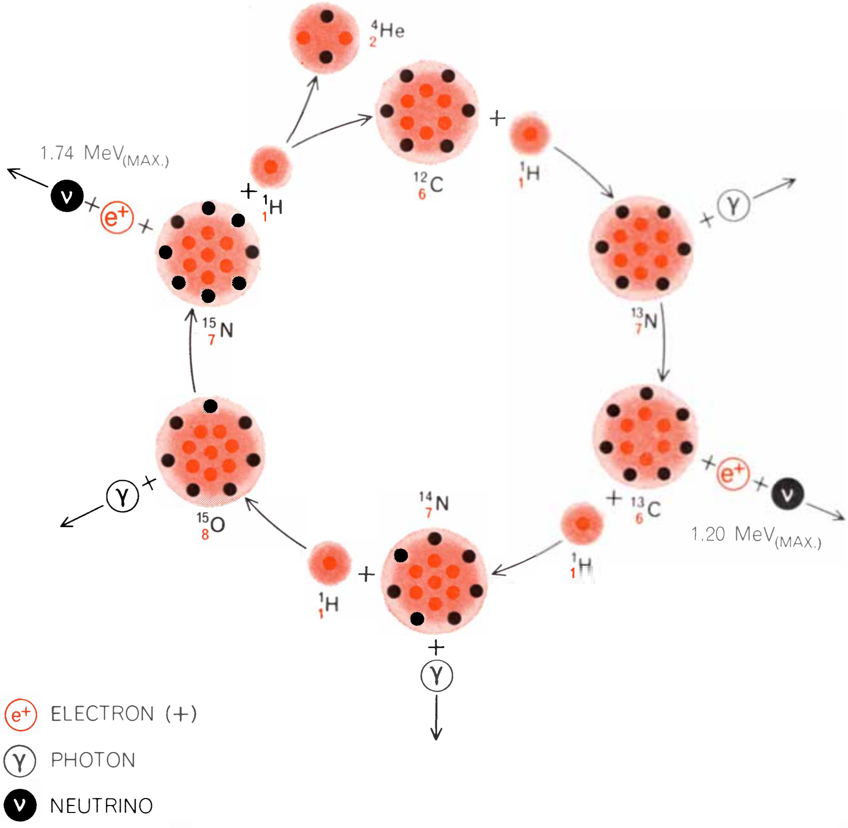
We are now ready to ask: How can tetrachloroethylene serve as a detector of solar neutrinos? Some 20 years ago Bruno M. Pontecorvo, then at the Chalk River Nuclear Laboratories in Canada, pointed out that an isotope of chlorine, ^{37}Cl, could capture a neutrino and be transformed into an isotope of the rare gas argon, ^{37}Ar, with the release of an electron. Subsequently the suggestion was discussed in detail by Luis W. Alvarez of the University of California at Berkeley. On the basis of Alvarez' discussion Davis and Harmer attempted to observe the argon produced by antineutrinos from the decay of fission products. (They placed a 3,000-gallon detector near a nuclear reactor.)

The argon isotope produced by neutrino capture is unstable and reverts to ^{37}Cl by capturing one of its own orbital electrons. Fifty percent of a sample of ^{37}Ar atoms will undergo such a transformation in about 35 days. The decay process shakes loose a low-energy electron from the argon atom, and this electron can be detected by counters placed around the sample. The detection of such electrons would be a sign that a few ^{37}Cl atoms had been transformed into ^{37}Ar atoms by neutrinos. The minimum neutrino energy for this reaction is .81 MeV [*see illustration on page 35*].

For the detection scheme to work one must end up with at least a dozen or so ^{37}Ar atoms. Calculations suggested that a practical experiment would require a detector consisting of 100,000 gallons of a chlorine-containing fluid, such as tetrachloroethylene. (In natural chlorine a fourth of the atoms are the isotope ^{37}Cl.) In the experiment designed by Davis and his colleagues this volume of tetrachloroethylene is contained in a tank 20 feet in diameter and 48 feet long, located 4,850 feet underground [*see illustration on page 31*].

Why underground? The answer is that the detector must be shielded from the shower of subnuclear particles of all kinds produced when cosmic rays (chiefly high-energy protons) crash into the earth's atmosphere [*see illustration on page 30*]. Several reactions triggered by such particles could simulate the reaction Davis was looking for, but it is particularly important to exclude free protons from the tank because if ^{37}Cl absorbs a proton it can be converted into ^{37}Ar by the release of a neutron. Although one does not expect free protons to penetrate many feet of rock, muons produced by cosmic rays are very penetrating and can cause reactions that will release protons many feet below the surface. As a shield against neutrons, which are another hazard, the entire tank can be surrounded by water.

The tankful of tetrachloroethylene is exposed to the flux of neutrinos from the sun for several months to allow the atoms of ^{37}Ar to accumulate. (I might add that the flux of neutrinos from the rest of the universe presumably bears roughly the same relation to the solar-neutrino flux as starlight does to sunlight; hence it can be ignored.) The ^{37}Ar formed by neutrino capture is then removed from the bulk of the liquid by bubbling large quantities of helium gas through the system. About 10 cubic feet of helium is circulated through the tank per minute. The argon is separated from the helium by adsorbing it in a charcoal trap maintained at the temperature of liquid nitrogen (77 degrees Kelvin). The efficiency of the extraction procedure is determined in each experiment by adding to the 100,000 gallons of tetrachloroethylene a known amount (less than a cubic centimeter) of



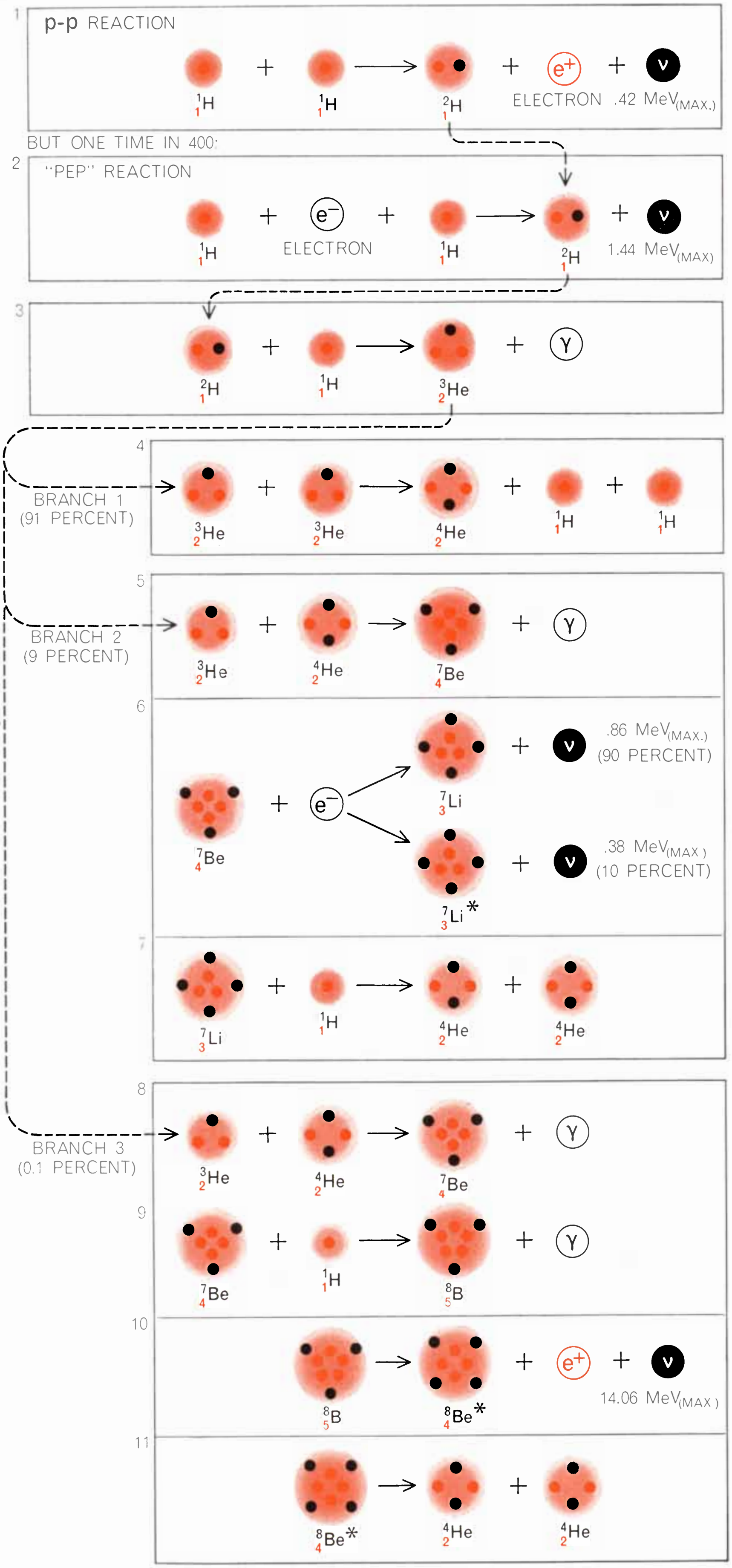
CNO CYCLE for fusing four protons into a helium nucleus employs ordinary carbon, $^{12}_{6}$C, as a catalyst, which is regenerated. Neutrinos are released in the second and fifth steps of the cycle. Because they share energy with the positive electrons that are emitted simultaneously, the neutrinos emerge with a spectrum of energies, whose maximum values are indicated. Unfortunately many of the neutrinos from the cycle lack the energy to trigger chlorine-37 detection system, which has a threshold of .81 million electron volt (MeV).

^{36}Ar, a rare nonradioactive isotope of argon. Davis finds that purging the tank for 22 hours with helium will usually recover 95 percent of the ^{36}Ar.

The argon that is finally removed from the tank consists primarily of ^{36}Ar, deliberately inserted, together with two other isotopes: a few atoms of ^{37}Ar produced by solar neutrinos and a tiny amount of the ordinary nonradioactive isotope of argon, ^{40}Ar, that might have leaked into the tank from the air. After the sample of argon is purified chemically it is placed in a small counter holding about .5 c.c. of gas. The counter is made small to minimize its exposure to cosmic rays or other unwanted particles. It is protected from outside radiations by a series of shields and by large counters that signal when something has penetrated the outer defenses. The shape of each pulse occurring in a counter is photographed, and the pertinent data (such as the time of occurrence and the energy of the pulse) are stored on computer tape.

Ray Davis tells me that the experiment is simple ("Only plumbing") and that the chemistry is "standard." I suppose I must believe him, but as a nonchemist I am awed by the magnitude of his task and the accuracy with which he can accomplish it. The total number of atoms in the big tank is about 10^{30}. He is able to find and extract from the tank the few dozen atoms of ^{37}Ar that may be produced inside by the capture of solar neutrinos. This makes looking for a needle in a haystack seem easy.

Let me explain now how I calculated the probability that a solar neutrino that enters the tank of tetrachloroethylene will be captured by one of the ^{37}Cl atoms. The fraction of neutrinos with energies in any given range can be determined for a particular neutrino source from laboratory experiments. One can also calculate with the aid of Fermi's theory of neutrino processes the likelihood that an atom of ^{37}Cl will capture a neutrino of a particular energy. From a threshold probability of zero for a neu-



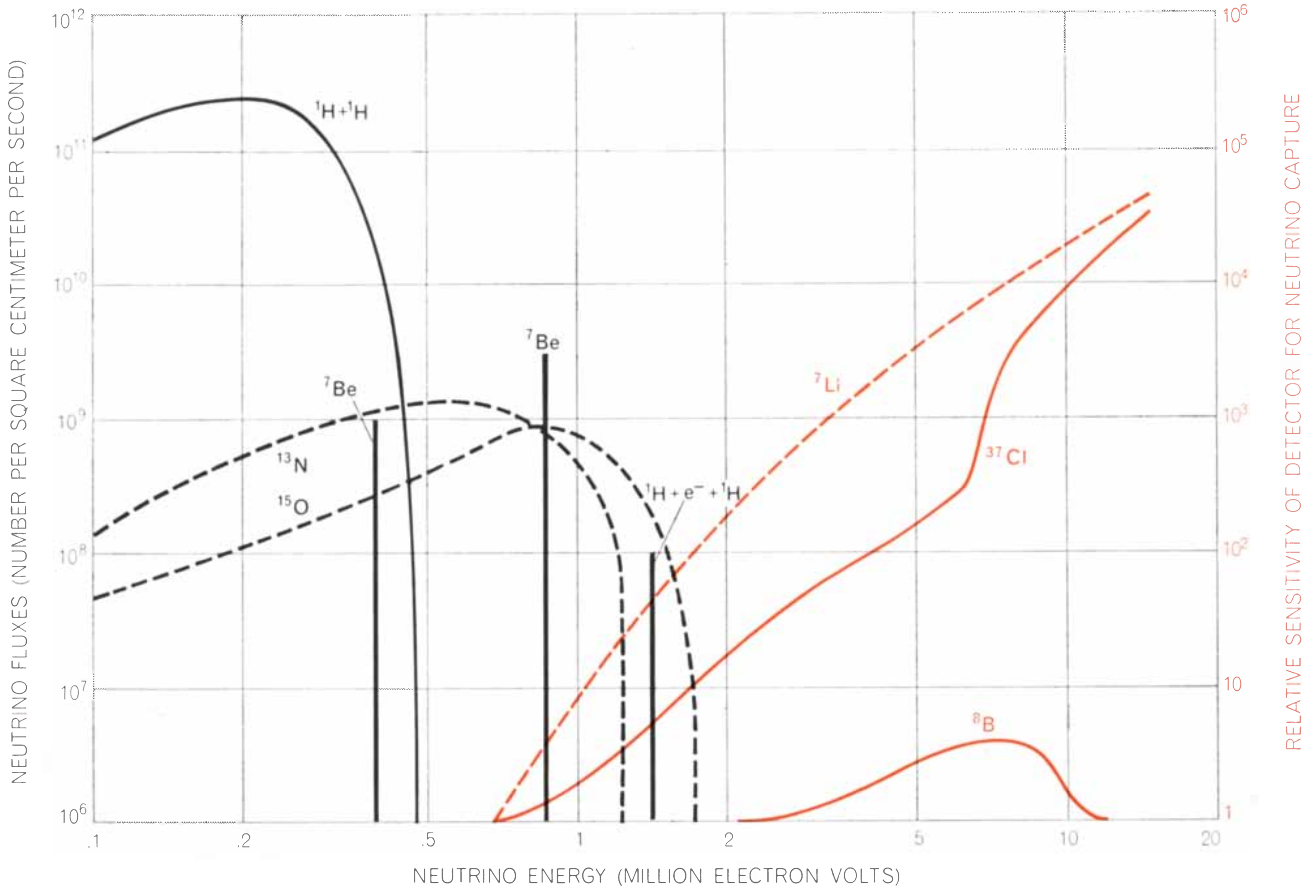
trino of .81 MeV the relative capture probability rises to 100 for a neutrino of 4 MeV, to 1,000 for a neutrino of 7 MeV and to 30,000 for a neutrino of 14 MeV. Thus the probability of capturing a 14-MeV neutrino from ^{8}B decay is some 3,000 times higher than the probability of capturing a 1.4-MeV neutrino from the pep reaction.

Moreover, the neutrinos from the decay of ^{8}B can do something that none of the other solar neutrinos can. They are so energetic they produce a ^{37}Ar nucleus that is in an excited state. This means that the nucleus has more internal energy than it would have in the ground, or normal, state. The significance of this is that favorable nuclear transitions can be caused by ^{8}B neutrinos that are not possible with the lower-energy neutrinos. The most important excited state of ^{37}Ar is quite similar to the ground state of ^{37}Cl; it is the nuclear analogue of the ground state of ^{37}Cl. The consideration of excited states led to an accurate determination of the probability that ^{37}Cl will capture an ^{8}B neutrino.

The chain of argument is based on the symmetry properties of nuclei containing the same number of nucleons and proceeds as follows. The nucleus $^{37}_{17}Cl$ (I shall again indicate the protons by subscripts) should behave very much like the calcium nucleus $^{37}_{20}Ca$, which was unknown when I made my nuclear model. The model predicted that $^{37}_{20}Ca$ should decay within 130 milliseconds, on the average, into an excited potassium nucleus $^{37}_{19}K$ plus a positive electron and a neutrino. In a nuclear sense this is exactly analogous to the capture of a neutrino by $^{37}_{17}Cl$, producing $^{37}_{18}Ar$ plus an electron.

About a year later the isotope ^{37}Ca was observed, and its decay rate was found to be within 25 percent of the value predicted. More important, subsequent measurements by Arthur M. Poskanzer and his associates at Brookhaven

PROTON-PROTON CHAIN is thought to be the dominant source of energy generation in the sun. The initial proton-proton reaction (*1*), which produces neutrinos undetectable with ^{37}Cl, establishes the basic rate for all subsequent reactions. Detectable neutrinos are released by the "pep" reaction (*2*), so named because the reactants are proton, electron and proton. Deuterons, $^{2}_{1}H$, produced in these two reactions fuse with protons to form a light isotope of helium, $^{3}_{2}He$ (*3*). At this point the proton-proton chain breaks into three branches. A few barely detectable neutrinos are produced in the second branch by Reaction *6*. The most energetic neutrinos are released (*10*) in the rare branch involving boron 8.



SPECTRUM OF SOLAR-NEUTRINO ENERGIES is plotted with curves showing the sensitivity of the ^{37}Cl detection system now in use (*solid line in color*) and the sensitivity of a proposed detection system employing lithium, ^7Li (*broken line in color*). Neither system is sensitive in the region below about .8 MeV, where the energies of most of the solar neutrinos would be found. The lithium system, however, would be more sensitive than the ^{37}Cl system to neutrinos produced by the pep reaction, $^1H + e^- + ^1H$. Most of the neutrinos expected to be captured by ^{37}Cl are those released by the decay of ^8B. Neutrinos from the proton-proton chain are indicated by solid black lines, neutrinos from the CNO cycle by broken lines. The neutrino fluxes are plotted as the number per square centimeter per second per MeV for continuum sources and as the number per square centimeter per second for line sources.

determined the fraction of decays of ^{37}Ca that lead to various excited states of ^{37}K. These were precisely the results needed to calculate the neutrino-capture rate of ^{37}Cl with an accuracy of better than 10 percent.

It is convenient to introduce a special unit to express the neutrino-capture rate in solar-neutrino experiments. The unit is the "solar-neutrino unit," or SNU (which we pronounce "snew"). One SNU equals 10^{-36} capture per second per target atom. This implies that an atom of ^{37}Cl would have to wait 10^{36} seconds, or roughly 10 billion billion times the age of the observable universe, before capturing a neutrino. Of course, in the 100,000-gallon tank, which contains about 2×10^{30} atoms of ^{37}Cl, the average waiting time for a single capture when the rate of capture equals 1 SNU is only 5×10^5 seconds, or about six days per capture.

Let us now see how the capture rate in SNU's varies, depending on which reaction, or combination of reactions, one thinks is responsible for the sun's thermonuclear energy [*see illustration on next page*]. If the CNO cycle is the dominant source of the sun's energy, I estimate that the capture rate is 35 SNU. On the other hand, if the sun derives its energy from the proton-proton chain, as most theorists now believe, the problem of predicting the capture rate becomes difficult. One has to calculate precise models for the interior of the sun and estimate the average temperature of the solar furnace to an accuracy of .1 percent in order to predict the capture rate to an accuracy of a few percent, which is our usual aim.

The equations needed for such models have been known for some time. The first equation states that the gravitational attraction of the solar gas is balanced at each point in the sun by the thermal pressure of moving gas particles and by the pressure of radiation (photons). The second equation states that the total energy emitted by the sun represents the sum of all the energy released by the individual thermonuclear reactions. Finally, there is an equation that describes how energy is transported from the interior to the surface of the sun. This equation requires one to assume a particular chemical composition for the solar material so that one can estimate its opacity (that is, how strongly it impedes photons trying to reach the surface). We make the conventional assumption that the abundances observed spectroscopically at the surface of the sun are the same today as when the sun was formed. This assumption has been questioned, however, by Icko Iben, Jr., of the Massachusetts Institute of Technology, who has pointed out that our calculated primordial helium abundance for the sun is different from the abundance observed in some other stars. The situation is still somewhat unclear, although we are encouraged by the fact

BASIS OF EXPECTATION	ESTIMATED CAPTURE RATE (SOLAR NEUTRINO UNITS)
CARBON-NITROGEN-OXYGEN CYCLE	35
p-p CHAIN (STANDARD S_{17})	6
p-p CHAIN (INDIRECT S_{17})	3
GENERAL IDEAS OF SOLAR INTERIOR	1-3
ABSOLUTE MINIMUM ("PEP" NEUTRINOS)	.3

PREDICTED NEUTRINO CAPTURE RATES in the ^{37}Cl detection system are listed for various assumptions about thermonuclear processes in the sun. One solar neutrino unit (SNU) is defined as 10^{-36} capture per second per target atom or, alternatively, one capture per atom every 10^{36} seconds. If all the sun's energy came from the CNO cycle, the expected rate would be 35 SNU. The text discusses the basis of the various estimates. The first experimental value obtained by Davis and his associates indicated an upper limit of 3 SNU.

that our models enable us to calculate correctly the abundance of helium atoms observed in those cosmic rays that come from the sun.

All the quantities mentioned—pressure, reaction rates and opacity—must be computed at temperatures some 50,000 times higher and densities 100 times greater than those normally encountered on the earth. The central temperature of the sun is believed to be about 15 million degrees Kelvin and the central density about 150 grams per cubic centimeter. The calculation of reasonably accurate values for the opacity of stellar material alone has taken years of effort by Arthur N. Cox and his associates at the Los Alamos Scientific Laboratory.

The calculation of a detailed solar model requires about 10 minutes on a modern high-speed computer. The first calculations of solar-neutrino flux based on detailed models of the sun were published in 1963 by Fowler, Iben, Richard L. Sears and myself. Our 1963 model indicated that the capture rate would be about 50 SNU. Subsequent pioneering work was done by Sears. Since then I have been trying to estimate and reduce the uncertainties in our calculations that arise from imperfectly known parameters. This work has been carried out with a number of able collaborators, including most recently my wife Neta Bahcall, Giora Shaviv and Roger Ulrich. Our best solar model, using what we consider the most likely set of parameters for the proton-proton chain, predicts a capture rate of only 6 SNU—smaller by nearly a factor of 10 than predicted by our 1963 model. The main difference between our 1963 estimate and the present one results from improved measurements of nuclear reaction probabilities and of the sun's composition. (The composition work was done by D. Lambert and A. Warner of the University of Oxford.) We estimate that the uncertainty in the new value of the capture rate is roughly a factor of two or three.

About 80 percent of the expected rate of 6 SNU represents neutrinos from the decay of radioactive boron, ^{8}B, produced when ^{7}Be captures a proton. The parameter describing the rate of this reaction at solar temperatures is usually designated S_{17} (1 stands for proton and 7 for ^{7}Be). The "standard" value for S_{17} was determined in 1968 by Peter D. Parker of Yale University, and is the value that gives 6 SNU. An indirect determination of S_{17}, yielding a lower value, had been made a few years earlier at Cal Tech by Thomas A. Tombrello. He made use of reactions involving ^{7}Li and neutrons instead of ^{7}Be and protons. If this lower value of S_{17} is used, the estimated capture rate falls to 3 SNU. Independent of the uncertainty surrounding S_{17} and other parameters, my wife, Ulrich and I have established that the most general ideas concerning the solar interior predict a probable capture rate of between 1 and 3 SNU.

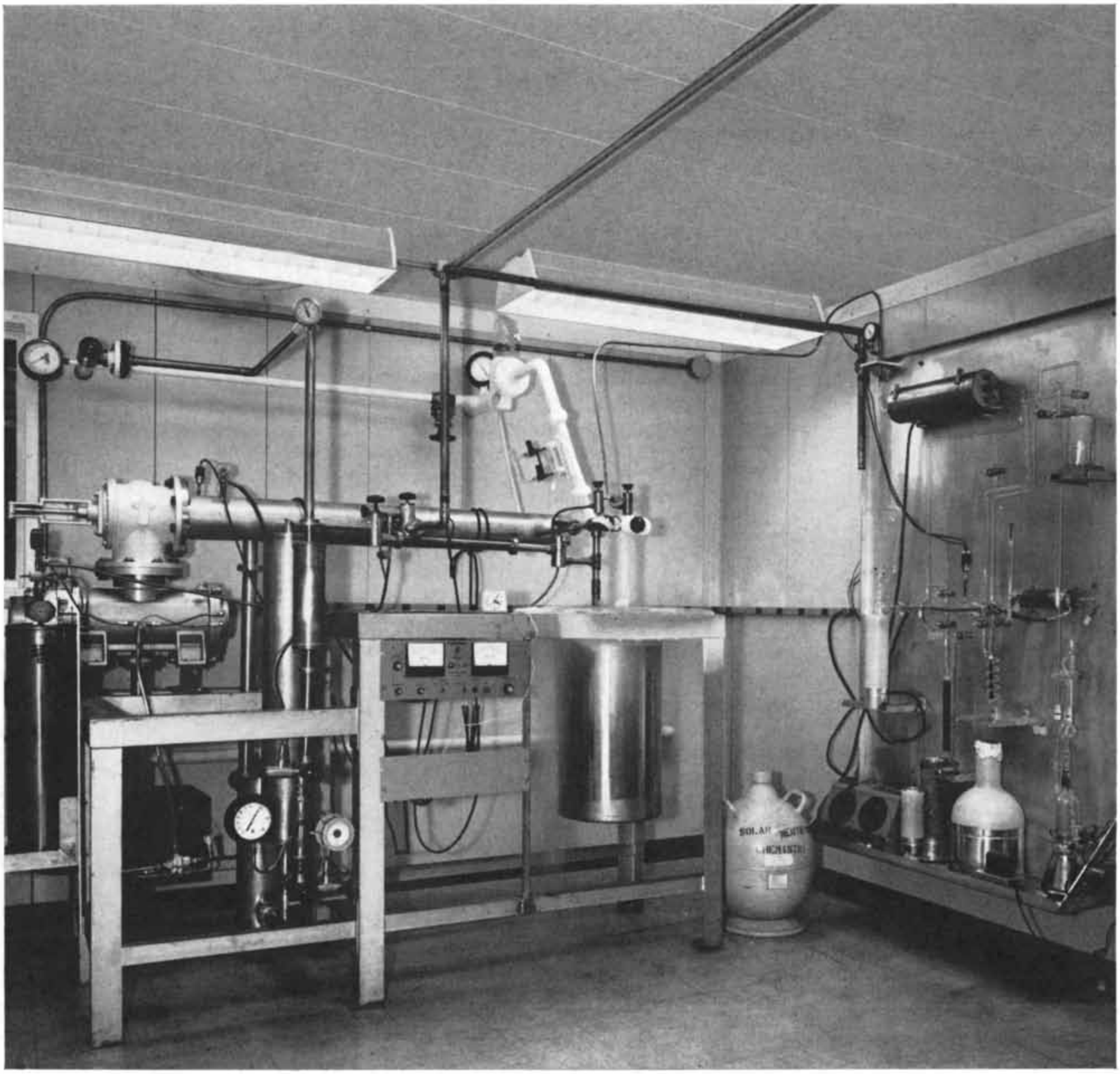
A minimum capture rate can be obobtained by calculating the contribution from pep neutrinos alone. Regardless of what model one selects for the interior of the sun, the ratio of pep reactions to standard proton-proton reactions is in the ratio of about one to 400. Moreover, the observed luminosity of the sun determines the rate of the basic proton-proton reaction. Therefore the capture rate attributable to pep neutrinos is an absolute lower limit (with one imaginative exception that will be mentioned below) consistent with the hypothesis that fusion reactions make the sun shine. Calculations I have made with the help of my wife, Shaviv and Ulrich show that this minimum capture rate is $.29 \pm .02$ SNU.

The results published last year by Davis and his co-workers show that the capture rate with ^{37}Cl is probably less than 3 SNU. The experimental value clearly implies that less than 10 percent of the sun's energy is generated by the CNO cycle. It also implies that the value of 6 SNU, based on "standard" parameters for the proton-proton chain, is at least twice too high. This discrepancy of a factor of two has caused considerable excitement in the scientific community. As we have seen, however, the uncertainties in some parameters are large enough so that Davis' result does not imply a conflict with general ideas about the solar interior.

Nevertheless, several theorists have suggested ways to explain the apparent discrepancy. D. Ezer and Cameron of the National Aeronautics and Space Administration suggest that the inner parts of the sun have somehow been mixed with the outer parts, thus reducing composition differences attributable to nuclear reactions in the solar interior. Their idea has been investigated quantitatively by a number of workers, who have found that mixing can indeed significantly reduce the expected solar-neutrino flux. Their suggestion, however, has not been widely accepted because the required amount and duration of mixing are quite large.

The most imaginative idea has come from the U.S.S.R., where V. N. Gribov and Pontecorvo (who originally suggested the use of ^{37}Cl to trap neutrinos) have proposed that neutrinos have a kind of double identity: approximately half the time they are the ordinary "electron neutrinos" we suppose them to be but half the time they are "muon neutrinos." Muon neutrinos were discovered at Brookhaven in 1962; they are created by reactions involving the production of muons. They seem to be identical in every way with ordinary electron neutrinos except that when they react with a proton or neutron they produce another muon rather than an electron [see "The Two-Neutrino Experiment," by Leon M. Lederman; SCIENTIFIC AMERICAN, March, 1963]. One can also prove that low-energy muon neutrinos will not react with ^{37}Cl. According to Gribov and Pontecorvo, the transformation from one kind of neutrino into another requires times (or distances) that are too large to be obtainable in the laboratory but that are available to neutrinos traveling from the sun to the earth. The neutrinos that arrive in their muon disguise cannot be detected, and thus all capture rates must be divided by a factor of about two. The suggestion made by Gribov and Pontecorvo implies that the minimum capture rate due to pep neutrinos should be reduced. It will not be easy to test this unusual hypothesis, but it cannot be lightly dismissed.

Meanwhile Davis is attempting to improve the sensitivity of his experiment. The improvement, if achieved, should indicate clearly whether the present discrepancy between observation and expectation is due to errors in some experimentally determined parameters used in our solar models or is caused by a basic defect in our theories. Beyond that I believe someone should undertake an experiment using a nuclear species that is more sensitive to low-energy neutrinos than ^{37}Cl. Ordinary lithium, ^{7}Li, is such a nucleus; on capturing a neutrino it yields ^{7}Be and an electron. (This is the reverse of Reaction 6 illustrated on page 34.) Lithium would respond much better than ^{37}Cl to the pep neutrinos of 1.4 MeV [*see illustration on opposite page*] and to the low-energy neutrinos produced by the decay of ^{13}N and ^{15}O in the CNO cycle. The combined results of ^{37}Cl and ^{7}Li experiments would constitute a stringent test of present theories of stellar interiors and neutrino reactions. I would not be too surprised to find myself writing another article a few years from now explaining why the results of a successful experiment with ^{7}Li do not agree with our astrophysical expectations.



ARGON-EXTRACTION SYSTEM is deep underground next to the 100,000-gallon neutrino trap. Helium is circulated through the tank to sweep up any atoms of ^{37}Ar that have been formed from ^{37}Cl. The efficiency of the extraction is determined by previously inserting in the tank a small amount of ^{36}Ar, a rare, nonradioactive isotope of argon. The helium and argon pass through the apparatus at left, where the argon condenses in a charcoal trap cooled by liquid nitrogen. This argon fraction is purified in the apparatus at the right. The purified sample is then shipped to Brookhaven, where the content of ^{37}Ar is determined in shielded counters.

Porphyria and King George III

The British monarch at the time of the American Revolution is generally believed to have been insane. In the light of modern knowledge it seems that he suffered from a metabolic disease

by Ida Macalpine and Richard Hunter

King George III, who is held in low regard on both sides of the Atlantic as the stubborn monarch whom the American colonies fought for their independence, was not a well man. His putative "madness" affected the course of Britain's history and, among other things, led to the establishment of psychiatry (then called the "mad-business") as a serious branch of medicine. Oddly enough, it has now become clear, a century and a half after his death, that George III was by no means psychotic. The much maligned king suffered spells of a painful and delirious metabolic disease that has only recently been recognized.

While working on a history of psychiatry, we learned with considerable interest how greatly its origins and development had been influenced by George III's alarming attacks, and we decided to find out what we could about the illness itself. Fortunately we were able to round up the notes and records of physicians who examined the king at the time; their manuscripts were preserved in Windsor Castle, the British Museum, the Lambeth Palace Library and in the hands of descendants. The recently published correspondence of George III also was helpful. The physicians' descriptions of the king's illness (not previously examined in recent times), together with the other available evidence, enabled us to arrive at a firm diagnosis of his disease in the light of present medical knowledge.

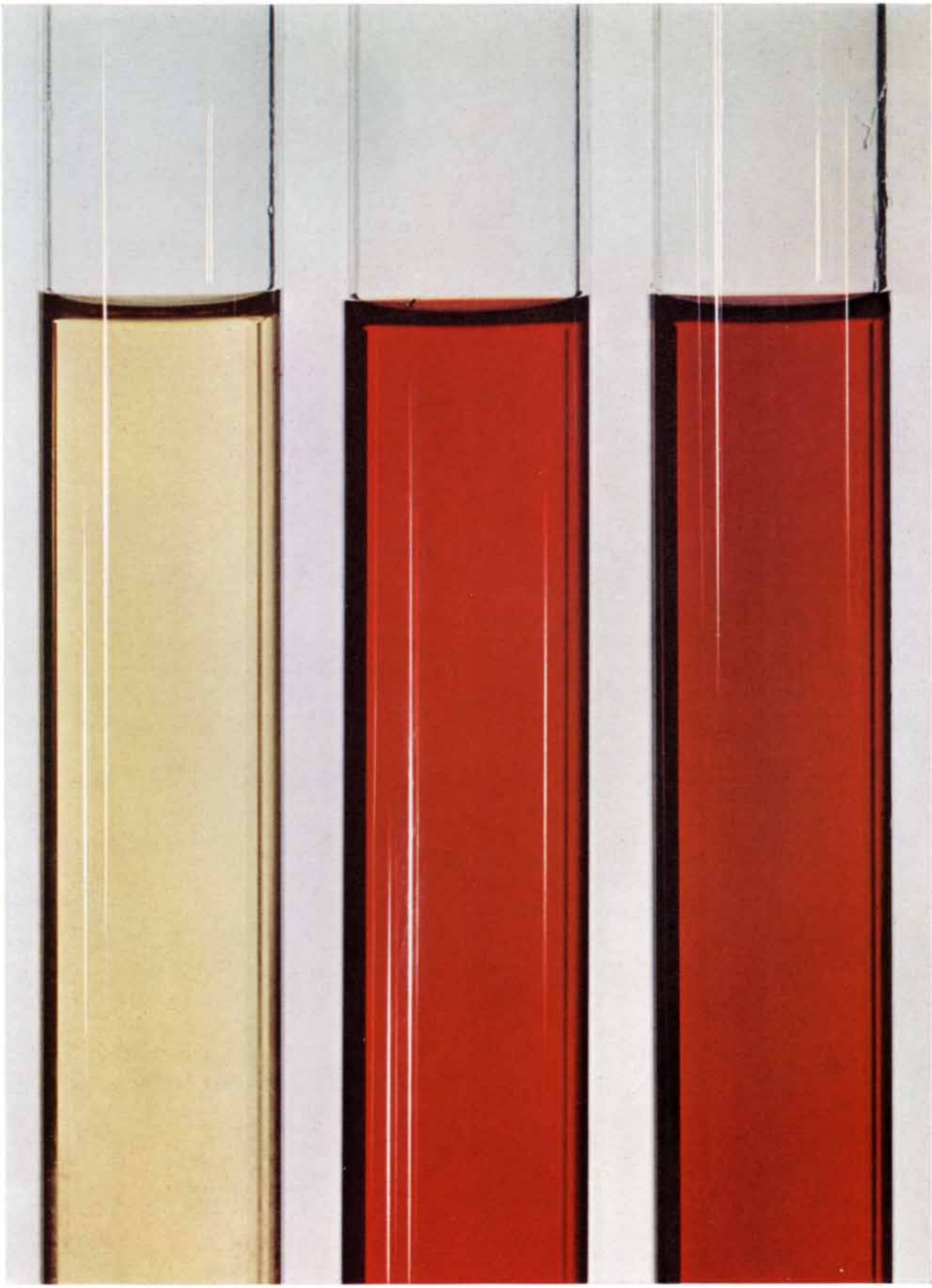
Let us begin with a review of his medical history as it was reported at the time. The first severe attack came in the fall of 1788, when the king was 50 years old. He had had a seizure of acute abdominal pain in June; his physician, Sir George Baker, diagnosed the cause as "biliary concretions in the gall duct" and sent him to Cheltenham Spa to drink the waters. The episode subsided, but in October the pains returned, accompanied by constipation, darkening of the urine, weakness of the limbs, hoarseness and a fast pulse. In the ensuing weeks the king was afflicted with insomnia, headache, visual disturbances and increasing restlessness. By the third week he became delirious, and over the weekend of November 8–9 he had convulsions, followed by prolonged stupor. His doctors feared that a fever had "settled on the brain" and that his life was in imminent danger. For a week he apparently hovered between life and death. Then his physical condition began to improve, but his mind was "deranged." There were periods of great excitement, interspersed with moments of lucidity and calm. "Wrong ideas" took hold of the king, and his physicians found him increasingly difficult to manage.

During all this time, although he was attended by coveys of physicians, the patient was not really examined in the present sense of the word. The doctors looked at the king's tongue, felt his pulse, inquired about his excretory functions, listened to his complaints and attempted to pronounce a diagnosis by "an estimate of symptoms and appearances." There were, indeed, no tools for examination to speak of in that era—no stethoscope, not even a reliable clinical thermometer to measure fever. The physicians often could not agree on the pulse rate, presumably because their timepieces differed. Doctors did not listen to the chest; even if they had, they would not have known what to make of what they heard. They were also handicapped by the fact that they did not dare to question the king about his symptoms unless he addressed them first. (After one session of fruitless silence the physicians plaintively reported: "His Majesty appears to be very quiet this morning, but not having been addressed we know nothing more of His Majesty's condition of mind or body than what is obvious in his external appearance.")

In contrast to the obscurity and vagueness of the physical symptoms, the king's mental symptoms spoke loudly and clearly. His physicians needed no modern aids to observe that his behavior was excited and irrational and his mind confused. Moreover, his mental state caused much concern about his fitness to rule and the dangers to the nation and the empire. The mental symptoms therefore overshadowed the physical complaints. Thus it came about that the king's physical sufferings were minimized (and later disregarded), whereas his mental derangement was magnified as if it were the whole illness. Physicians who specialized in "intellectual maladies" were called in, took up residence in the palace and took charge of the sickroom.

One of these practitioners was the Reverend Dr. Francis Willis, called "Doctor Duplicate" because he was a doctor of medicine as well as of theology. Dr. Willis, who managed a madhouse, arrived at Kew Palace with the aids and tools of his establishment, including attendants and a straitjacket. He applied to the king the usual treatment of the day for insane persons: coercion and restraint. The king was put in the straitjacket for infringements of discipline such as throwing off his necktie and wig when he had attacks of sweating, or refusing to eat when he had difficulty swallowing, or walking about the room when he became too restless to lie down. The king's unpredictable and obstreperous behavior was taken to be the ebullition of furious mania, and his fierce (and understandable) dislike of his doc-

GEORGE WILLIAM FREDERICK, the third Hanoverian king of England, is seen in an official portrait by Allan Ramsay, painted when the monarch was 30 years old. Born in 1738, George III ruled from 1760 to 1811, when the fourth in a series of misdiagnosed bouts of "madness," apparently a hereditary enzyme imbalance known today as porphyria, required the appointment of a regent.



WINE-COLORED URINE, shown in the middle test tube, was produced by a patient during an acute attack of porphyria. For comparison, normal urine is at left, port wine at right. James I, who also had porphyria, commented that his urine resembled port.

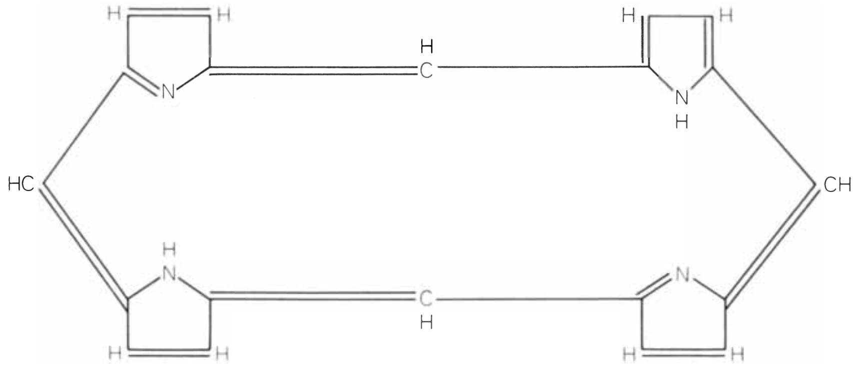
tors and keepers was attributed to delusions.

His illness precipitated a historic party struggle in Parliament known as the "Regency Crisis." The Whigs, led by Charles James Fox, Edmund Burke and Richard Brinsley Sheridan (who was a member of Parliament as well as a celebrated playwright), tried to oust the king's prime minister, William Pitt, and the other members of his cabinet. For four months Parliament gave its entire attention to the king's illness and the constitutional issues it raised. Members of Parliament interrogated the physicians exhaustively on the question of whether the king was suffering merely a prolonged delirium, from which he could be expected to recover with unimpaired mind, or was actually afflicted with "a lunacy" that would permanently cloud his judgment.

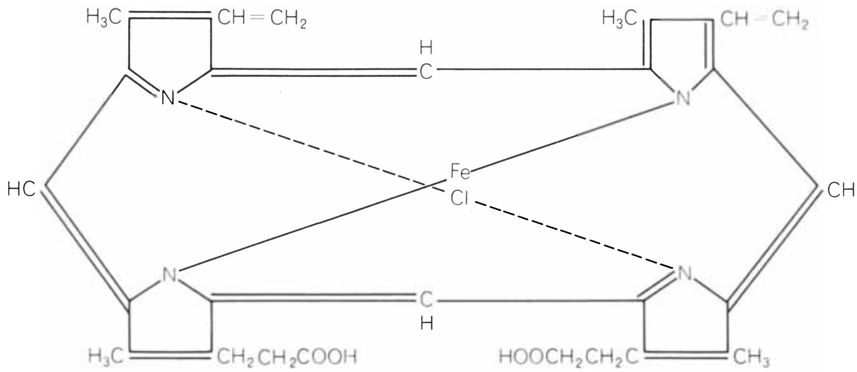
Then, just as Parliament was about to pass a bill setting up a regency, George's mind suddenly began to clear. At the end of February, 1789, his doctors announced "the entire cessation" of his illness. Although Willis claimed the credit for the cure, in retrospect it is clear that the king's recovery must have been spontaneous. He was soon well enough to leave his confinement in Kew Palace and return to Windsor Castle, his favorite residence. His recovery was celebrated with demonstrations of national rejoicing the like of which had never before been witnessed.

In 1801 and again in 1804 George III had recurrences of the same illness. Each time he was at first dangerously ill with identical physical symptoms and then deranged mentally for only a brief period. Eventually, in 1810, he fell into an illness that incapacitated him to the point where he was replaced by the Prince of Wales under the regency act of 1811. For at least a year there were hopes that he would again recover, and his son, as regent, refrained from dismissing George's ministers to avoid embarrassing him in case he became able to resume the throne. The king did experience periods of recovery, but each time he relapsed. He was then well past 70, blind and much reduced physically and mentally by the repeated onslaughts of his illness. Senility had set in. During his last years George was on the whole tranquil, played the harpsichord and had intervals of good humor and cheerfulness; however, he was often "sullen and lost in mind," tears and laughter would come in quick succession and from time to time he was stricken with the old, painful paroxysms. A month before his death, in the last of these attacks, he spent 58 turbulent hours without sleep or rest and "gave other remarkable proof of the extraordinary energies of his constitution." He died quietly on January 29, 1820, at the age of 81.

PORPHIN



HEMIN



PORPHYRIN BUILDING BLOCK, the porphin molecule, is comprised of four pyrrole rings joined together by four methene bridges. The pigments that may be constructed from porphin molecules include three that are essential to animal and plant life: hemoglobin, chlorophyll and cytochrome. For comparison a hemin molecule is illustrated; it differs from porphin mainly in having an iron and a chlorine atom attached to the pyrrole rings.

After his death political bias and professional opinion developed an image of George III as a "mad king" who was more or less deranged throughout his life. A spell of sickness he had experienced in 1765, when he was 26, was taken to have been an early sign of his madness. There is not a shred of evidence that any mental disturbance accompanied that early illness, but it was popularly believed the king must have been insane to permit the 1765 enactment of the infamous Stamp Act that sowed the seeds of the American War of Independence. Furthermore, psychiatrists who later diagnosed George III's illnesses as primarily mental also adopted the lunacy interpretation of the king's 1765 illness to support their theory; it would not make sense to suppose that the king, if mentally unstable, would have come through the first 28 stormy years of his reign without any sign of psychological distress.

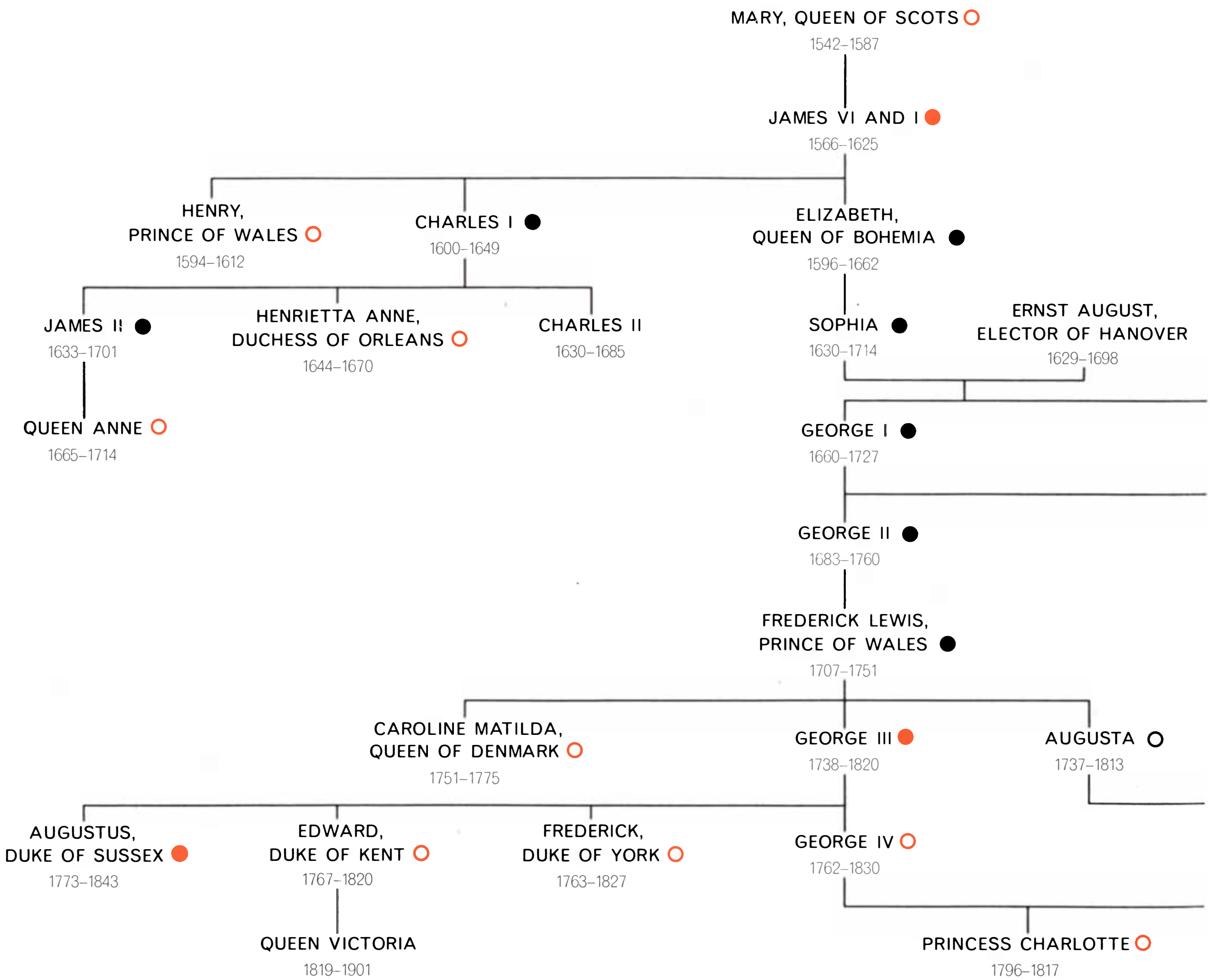
The great prominence given to George III's supposed insanity aroused wide public and professional interest in mental illness and generated the first systematic attempts to deal with it as a medical problem. William Black, a contemporary teacher of medicine who was intrigued by the physicians' fumbling efforts to forecast the prospects for the king's recovery, looked into the question statistically and thus became the founder of psychiatric statistics. Studying the records of people who had been pronounced insane, he came to the conclusion, which may be called "Black's law," that a third of such patients could be expected to recover to full mental health, a third recovered somewhat but did not regain all their former mental capacities and a third did not improve at all or sank into deeper illness.

Richard Powell, another physician with a statistical bent, found that in the years immediately following the king's 1788 attack there was a big increase in the number of insane persons admitted to private asylums. He presented his findings graphically in a histogram, introducing this device into medical reporting for the first time. Dr. Powell attributed the apparent rise in mental illness to the mounting complexities of civilization, and his social interpretation is still widely put forward as an explanation of increases in the incidence of mental disorders.

Two of George III's sons, the dukes of Kent and Sussex, set up the first fund for research in psychiatry and initiated the first controlled trial of a treatment for insanity. The trial was conducted by two laymen who had developed a secret remedy they hoped would be used on the king. A London physician named Edward Sutleffe also offered a remedy; he called it a "herbaceous tranquillizer," thereby introducing the term that describes the dominant treatment of mental illness with drugs today.

Parliament, prodded by demands for better care of the mentally ill, particularly among the poor ("pauper lunatics"), set up a committee "to enquire into Madhouses." Under the chairmanship of George III's personal friend George Rose, the committee took evidence for two years and published reports that paved the way to the system of caring for mental patients in "asylums," which lasted well into our century and whose memorials are still with us. This advance had some unfortunate consequences. It isolated patients from society, often in remote establishments, and it created an artificial separation between mental and physical disease, each with its own specialists. Thus psychiatry was unhappily set apart from the mainstream of medicine, and physicians and psychiatrists became two separate breeds.

In view of the historic importance of George III's illness, it is remarkable that so little inquiry has since been made, either by psychiatrists or by physicians, into what was really the matter with the king. Astonishingly, only two medical studies have ever been attempted. Both were made by individual U.S.



THREE ROYAL HOUSES suffered from porphyria. First to be afflicted was Mary, Queen of Scots, a Stuart. From her descendants the disorder spread to both the Hanoverian and the Prussian royal lines. Colored circles mark those who showed some signs of the psychiatrists, almost a century apart, and both completely missed the medical complexities of the case.

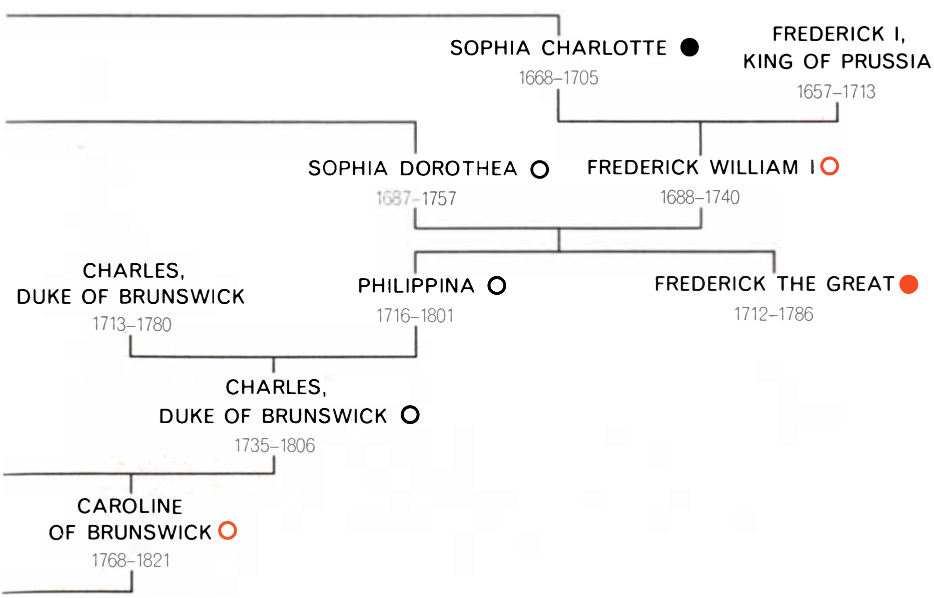
In 1855 Isaac Ray, the distinguished president of the Association of Medical Superintendents of American Institutions for the Insane (since renamed the American Psychiatric Association), reviewed the then available information on George's sickness. He was surprised by the lack of background for the king's attacks of mental derangement. Dr. Ray wrote: "Few men would have seemed less likely to be visited by insanity. His general health had always been good; his powers were impaired by none of those indulgences almost inseparable from the kingly station; he was remarkably abstemious at the table, and took much exercise in the open air. Insanity had never appeared in his family, and he was quite free from those eccentricities and peculiarities which indicate an ill-balanced mind." Nevertheless, on the basis of the reports to which he had access Dr. Ray diagnosed George III's malady as "mania" (which is as unspecific for mental illness as "fever" is for a physical complaint). Ray's attempt at diagnosis was severely handicapped by the paucity of facts he had on the case and by the comparatively primitive state of medical knowledge in the 19th century.

In 1941 the eminent Baltimore psychiatrist Manfred S. Guttmacher reexamined George III's case from the angle of modern psychoanalysis. It is characteristic of the psychoanalytic point of view that, given a case of mental aberration, it attaches little weight to physical symptoms and causes. Guttmacher dismissed the king's physical complaints, attributing them in part to efforts by the court to cover up the king's madness and in part to neurotic imaginings by the king himself. Describing the illness in modern terms as manic-depressive psychosis, Guttmacher added: "Self-blame, indecision and frustration destroyed the sanity of George III.... A vulnerable individual, this unstable man ...could not tolerate his own timorous uncertainty [and] broke under the strain. [Had the king] been a country squire, he would in all probability not have been psychotic." (Actually the king was known to his subjects as Farmer George because of his interest in agriculture.)

When we came to our detailed study of George III's career and illnesses, we found no grounds for support of this psychoanalytic interpretation of his case. George's contemporaries and early biographers described him as one of Britain's most devoted and best-informed rulers; he was a musician, a book collector (whose collection forms an important part of the British Museum), a patron of the arts and sciences, fond of country life and his family. If he had been emotionally and mentally unbalanced, how could he have lived through the disastrous period of his reign—the loss of the American colonies and the 18-year struggle leading up to it—without a suspicion of breakdown? In view of the political troubles that beset him, not to mention his large and unruly family, one should be surprised that he was ever sane at all, if the psychoanalytic diagnosis of his personality were correct.

The fact is that, before physical illness and senility finally incapacitated him, George had only three attacks of mental derangement, and all together these periods did not add up to more than six months. In each instance the nervous disorder was ushered in by serious physical symptoms that perplexed his physicians and brought him to the brink of death. "It is not merely the delirium of fever, nor is it any common form of insanity," said one of his doctors, William Heberden, Jr. "The whole frame has been more or less disordered, both body and mind... [due to] a peculiarity of constitution of which I can give no distinct account." Sir Henry Halford, another eminent physician of the time, remarked: "The King's case appears to have no exact precedent in the records of insanity."

There were clues to the root of George's illness, if the physicians had



disorder, colored dots those whose urine was also abnormal. Black dots mark transmitters who did not suffer from the disorder; black circles, those who may have been transmitters.

"DOCTOR DUPLICATE" WILLIS, the chief physician during George III's first porphyria attack, maintained a private asylum, shown here in a cartoon by Thomas Rowlandson. Willis' nickname derived from his being both a physician and a doctor of divinity. His method of treatment emphasized restraint and discipline for any disorderly patient; two here are in "winding sheets." Use of his method, including straitjacketing when his delirious royal patient failed to follow his orders, earned all doctors the king's enmity.

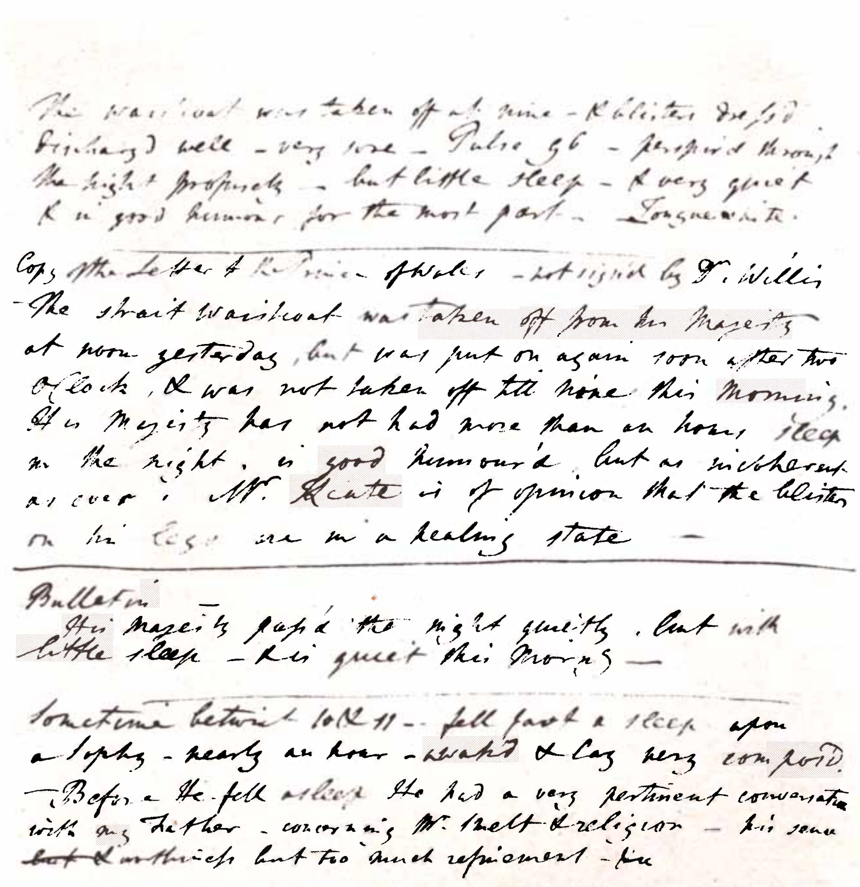
SAVAGE CARICATURE of the royal family was published in the year preceding the king's first seizure. The work, by James Gillray and titled "Monstrous Craws at a New Coalition Feast," was inspired by popular belief that "foreign" Hanoverians squandered the nation's funds for their own benefit. The queen (*left*), the Prince of Wales (*center*) and the king (*right*) are shown seated outside the Treasury, gorging themselves on gold. The king was in fact frugal, but the Prince of Wales (later his regent) was a notorious spender.

only known how to interpret them. The doctors reported, for instance, that his attacks appeared to be caused by "the force of a humour" that first showed itself in the legs, then drove "into the bowels" and finally was projected "upon the brain." Quaint as this description now sounds, it was a significant account of the course of the king's attacks, involving a progression of symptoms from the limbs to the abdomen to the brain. Of all the king's symptoms, the most revealing one, which has led us now to the discovery of the true nature of his illness, is the color of his urine. At least half a dozen times the doctors who examined him noted that the king's urine was "dark," red or discolored.

Considered in connection with the king's other symptoms and the character of his attacks, it is quite clear today that this discoloration of his urine must have been due to the presence of porphyrins. Porphyrin is a pigment, contained in the hemoglobin of the blood, that normally is metabolized in the body cells. Hence its presence in the urine is a signal of faulty metabolism: namely, inability of the cells to convert porphyrin, presumably because of the absence of a necessary enzyme. The clinical seriousness of such defects was first called to the attention of the medical world in 1908 by the London physician Sir Archibald Garrod, who discovered that "inborn errors of metabolism" could cause profound disorders [see "The Chemistry of Hereditary Disease," by A. G. Bearn; SCIENTIFIC AMERICAN, December, 1956]. It has since been found that the inability to metabolize porphyrin produces a disease, called porphyria, that attacks the nervous system [see "Pursuit of a Disease," by Geoffrey Dean; SCIENTIFIC AMERICAN, March, 1957]. The attack usually begins in the autonomic system, then advances to the peripheral nerves, the cranial nerves and finally the brain itself. At the height of the attack the patient is paralyzed, delirious and in agonizing pain.

George III's symptoms, the sequence of their development and the climaxes of his illness read like a textbook case of porphyria. His attacks started with colic, constipation and nausea; there followed a painful weakness of the limbs, so that he could not walk or stand, a speedup of his pulse, attacks of sweating, hoarseness, visual disturbances, difficulty in swallowing, intractable insomnia, mounting excitement, nonstop rambling, dizziness, headache, tremors, stupor and convulsions. The physicians described his climactic mental state thus: "Delirious

LIKENESS OF WILLIS appeared on one side and a patriotic injunction on the other of a medal that "Doctor Duplicate" distributed to the public when the king, in February, 1789, spontaneously recovered four months after the onset of his chief porphyria attack.


The waistcoat was taken off at nine - & blisters drefs'd
discharg'd well - very sore - Pulse 96 - perspir'd through
the night profusely - but little sleep - & very quiet
& in good humour for the most part - Tongue white.

Copy of the Letter to the Prince of Wales - not sign'd by Dr. Willis
- The strait waistcoat was taken off from his Majesty
at noon yesterday, but was put on again soon after two
oClock, & was not taken off till nine this morning.
His Majesty has not had more than an hours sleep
in the night, is good humour'd, but as incoherent
as ever: Mr. Keate is of opinion that the blisters
on his legs are in a healing state -

Bulletin -
His Majesty pafs'd the night quietly, but with
little sleep - & is quiet this morning -

Sometime betwixt 10 & 11 - fell fast a sleep upon
a Sophy - nearly an hour - awak'd & lay very compos'd.
- Before He fell asleep He had a very pertinent conversation
with my Father - concerning Mr. Smelt & religion - his sense
& worthinefs but too much refinement - &c

PHYSICIANS' JOURNAL, a chronological record of the king's illness, notes events of December 23 and 24, 1788, as follows: "The waistcoat was taken off at nine—& blisters drefs'd—discharg'd well—very sore—Pulse 96—perspir'd through the night profusely—but little sleep—& very quiet & in good humour for the most part—Tongue white. Copy of the letter to the Prince of Wales—not sign'd by Dr. Willis—The straight waistcoat was taken off from his Majesty at noon yesterday, but was put on again soon after two oClock & was not taken off till nine this morning. His Majesty has not had more than an hours sleep in the night, is good humour'd but as incoherent as ever. Mr. Keate is of opinion that the blisters on his legs are in a healing state—Bulletin—His Majesty pafs'd the night quietly but with little sleep—& is quiet this morning—Sometime betwixt 10 & 11—fell fast a sleep upon a Sophy—nearly an hour—awak'd & lay very compos'd. Before He fell asleep He had a very pertinent conversation with my Father [Dr. Willis] concerning Mr. Smelt & religion—his sense [struck out] & worthinefs but too much refinement—&c. [conclusion of page]."

all day . . . impressed by false images . . . continually addressed people dead or alive as if they were present . . . engrossed in visionary scenery . . . his conversation like the details of a dream in its extravagant confusion."

These mental symptoms are the hallmarks of a state in which the brain is disordered by toxin. Other aspects of the king's attacks also were characteristic of porphyria: they were usually precipitated by mild infections; his condition fluctuated rapidly, and each attack was followed by a protracted convalescence. Porphyria is usually accompanied by high blood pressure; there were of course no measurements of the king's blood pressure, but the repeated crises that made his doctors fear "a paralytic stroke" may well have been hypertensive. As for the illness of 1765, that was probably a mild attack of porphyria that did not go on to involve the brain.

Since porphyria is a hereditary disease, we looked into the medical histories of George III's blood relatives. The available records showed that signs of porphyria in his family went as far back as his 16th-century ancestor Mary, Queen of Scots. Her son, King James, suffered from colics (which he told his physician he had inherited from his mother) and described his urine as the color of his favorite Alicante wine. George III's sister, Queen Caroline Matilda of Norway and Denmark (who is the subject of many novels and of a Verdi opera), died at 23 of a mysterious illness that was featured by rapidly progressive paralysis. Some of George's children were afflicted with his disorder. The son who succeeded him on the throne, George IV, had a disease that his physicians called "unformed gout" but that must certainly have been porphyria. George IV's daughter, Princess Charlotte, showed characteristic symptoms of the disease and died in childbirth, apparently during an acute attack. George III's son Augustus, the Duke of Sussex, had severe attacks of illness accompanied by discoloration of his urine. Another son, the Duke of Kent (who was the father of Queen Victoria), suffered severely from colics and died of an attack a week before the death of George III. Porphyria, introduced into the House of Brandenburg-Prussia by George I's sister, also claimed Frederick the Great as a victim. The disease has persisted in descendants of George III up to the present day. We examined some of them and found the characteristic signs, including the discoloration of the urine. Our laboratory tests showed that the family had a form of porphyria that makes the skin sensitive to the sun and to injury.

We see, then, from the perspective of 20th-century medical knowledge, that George III's image, like his pain-racked body, has been the victim of a cruel misunderstanding. His episodes of derangement were merely the mutterings of a delirious mind temporarily disordered by an intoxicated brain. The royal malady was not "insanity" or "mania" or "manic-depressive psychosis"—whatever meaning these nebulous terms may retain in the modern era of diagnostic and investigative medicine. Partly because of the backwardness of medical knowledge at the time and partly because of the king's position, the bodily disorder he suffered was pushed into the shadows. With a good diet, avoidance of medication with drugs and generally rational treatment his attacks of delirium might have been curtailed.

PORCELAIN PLAQUE, made by Josiah Wedgwood in commemoration of the king's recovery, shows George III crowned with laurels. It bears the inscription "Health restored."

We go to great lengths to be useful

One thousand sixty feet beneath Retsof, N.Y., the International Salt Company operates the world's largest salt mine. There we store a film we believe to be the world's most sensitive medium for integrating and recording a flux of ionizing radiation. More than structural lead, which always carries remnants of its ancestral radionuclides, and more than rock, which must contain at least some K^{40}, the salt is radiologically silent. Retsof salt is strangely devoid of potassium. Down where Geiger counts from cosmic rays come long minutes apart, the hottest thing around is what we introduced ourselves: the carefully selected metal in the panels from which we built our storage room in our rented salt cavern. At least it's not as hot as wood.

Purpose of all this is to vie for favor to KODAK Personal Monitoring Film by the few organizations entrusted to keep utterly reliable tabs on exposure of radiation workers. By storing in the mine, where only the chemical component of density buildup remains to create noise against the signal being measured, we can supply longer runs of radiologically fresh film with the same coating number. Thus, with less calibration, our customers are that much surer of the precision in their reports.

Cold fireworks

The oxidation of one milliliter of a solution of 5-Amino-2,3-dihydro-1,4-phthalazinedione at a certain concentration can be counted upon to yield $9.75 \pm 0.7 \times 10^{14}$ photons of visible light. Hemoglobin—from your own finger if desired—can serve as the catalyst to raise the intensity to a level useful in absolute calibration of phototube detectors for the laboratory or the astrophysical observatory. To know this may prove useful in your work. Full details, including a discussion of emission spectra and spectral sensitivity considerations, begin on p. 35 of "Bioluminescence in Progress," Princeton University Press, 1966. The compound, better known as "luminol," is obtainable as EASTMAN Organic Chemical No. 3606 from laboratory suppliers.

A spectacular light show can be put on with luminol. Directions can be found in *Journal of Chemical Education* for March, 1934 and in *Photographische Korrespondenz 74,* 97 (1938). If we wanted to keep Eastman laboratory chemicals out of nonprofessional hands, we would promote them with literature references like those.

Image processing

James Webb's unusually good luck with the more intricate kind of bronze casting has been noted in Rochester foundry circles. Angela Webb, the 13-year-old on the right, faithfully gets dinner on the table the three evenings a week when Mother's class in algebra and geometry keeps her at Kodak until 6:30. We wish to tell about Mother's job. The more algebra and geometry she learns, the better she can serve the 14 investigators who carry forward the basic research program of the Kodak Research Laboratories in image-processing.

"Image-processing" has little to do with developers and hypo. It means we scan images of various kinds, dump the data from them into the computer, play games within the computer to transform an image into another image easier to recognize, diagnose, transmit. Thus the boss physicist of the group explains the project.

The boss no longer gets to do much programming himself. Since he is a bit rusty at it, Mary Webb, who was asked to learn FORTRAN and did, catches his mistakes for him when he tries it. To operate an 1130 computer and a PDP-7 computer, to set up jobs on them, to edit inputs, to carry the responsibility for transferring the content of their memories to tape, to maintain an accurate inventory of hundreds of tapes, to be permitted to program the compilation of an index of operating procedures—such complex duties strongly stimulate Mary Webb.

Interesting that our need for deep study of image-processing should affect the life of a lady who, though she dropped out at the 10th grade from West Side High School in Anderson, S.C. to get married, is finding more in the world outside the home than dust on other ladies' furniture.

EASTMAN KODAK COMPANY An equal-opportunity employer

Rolls-Royce unlimited.

△**Anything to prove a point**
This airborne anomaly doesn't exist yet (this is a retouched photograph). But they're working on it. It's going to be a flying test bed for the RB.211, the engine that Rolls-Royce designed for Lockheed's L-1011 TriStar jetliner.

This flying test bed started life as a standard VC-10 jet transport. Two of its four Conway engines are being replaced with a single RB.211.

One of the big points Rolls-Royce wants to prove is the quiet running of their new engine. The RB.211 has three shafts where other engines of similar power have only two. Using three shafts instead of two allows each stage of the RB.211 to run at optimum speed. The fan can be slowed down on approach to landing to reduce noise. Unique three-shaft design and other sophisticated technology help make the RB.211 quieter than any fanjet now in use. Tests to date show splendid results, and prospects are bright for its in-flight performance.

In addition to fly-over noise tests, the flying test bed will also be used to put the RB.211 through a thousand hours of typical TriStar operating routine. Although the TriStar can carry more than 300 passengers from coast to coast, it can also make short intercity hops—and do it economically.

The latest order for TriStars comes from Air Jamaica. Other customer airlines include Eastern, TWA, Delta,

Northeast and Air Canada. 181 TriStars are on order.

Incidentally, the Conway engines that power the VC-10 are also built by Rolls-Royce. The Conway was the world's first fanjet to go into commercial service.

△World's first vertical-take-off transport
The days of the long-runway airport may be numbered. Germany's Dornier Company and Rolls-Royce have collaborated on the world's first V/STOL transport. It's the Do31. Successful flight trials were completed last month.

At a gross weight of thirty tons, the Do31 can rise vertically, like a helicopter, and in midair convert to forward flight. Top speed in level flight is 460 miles per hour.

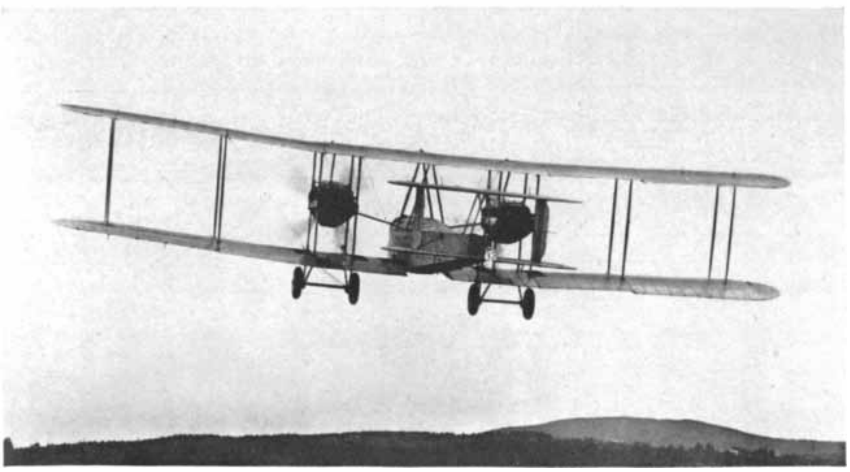
This unique plane has ten Rolls-Royce engines. Eight RB.162 engines, located in wingtip pods, provide most of the direct lift. Each of these remarkable engines can lift sixteen times its own weight.

Part of the lift, and all of the forward power, comes from a pair of Rolls-Royce Pegasus vectored-thrust turbofan engines, the same engine that powers the Harrier, the world's only V/STOL fighter. The exhaust of the vectored-thrust engine can be directed by rotating vanes, so the engine's thrust is applied vertically, horizontally or at any angle in between.

The Do31 is still primarily a research vehicle, but the potential uses for a plane 68 feet long that can take off on a 68-foot airport are too good to be overlooked.

More gas turbines go to sea ▷
The first major warship entirely powered by lightweight marine gas turbines is now in service with the Royal Navy. The ship is the Exmouth, a 1500-ton frigate originally steam-driven and now powered by a Rolls-Royce Olympus gas turbine for boost and two Proteus gas turbines for cruising power. Exmouth will give operational experience in preparation for the next generation of Royal Navy frigates and destroyers entering service in the 1970's, which will also be Rolls-Royce powered.

Thirteen other navies are operating or have ordered Rolls-Royce marine gas turbines. The Royal Navy has been operating them for more than ten years.



◁First nonstop flight across the Atlantic
Not Lindbergh, not the NC4, but a Vickers Vimy biplane, piloted by Captain John Alcock and Lieutenant Arthur Whitten Brown, and powered by two V-12 Rolls-Royce Eagle engines. The Vimy left Newfoundland on June 14, 1919, and landed in Ireland 16 hours and 12 minutes later. Average speed was 110 miles per hour. Vickers won £10,000 for the feat. The money was a prize offered by the London Daily Mail.

ROLLS ROYCE

Rolls-Royce Limited, Derby, England
Rolls-Royce Aero Engines, Inc.
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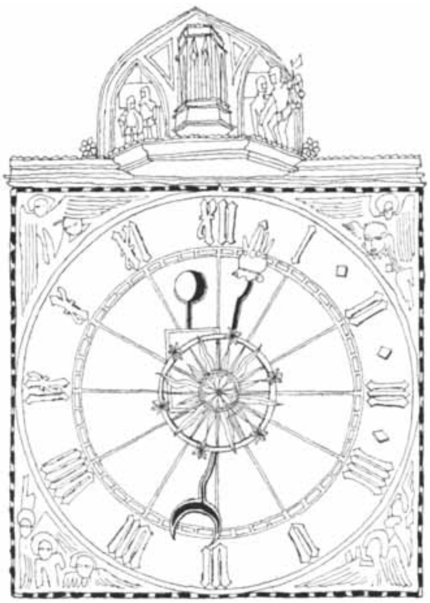


SCIENCE AND

"A More Balanced Program"

The Massachusetts Institute of Technology will retain its two large defense-oriented special laboratories, and they will continue to do secret research. They may do less of it, however. A special M.I.T. panel has urged that the Instrumentation Laboratory and the Lincoln Laboratory should pursue a "more balanced" research program, with less emphasis on military technology and more on the major problems confronting society. The 22-member panel had been appointed by M.I.T. president Howard W. Johnson in April to examine the relation between the laboratories and M.I.T., reviewing the appropriateness of their current work and its effect on the institute's research and education as a whole. The two laboratories do mission-oriented contract research, almost all of it in behalf of Federal agencies and most of it for the Department of Defense; their combined budget has been running about $120 million a year, more than half of the total M.I.T. budget.

The panel found that U.S. emphasis on defense-related research "detracts from similar efforts aimed at other urgent needs of society" and produces a bias in M.I.T.'s total program. It therefore recommended that the laboratories and M.I.T. should "energetically explore new projects to provide a more balanced research program," and do so with "a real sense of urgency." On the other hand, the scientific and technological resources of universities "should be available to support advances in defense-related fields," and the laboratories should therefore continue research on defense problems. On receiving the report Johnson lifted a moratorium on new classified research.

The panel also recommended increased interaction between the laboratories and the M.I.T. campus; "intensive efforts" to reduce classification and clearance barriers, particularly classification that keeps secret the very nature of some work done in the laboratories; appointment of a standing committee of faculty members, students, administrators and laboratory staff members to review the laboratories' programs, advise on the acceptability of specific projects and press for the desired evolution away from military research. In considering what research is appropriate, the panel drew a line between research and development and "the actual development of a prototype weapons system." On that basis, it said, the present Instrumentation Laboratory program to develop a guidance system for the Poseidon multiwarhead missile should be terminated.

Designed Genetic Change

The possibility of human genetic modification is implicit in man's new understanding of the mechanism of the living cell. If an organism's form and function are ordained by its proteins (including its enzymes), if proteins are specified by genes, if genes are segments of nucleic acid molecules whose instructions are written in a genetic code that is now largely deciphered and if means exist whereby bits of DNA can be introduced into living cells—then may it not be possible to design genetic change? The possibility is real, according to Robert L. Sinsheimer of the California Institute of Technology. In an article in the institute's magazine *Engineering and Science* he suggests that the prospect may be analogous to the prospect in the 1930's that the energy of the atomic nucleus might be unlocked: "The principles seem in hand. All that seems really needed is optimism, sustained effort and support commensurate with the importance of the problem."

Sinsheimer defines genetic change as an alteration of any process that appears to be "programmed into us through our inheritance." Such change might be achieved either in a "genetic mode," by changing inheritable characteristics, or in a "somatic (noninheritable) mode," by changing the action of inherited genetic components or supplying components to body cells. Somatic modification is more limited but likely to be achieved sooner. Sinsheimer examines the feasibility of making this kind of change for the "genetic therapy" of diabetes.

In a person with diabetes the beta cells of the pancreas fail to produce enough insulin. In a normal person the genetic instructions for making proinsulin, the precursor of insulin, are probably present in all the body cells but are not activated—are "repressed"—in all but the beta cells. The instructions are presumably present in a diabetic's cells too, but the beta cells have degenerated or the instructions have become repressed even in the pancreas. If that is the case, perhaps one can "turn on" insulin synthesis in the diabetic, if not in the beta cells, then in some other cells. Genes are, in fact, turned on by hormonal and other action in many situations; the beta cells themselves are activated somehow at a stage of embryonic development. The problem is to find an agent that can do this.

An alternative approach would be to supply to some group of cells a new gene or genes that carry the instructions for the synthesis of insulin but that are not subject to repression. The necessary transfer might be accomplished by transduction, in which a virus carries new genetic material into a host cell. Where is one to find a virus carrying the genes of manufacturing insulin? Sinsheimer says: "I propose that we should quite literally, in time, be able to make it to order." In the "not distant future" it should be possible to synthesize the appropriate chain of DNA subunits and wrap it in a proper virus coat.

Beyond such genetic therapy lie the "larger and deeper challenges" of "a new eugenics." One essential in which the new differs from the old eugenics is that the old called for breeding the fit and culling the unfit; the new eugenics can aim to convert all the unfit to the highest genetic level. If that prospect seems frightening, Sinsheimer writes, we should reflect on the alternative; consider "the losers in that chromosomal lottery that so firmly channels our human destinies"—the 200,000 or so children born each year in the U.S. with genetic defects. Faced with this need, he suggests, we should "shoulder the responsibility for intelligent genetic intervention." The concept of designed genetic change, he writes, "marks a turning point in the whole evolution of life. For the first time in all time a living creature understands its origin and can undertake to design its future."

X-Ray Pulsar

X-ray detectors sent aloft in rockets have disclosed that a pulsar in the Crab Nebula generates X-ray pulses in precise step with its radio and optical emissions. The pulsar, designated NP 0532, emits a pulse every .033099522 second, the highest flicker rate yet observed in a pulsar. The first evidence for a pulsating radio source near the center of the Crab Nebula was reported last November. Two months later observers at the University of Arizona recorded the first optical flashes from the object. The source was subsequently identified as a star of about the 16th magnitude previously hypothesized to be the remnant of a supernova seen on the earth in A.D. 1054. The suspicion is growing that many if not all of the 30-odd pulsars now known may be supernova remnants. None of the others, however, has yet been identified with a visible object.

The first detection of X-ray pulses from an object believed to be NP 0532 was made during the flight of an Aerobee rocket launched from the White Sands Missile Range in March. The experiment was conducted by G. Fritz, R. C. Henry, J. F. Meekins, Talbot A. Chubb and Herbert Friedman of the Naval Research Laboratory. They estimate in *Science* that the X-ray power of the pulsar is 200 times its optical power and 20,000 times its radio power.

A subsequent rocket flight carried out by Hale V. Bradt, Saul A. Rappaport and William F. Mayer of the Massachusetts Institute of Technology positively identified the Crab X-ray source with NP 0532. With the help of observers at the McDonald Observatory (R. E. Nather, Brian Warner and Malcolm MacFarlane) and at the Mount Wilson and Palomar Observatories (Jerry Kristian) they proved that the X-ray pulses arrive at exactly the same time as the optical pulses.

The Peroxisome

A new organelle, the peroxisome, has been added to the growing list of organized elements that populate the cytoplasm of the living cell. The peroxisome takes its place with such organelles as centrosomes, ribosomes, mitochondria, Golgi bodies, lysosomes and (in plant cells) chloroplasts. As more organelles are identified and as their relations are clarified by cytochemistry, electron microscopy and biochemistry, the cytoplasm—which once seemed to be an amorphous gel—takes on more and more the appearance of a highly organized structure of interconnected elements.

The peroxisome was first identified in 1960 by Christian de Duve, of the University of Louvain in Belgium and Rockefeller University, and his colleagues. They noticed that when rat liver cells were spun in a centrifuge, certain enzymes behaved in a way that showed they were associated in a single particle. They called the particle the peroxisome because the enzymes produce hydrogen peroxide and then break it down. De Duve reviewed current knowledge of the peroxisome at a Royal Society discussion meeting last year and his paper has now appeared in the *Proceedings of the Royal Society of London*.

Peroxisomes and related particles are apparently widely distributed in animals and plants. They are probably not present in all cells, however, and they seem to vary widely in enzyme content from species to species; their function in each is therefore not clear. In rat liver and kidney they reduce oxygen to water via hydrogen peroxide (H_2O_2); they do this by oxidizing various substrates: removing electrons from them and transferring the electrons to the oxygen and hydrogen peroxide. This respiratory process is suggestive of what happens in mitochondria, but in mitochondria it produces ATP, the primary energy currency of the cell. In peroxisomes the respiratory system is not, as far as is known, coupled to any energy-producing mechanism. Moreover, in certain protozoa and plants the respiratory function is only part of the story. The peroxisomes in these organisms include enzymes for another metabolic process, the glyoxylate cycle, in addition to the enzymes that catalyze the respiratory process.

Fuzzy Shell

New information about the architecture of the atomic nucleus has been obtained by creating atoms in which a *K*-minus meson, or kaon, spins in tight orbits around a nucleus for less than 10^{-12} second before it encounters a nuclear particle and is annihilated. As the kaon falls toward the nucleus in a succession of quantum jumps it emits X rays of shorter and shorter wavelength, which reveal the radius of the final orbit before annihilation. It turns out that a kaon will generally encounter a nuclear particle at a distance 10 percent greater than the radius of the nucleus as determined by previous methods. These methods, which show the region occupied by protons, show that a typical nuclear radius is about five fermis. (A fermi is 10^{-13} centimeter.) Kaons, however, encounter nuclear particles and are annihilated at a distance of about six fermis from the center of the nucleus. The inference is that outside the central region occupied by protons there must be a fuzzy shell occupied by neutrons.

The experiment was conducted by Clyde Wiegand using the six-billion-electron-volt accelerator of the Lawrence Radiation Laboratory at the University of California at Berkeley. The proton beam of the accelerator generates kaons when it strikes a suitable target; the kaon beam, in turn, is directed toward a target of the particular element being studied. To date Wiegand has been able to put kaons in orbit around 24 different elements ranging in mass from lithium to uranium. The X rays emitted by the "kaonic" atoms are analyzed by a nuclear X-ray spectrometer built at the laboratory with the help of Fred Goulding and Richard Pehl.

Mountain Power

A 1,000-megawatt pumped-storage hydroelectric plant, the largest installation of its kind in the world, is to be built at Northfield Mountain in western Massachusetts. The project, which is scheduled for completion in 1971, is a major element in the long-range strategy adopted by the power companies of the New England states to meet the growing demand for electric power in that region by combining two principal methods of power generation: nuclear-fueled steam generating systems and pumped-storage hydroelectric systems. The rationale behind the new strategy is outlined in a recent issue of *IEEE Spectrum* by Sherman R. Knapp, chairman of Northeast Utilities.

Historically electric utilities in the U.S. have met the demand for long-hour base-load generating capacity with fossil-fueled steam-generating plants. The morning and evening peak loads have been supplied by "limited pondage" hydroelectric plants located on the major rivers or by older, less efficient steam units. According to Knapp, two problems forestall further expansion in this direction: "Utilities such as those in the

Basic Research at Honeywell
Research Center
Hopkins, Minnesota

The use of Infrared Detection in Industrial Measurement of Temperature

New processes and materials have increased the need for devices measuring temperatures from 100° to 500°F. Sensing Infrared energy may offer practical solutions.

Industry today, working with plastics, rubber, textiles, paper and glass, requires a new order of devices for temperature measurement, with greater precision, speed of response, and reliability. Requirements vary considerably for production processes, however most uses demand a device which can make a very rapid and accurate measurement of a small "target" portion of the product. Because the product may be moving rapidly or may be corrosive, the sensing must be accomplished without coming in contact with the surface.

One basic temperature measurement device, the thermocouple, is still used. Unfortunately, the sensing portion of the thermocouple is usually placed in a mold or tool, so it yields an *indirect* measure of average heat. Also, a thermocouple requires a large temperature differential between the sensor and the reference junction to produce a practical measureable voltage.

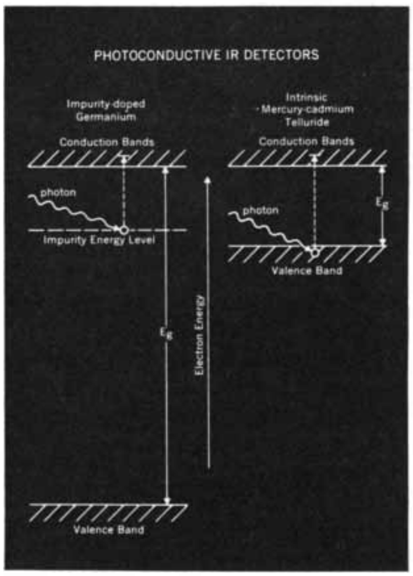
Connecting a number of thermocouples, in series, as in a thermopile, does increase the voltage output, but both the thermocouple and thermopile share the additional disadvantage of slow response.

If we could measure heat (radiant energy) rather than heat transfer directly, the delay in response would be eliminated. Radiant, or infrared energy, is directly proportional to temperature by the formula: $E = \epsilon\sigma T^4$ (σ = emissivity constant). The amount of infrared radiation is determined by the number of photons which are emitted by a hot object and by their energy or wavelengths. An instrument which counts the number of photons of the proper energy would give a signal which could be directly converted to temperature.

Semiconductors convert photons of infrared radiation into signals. One elemental semiconductor, germanium — to which impurities have been added to produce "doped" germanium — has been used in temperature measurement. When IR radiation impinges on a doped crystal of germanium, the photons are absorbed by electrons from the crystal impurities. The photon energy enables the electrons to escape the bonds holding them to the atoms. In this phenomenon, called photoconductivity, the photo-excited electrons carry a current freely through the crystal which can be measured electrically and converted to a measure of temperature.

However, doped germanium detectors are largely restricted to laboratory or military use because only small amounts of impurities can be added to pure germanium crystals, resulting in few potentially excitable electrons and a faint signal. These faint photoelectric signals are obscured by conduction from thermally excited electrons unless the sensor is housed in an elaborate liquid helium cooling apparatus.

To eliminate the low temperature requirement limiting the practical use of doped germanium detectors, scientists at Honeywell began, in 1960, to search for a compound with intrinsic excitability, on the theory that, if the electrons of the crystal material itself could be photoexcited, there would be a greater number of current-carrying electrons and a stronger signal.



Electron energy level diagram of photoconductors. The small impurity energy gap gives germanium its photoconductive property.

The Honeywell scientists assumed that an alloy combining a compound having a vanishingly small energy gap, with a wide energy gap semi-conductor compound, would have intrinsic excitability. After comparing a number of different alloys, they developed a photoconductive alloy of mercury telluride and cadmium telluride which could effectively sense lower energy, longer wavelengths, and which could be cooled either thermoelectrically or by liquid nitrogen, thus obviating the need for an elaborate apparatus.

The alloy mercury-cadmium telluride also proved to be designable. By varying the amounts of HgTe and CdTe, an alloy could be designed to yield an optimum response at the specific wavelength dictated by the temperature of the material being measured.

Since these materials are extremely sensitive to the presence of impurities, highly pure single crystals of the alloy had to be produced. By solidification from a molten mixture of HgTe and CdTe, homogeneous crystals were grown to fit specific industrial requirements. The crystals, combined with optical equipment to focus the radiation, plus a signal amplifier and a cooling system, produce a practical industrial instrument which is now being used at temperatures ranging from room temperature to greater than 2000° F. The Honeywell infrared pyrometer can measure temperature in less than 10 ms at temperatures from 100° F., with a target size of less than .25 sq. in. Error tolerances are ±2% and repeatability is 0.5%.

Future research will center on the problem of greater accuracy, particularly in room-temperature applications.

If you are working in the field of infrared pyrometers, and want to learn more about Honeywell's research in infrared detection, contact Dr. Donald Long, Honeywell Research Center, Hopkins, Minnesota. If you are interested in industrial applications for Honeywell's infrared pyrometer contact Mr. John Myers of the Honeywell Research Center. If you have an advanced degree and are interested in a career in research at Honeywell, please write to Dr. John Dempsey, Vice President Science and Engineering, Honeywell Inc., 2701 4th Avenue So., Minneapolis, Minn. 55408.

Honeywell
AUTOMATION

northeastern region of the U.S. are remote from sources of fossil fuel and are faced with rising rail and water transportation costs. At the same time, development of hydro-generating facilities on the rivers is reaching the point of full utilization of the natural head."

In view of this situation power companies are turning increasingly to nuclear-fueled steam generating stations to meet their base-load requirement more economically. And it is the low incremental energy cost of power from large-scale nuclear plants, Knapp asserts, that makes the consideration of pumped-storage hydropower very attractive.

The method of operation of a pumped-storage hydro plant such as the Northfield Mountain project is quite simple. During base-load, or off-peak, hours of the day a certain fraction of the power-generating capacity of a large non-project power plant is devoted to pumping water from a lower reservoir to an upper reservoir. Then during peak-load hours the system operates as a generator by releasing water from the upper reservoir through hydroelectric turbines to the lower reservoir.

Among the many advantages of such a system is the fact that "the pumped-hydro plant can be designed in such a manner that it can be brought on the line rapidly enough to be classed as a reliable source of spinning or assured reserve capacity at all times. Further, its ability to accept or reject load almost instantaneously makes it much more flexible than other types of generation, peaking or base load."

Natural Weed Killer

A substance secreted by one of the nitrogen-fixing soil bacteria has proved to be a powerful plant poison that has two major advantages over the synthetic herbicides now in use: the toxin has little or no effect on animal life and it degrades without residue within 72 hours after reaching the soil. Named rhizobitoxine by L. D. Owens of the Agricultural Research Service, the substance is manufactured by certain strains of the bacterium *Rhizobium japonicum* and was first detected in the root nodules of soybeans. By the culture of the productive strains in the laboratory, amounts of the toxin adequate for experiment are now being produced.

Rhizobitoxine is poisonous because it has an affinity for an enzyme that normally promotes the synthesis of protein in plant growth processes; the toxin inactivates the enzyme on contact, halting further plant development. Because no such biochemical pathway exists in the synthesis of animal proteins, the poison should be harmless or only slightly toxic to animals. Against young plant growth and new leaves the poison is effective in applications as dilute as three ounces per acre, but it causes little harm to mature plants. For use against weeds it would be sprayed on fields after they were sown but before the crop seedlings had emerged, and it would later be applied directly to the ground under the foliage of the maturing crop. The use of rhizobitoxine on a commercial basis, however, awaits the development of an economic means of manufacture.

Abyssal Oil?

Navy oceanographers have discovered that there may be oil-bearing formations in the deep-ocean floor of the Atlantic, well beyond the continental shelf. According to Eric Schneider of the Naval Oceanographic Office, seismic-reflection records made by the research ship *Kane* last July disclosed the existence of geologic structures resembling salt domes in sedimentary layers of the ocean bottom at a depth of 15,000 feet, northwest of the Cape Verde Islands. Salt domes are widely associated with oil deposits on land, in shallow seas and on continental shelves. The Cape Verde structures also resemble an oil-bearing salt dome discovered at oceanic depth in the Gulf of Mexico last summer by the deep-drilling ship *Glomar Challenger*.

The presence of salt domes in the deep-ocean floor is something of a surprise because it contradicts the prevailing geological view of such structures. According to this view, the salt of the domes was deposited in warm, shallow, landlocked seas. The rapid evaporation of such a sea caused salt to crystallize and sink to the bottom, where it was covered with layers of sediment rich in decaying organic matter. The circulation of the sea would have been sluggish and its oxygen content low; its sediments would have been poor in aerobic bacteria, which normally break down the carbon compounds of organic matter. Thus hydrocarbons could accumulate and form oil deposits. Later the salt, which has a specific gravity lower than sediment, pushed upward in domes, carrying with it some of the oil in the layers above it. This kind of formation not only survives on dry land and in later shallow seas but also might have subsided to deeper levels; such subsidence might account for the salt dome in the Gulf of Mexico.

The shallow-sea concept does not, however, satisfactorily explain the salt domes in the deep Atlantic floor. An area the size of the Gulf of Mexico might subside, but it is unlikely that an entire ocean basin would. For this reason Schneider has put forward an explanation based on the concept of continental drift. This concept holds that the Atlantic was once a narrow, landlocked but deep "proto-ocean" separating South America and Africa. According to Robert F. Schmalz of Pennsylvania State University, who has done the relevant geochemical calculations, salt domes and oil could form in such an ocean much as they would in a shallow sea: evaporation would cause salt to crystallize and sink, the lack of strong currents and oxygen would lead to the formation of oil, and salt domes would rise through the sediment.

The *Kane*'s discovery indicates that the world's reserves of petroleum may be much greater than has been estimated. It may also raise legal questions as well as scientific ones. If there is oil on the deep-sea floor, who owns it?

Total Pulp

A new process for converting wood into pulp has been disclosed by workers at the Institute of Paper Chemistry in Appleton, Wis. The process, which is called holopulping to reflect its ability to retain in the pulp nearly all the cellulose and other carbohydrates from the wood, has proved successful in the institute's laboratory and soon will be tried on a larger scale in a pilot plant. The workers at the institute, noting projections that the demand for paper and paper products will require a doubling of pulp production within the next 20 years, foresee holopulping as a major supplement to the traditional sulfite and sulfate methods of chemical pulping.

Pulping involves separating the lignin of wood from the cellulose and other carbohydrates. The chemical pulping processes degrade the lignin so that it becomes soluble and can be drawn off with a solvent; cellulose remains in fibrous form for use in the manufacture of paper. The sulfite and kraft processes also attack the carbohydrates to a certain extent. Holopulping involves a selective delignification that focuses on the lignin and leaves more of the carbohydrates.

In holopulping, the wood, in the form of fine chips, is subjected to a process that modifies the lignin with a mild oxidant such as chlorine dioxide. The lignin is then extracted with a solvent such as sodium hydroxide, and the pulp is bleached with hypochlorite.

Today's planes are riveted, welded and bolted together piece by piece. There's a lot of skilled (and expensive) hand work involved.

Most of tomorrow's aircraft will probably be wound in single units without seams or fasteners . . . fuselage, wings, tail assembly. A computer will handle each operation precisely, automatically.

These processes of Monsanto's Goldsworthy Engineering subsidiary are called Filament-tape Placement and Filament Winding. Super-strong, uniquely rigid filaments of boron, graphite or fiber glass can be wound or placed onto a mandrel in the shape of a fuselage . . . or wing, or tail. And because the relative thickness of each layer of filaments is only a few thousandths of an inch, it's possible to make any part as thick or as thin as you want at any point.

The result is a new kind of tailor-made airframe . . . pound for pound more than *twice* as strong and stiff as steel.

At Monsanto, we're constantly solving problems by exploring the total science spectrum. Monsanto—where science and research are working for people.

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

Coexistence on

King Ranch is a hunk of pure Americana under the huge Texas sky. It is a lot of things in a large place. And they all get on remarkably well together.

There are thirty thousand cattle and twenty-eight oil and gas fields; two thousand miles of fencing and one thousand miles of buried pipeline; over three hundred windmills and the world's largest natural gas plant. You can see it in our picture.

There are schools and stores and fire stations. Five hundred cowboys. Two thousand cow ponies. A training track for race horses. And five hundred miles of private road. Yet there is more wildlife on the ranch today than ever before in its history.

We, at Jersey, believe this last fact proves something about our affiliate, Humble Oil & Refining Company. Good housekeeping.

They have been drilling for oil and gas on the ranch for forty-five years. If running an oil field were the noisy, messy business some people think it is, how come wild geese, wild turkey

the King Ranch.

and bobwhite quail elect to stay and multiply by the thousand?

If pipelines and gas plants pollute the water, how come deer, nilgai and javelinas guzzle it? And thrive.

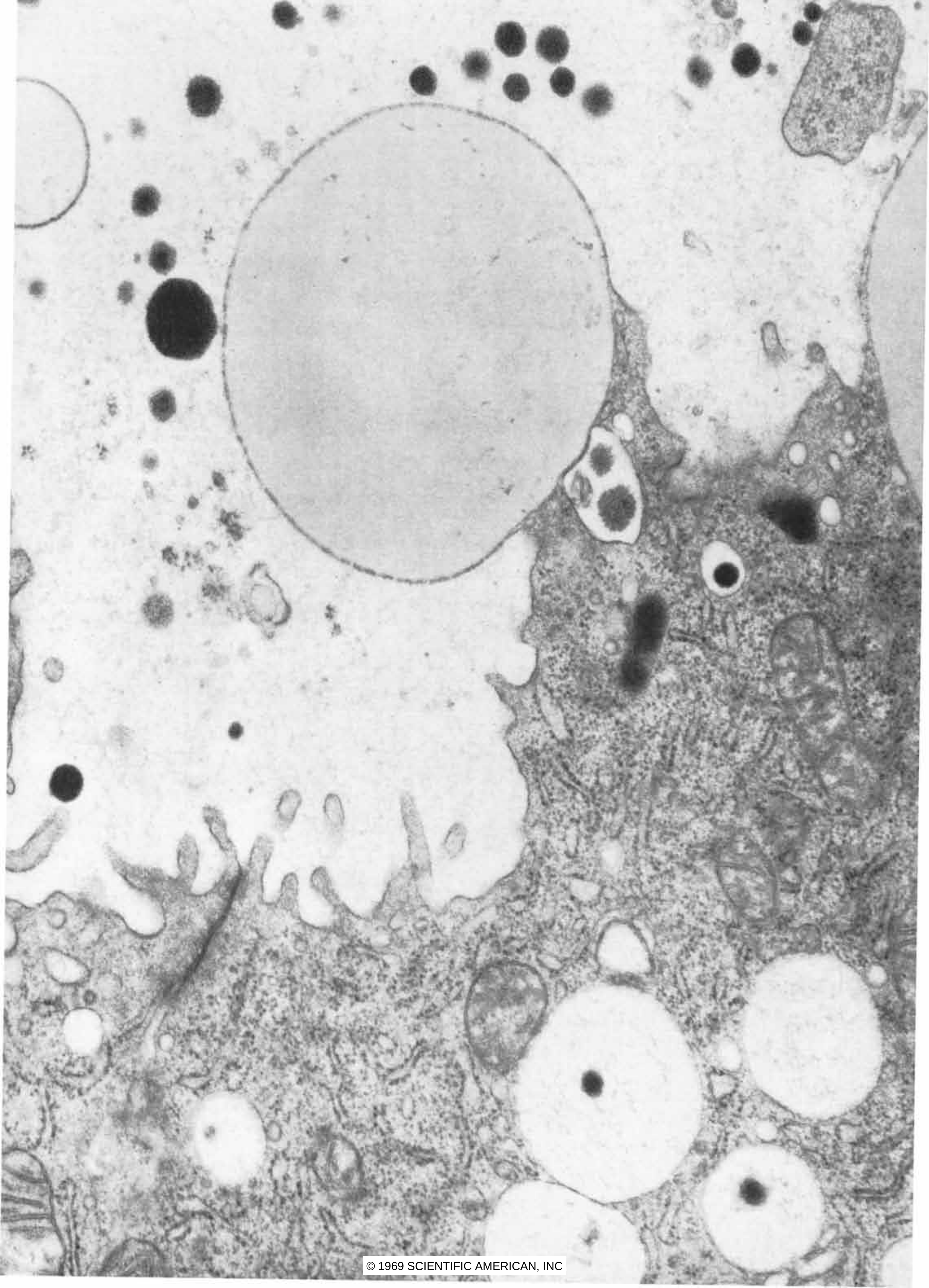
One more point about this precious water. The King Ranch gas plant uses thousands of gallons an hour for cooling purposes. When this water is returned to the ponds and creeks, the cattle drink it.

These include the famous Santa Gertrudis, the first breed of cattle developed in the Western Hemisphere. They are now bred in forty-eight foreign countries. Quite an export.

Would the owners of King Ranch expose these rich, red beauties to anything less than good water? Not on your life.

Standard Oil Company (New Jersey)

Esso



MILK

The fluid made by the mammary gland is a remarkable blend of complex biological molecules. How the gland does its work is the subject of active investigation

by Stuart Patton

According to the census of manufactures taken in 1967 the production, distribution and sale of dairy products constituted the seventh largest industry in the U.S., exceeded in value of shipments only by the motor vehicle, steel, aircraft, meat, petroleum and industrial-chemical industries. The basic product of the dairy industry is of course milk, which in the year of the census was produced in the amount of 118,769,000,000 pounds by 15,198,000 cows. As one might expect, the basic product has been studied intensively: nearly every state university has a program of dairy research, and the industry itself maintains a substantial research program. Notwithstanding these activities, much remains to be learned about milk. One reason is that milk is a remarkably complex substance; another is that the cellular processes whereby it is produced in the mammary tissue are highly intricate.

Milk's role, as a nearly complete food, in sustaining life processes is well known. Of equal importance is its role as a product of life processes. Milk is a record of the exquisite functioning of a cell, a fascinating cell that might be described as a factory, but a factory with the unusual property of becoming, to a certain extent, a product. Indeed, the lactating mammary cell ranks second in importance only to the photosynthesizing cell as a factor in sustaining life. For these reasons I shall focus here on the biology of milk, dealing to a lesser extent with its physical and chemical properties.

One's senses readily ascertain that cow's milk is a white, opaque liquid with characteristics of odor and flavor that are normally quite faint; a taste shows that it is slightly sweet and just perceptibly salty. One might go a step further and reason that rather large particles or molecules must be suspended in milk, because if all the constituents were fairly small dissolved molecules, milk would be as clear a solution as water is. Milk does have large components in suspension; they are mainly globules of fat and particles of protein.

Constituents of Milk

These observations indicate the gross composition of cow's milk: it is about 3.8 percent fat, 3.2 percent protein, 4.8 percent carbohydrate, .7 percent minerals and 87.5 percent water. Such an analysis, however, greatly oversimplifies cow's milk. For example, milk contains a large number of trace organic substances, some that pass through the mammary gland directly from the blood and others that result from the synthesis of milk in the mammary tissue. Moreover, the fat globules contain thousands of different molecules and are enclosed by a complex membrane acquired at the time of secretion. Milk protein was originally thought to have three components: casein, albumin and globulin. It is now known that there are four caseins, each with a number of genetic variants, and that albumin and globulin are actually a complex group of proteins known as the whey proteins. The number of proteins eventually discovered in this group probably will be limited only by the patience of the investigators and the sensitivity of the methods they apply. Only lactose, the sugar of milk, seems to be a pure and relatively simple compound.

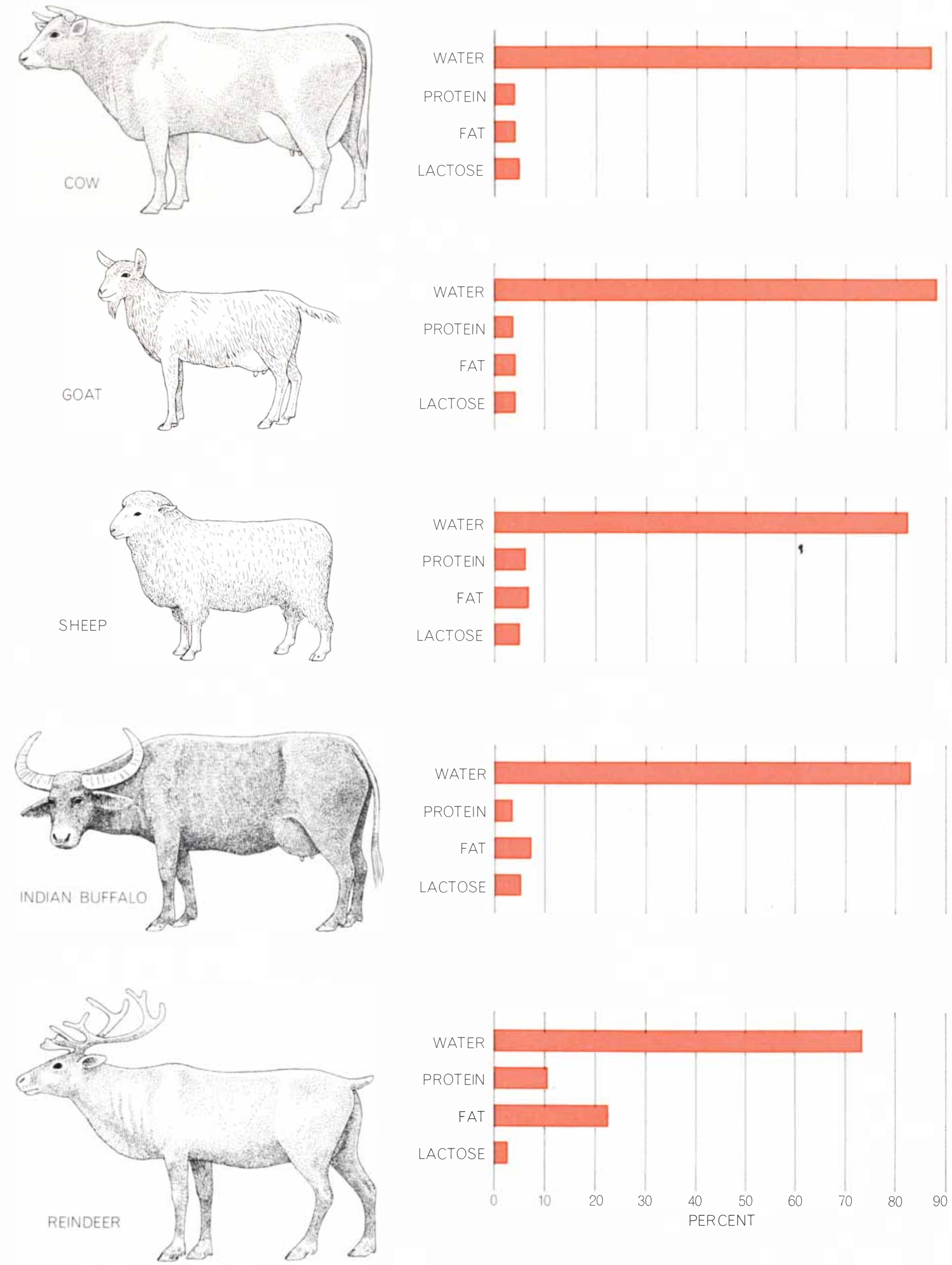
The statements that can be made about cow's milk do not apply uniformly to the milk of other mammals, because there are large variations in the composition of milk. For example, the pinnipeds (the group of aquatic mammals including seals, sea lions and walruses) have milk that is often like heavy cream, containing 40 to 50 percent fat. In addition, depending on the species, pinniped milk contains little or no lactose. These variations can be explained in terms of their value in assisting the survival of the young of the species. A young pinniped is in special need of fat (in the form of blubber) as insulation against its cold environment, as an aid to buoyancy, as a source of energy and as a source of metabolic water in a salty environment.

A Closer Look

With the request that the reader keep in mind the important fact that milk differs substantially among mammalian species, I shall now be discussing milk in terms of cow's milk. Because of its commercial importance as a food and a raw material for foods, more is known about it than about the milk of other mammals. Moreover, the mechanisms of the synthesis of milk by the cow have been investigated closely because of the cow's importance as a unit of agriculture.

In addition to the major constituents already described, milk contains a large number of substances that occur in small amounts, ranging from .1 percent or so down to parts per billion. Among them

LACTATING CELL secretes a droplet of milk fat in the electron micrograph on the opposite page. The fat droplet is the large circular object at top center. The dark region from which it is emerging is the cell; the light region the droplet is entering is the lumen, or hollow portion, of an alveolus, one of the many pear-shaped structures that are basic units in lactation. The small dark circles visible in several places are granules of protein. The electron micrograph, which is of mammary tissue of a mouse, was made by S. R. Wellings of the University of Oregon Medical School; the enlargement is about 48,000 diameters.



COMPOSITION OF MILK yielded by five kinds of animal is compared. In a few species the variation is even more marked; for example, the pinniped group, which includes seals and walruses, has milk that is about 50 percent fat and contains little or no lactose.

are fatty acids, amino acids, sugars and sugar phosphates, proteoses, peptones, nitrogenous bases, gases and other volatiles. Many of these substances, such as the vitamins and minerals, play a key role in nutrition. Nonetheless, the most important components of milk are the lipids (fats), the proteins and the carbohydrate (lactose). A more precise description of them will lay a foundation for considering the remarkable processes of their synthesis and secretion by the cells of the mammary gland.

The term lipid specifies a broad group of fatty (greasy, waxy or oily) substances found in biological systems, including those used for food. The term fat is often used interchangeably with lipid, but in fact fat refers more narrowly to edible oils or the characteristically fatty tissue of the animal body. The lipids in milk are sometimes called its butterfat content; they exist as minute droplets or globules that under proper conditions will rise to form a layer of cream. The process known as homogenization reduces the globules in size and stabilizes their suspension, so that they no longer form a layer of cream. Agitation, in the form of churning, causes the globules to aggregate into granules that can be gathered and worked into butter. Butter is about 80 percent fat, and the part that is not fat is mainly water. If butter is melted, clarified and dried, it yields a product that is almost 100 percent fat and is known as butter oil; it is used commercially in the making of candy and baked goods.

The fat droplets in milk have an average diameter of three to four microns (about .00014 inch). A droplet consists of a membranous coat about .02 micron thick and a core that is virtually pure glyceride material. A glyceride is the ester, or product, resulting from the combination of glycerol with fatty acid. Because a molecule of glycerol has three reactive sites, it is possible to have monoglycerides, diglycerides or triglycerides, depending on how many molecules of fatty acid react with each molecule of glycerol. The lipids of milk are mostly triglycerides.

The fatty acids that are esterified with glycerol to form glycerides can vary in many ways. At least 150 different fatty acids can be found in the glycerides of milk, but only 10 of them occur consistently in amounts larger than 1 percent of the total. The principal ones are oleic acid, palmitic acid and stearic acid, which are also common in the glycerides of many other natural fats. The fat of cow's milk is unusual in that it contains the short-chain fatty acids, including butyric acid and caproic acid. Short-chain fatty acids are also found in the milk fat of other ruminants, such as the sheep and the goat. As I shall describe more fully below, the rumen, or first stomach, in these animals has a profound effect on their metabolism and on the composition of their milk fat. Another point to note in passing is that the short-chain fatty acids are highly odorous, and when they are released from the glycerides by the enzymes known as lipases, they contribute significantly to the flavor of many kinds of cheese.

The membrane that forms the surface of the milk-fat droplet is derived from the outer membrane of the lactating mammary cell at the time of secretion. It also appears to include materials that were at the surface of the droplet while it was still in the cell. The structure and composition of the membrane are the subject of intensive study. It is known that the portion of lipids not accounted for in the triglyceride fraction is involved in the membrane. The membrane lipids include part of the milk's cholesterol, phospholipids and glycolipids and most if not all of the vitamin A and carotene (a yellow pigment). The membrane also comprises unique proteins and enzymes, and its structure seems to be an aggregate of lipoprotein subunits. All in all, the milk-fat globule—a droplet of fat wrapped in a membrane—is a remarkable biological package.

Proteins of Milk

As with proteins in general, the proteins of milk are fundamentally chains of amino acid units. Since there are 18 common amino acids, the number of protein chains that could be formed is very large indeed. About 80 percent of the protein in milk, however, is casein. No other natural protein is quite like it. One aspect of its uniqueness is that it contains phosphorus; it is known as a phosphoprotein. In milk the molecules of casein are marshaled in aggregates called micelles, which are roughly spherical in shape and average about 100 millimicrons in diameter.

Casein occurs in four distinct types called alpha, beta, gamma and kappa, respectively representing about 50, 30, 5 and 15 percent of this protein. The four types differ in molecular weight and in a number of other characteristics. Kappa casein is unique in that it contains a carbohydrate, sialic acid. Little is known about the internal organization of the casein micelle and its subunits. It is assumed, however, that each subunit contains each of the four caseins.

The alpha, beta and gamma caseins can be made to aggregate by calcium ions, but kappa casein is highly resistant to such aggregation. Hence kappa casein serves as a protective colloid that keeps the casein micelles themselves from aggregating, which would give milk a curdlike consistency. In the making of cheese the enzyme rennin is added to milk to promote the formation of curds; the enzyme splits from kappa casein a peptide containing sialic acid, thereby destabilizing the casein micelles and giving rise to the formation of curds. After the resulting whey, or watery portion, has been drawn off, the curd can be used to make cheese.

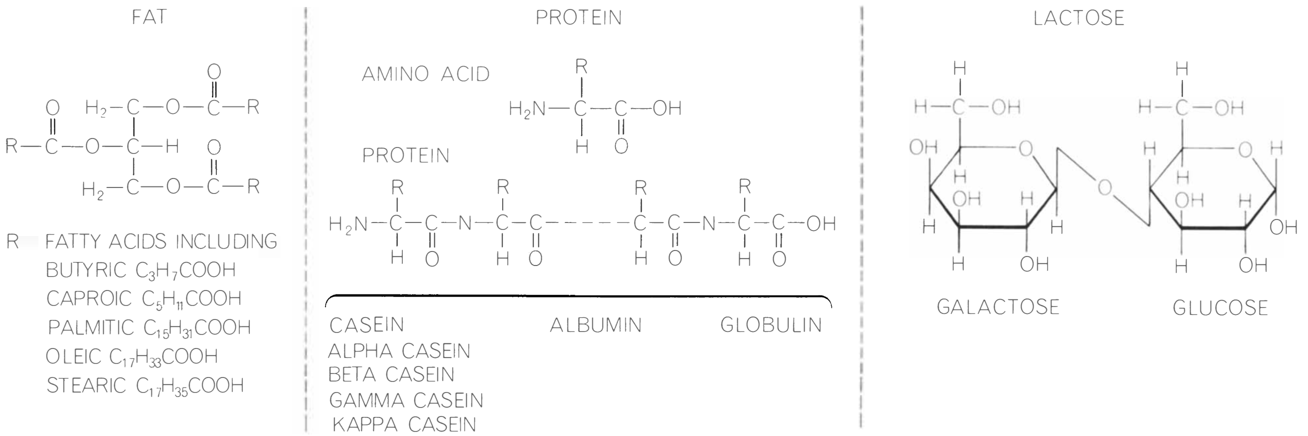
Another protein unique to milk is beta-lactoglobulin, which accounts for about .4 percent of milk and is found in two common forms, *A* and *B*, and two uncommon ones, *C* and *D*. Beta-lactoglobulin contains a comparatively high proportion of the amino acid cysteine, which bears a reduced sulfur group (—SH). When milk is heated, these groups (starting at a temperature of about 70 degrees Celsius) are released from the protein as hydrogen sulfide; this is the source of the cooked flavor in heated milk.

Beta-lactoglobulin has much practical importance for the processing properties of milk proteins. If it is denatured beforehand, evaporated milk is stabilized against coagulating during sterilization by heat. On the other hand, if milk for cottage cheese is overheated so that the beta-lactoglobulin is denatured, an unsatisfactory soft curd is formed. Presumably the denatured protein is adsorbed on the surface of the casein micelles, thus hindering the action of rennin and the coalescence of the casein into a curd.

Enzymes are of course proteins too, and freshly secreted milk contains a great abundance of them. Robert D. McCarthy, working with radioactively labeled substances in our laboratory at Pennsylvania State University, has shown that enzymes in milk can incorporate fatty acids into glycerides and phospholipids and can convert stearic acid into oleic acid. It is also known that milk can synthesize lactose from added glucose. Such activities make it appropriate to describe milk as an unstructured tissue, in many ways resembling the enzymatically active solid tissues of the body.

The Carbohydrate of Milk

The substance responsible for the slightly sweet taste of milk is lactose, a



CONSTITUENTS OF COW'S MILK, exclusive of water and minerals, are portrayed with diagrams of basic chemical structure of its fat, protein and lactose. Casein is the major protein, and lactose the carbohydrate, of milk. Milk has many other fats and proteins.

carbohydrate with about a fifth the sweetness of ordinary sugar. Like casein, lactose is found only in milk. Lactose is composed of a molecule of galactose combined with a molecule of glucose, the simple sugar of the blood.

Since lactose is found only in milk, and only in the milk of certain species, one wonders why it is there. Indeed, it is reasonable to ask why milk contains carbohydrate of any kind, inasmuch as the most obvious role of lactose—providing a source of energy for the newborn—is filled by fat in milk from species such as the pinnipeds. The synthesis of lactose in the mammary gland does lock up molecules of glucose drawn from the blood, and since glucose is a highly active metabolite that might otherwise go elsewhere in the body or be metabolized in a different way, it may be that the synthesis of lactose provides a means of ensuring that glucose remains in the lactating cell and so becomes a part of the milk. Another possible role for lactose arises from its solubility; soluble molecules are important to the osmotic relations of cells, and lactose, which accounts for approximately 5 percent of milk, probably affects the osmotic relations of the lactating cell. Lactose may also be the carbohydrate of milk because it encourages certain desirable bacteria, which form lactic acid, to thrive in the intestine. Lactic acid is thought to promote the absorption of the calcium and phosphorus the young animal needs for the formation of bone. In any event, it would appear that the net effect of lactose from an evolutionary point of view was to promote the survival of the young, and so its synthesis was favored by natural selection.

A factor in the synthesis of lactose is the enzyme lactose synthetase, which is composed of two proteins. One of them, the *B* protein, was identified by Urs Brodbeck and Kurt E. Ebner of Oklahoma State University as alpha-lactalbumin. Thus for the first time a metabolic function for one of the principal milk proteins was identified. Then it was shown by a group at Duke University that the *A* protein is an enzyme that normally incorporates galactose into glycoproteins. In the presence of alpha-lactalbumin the enzyme has its specificity changed to the promotion of the reaction of galactose with glucose to form lactose. This seems to be the only case known where such a protein modifies the specificity of an enzyme. In subsequent work led by Roger W. Turkington the Duke group showed that organ cultures of mouse mammary gland, when pretreated with the hormones insulin and hydrocortisone, would produce both *A* and *B* proteins after treatment with the hormone prolactin. These three hormones are known to be necessary for the synthesis of milk in the mouse to begin.

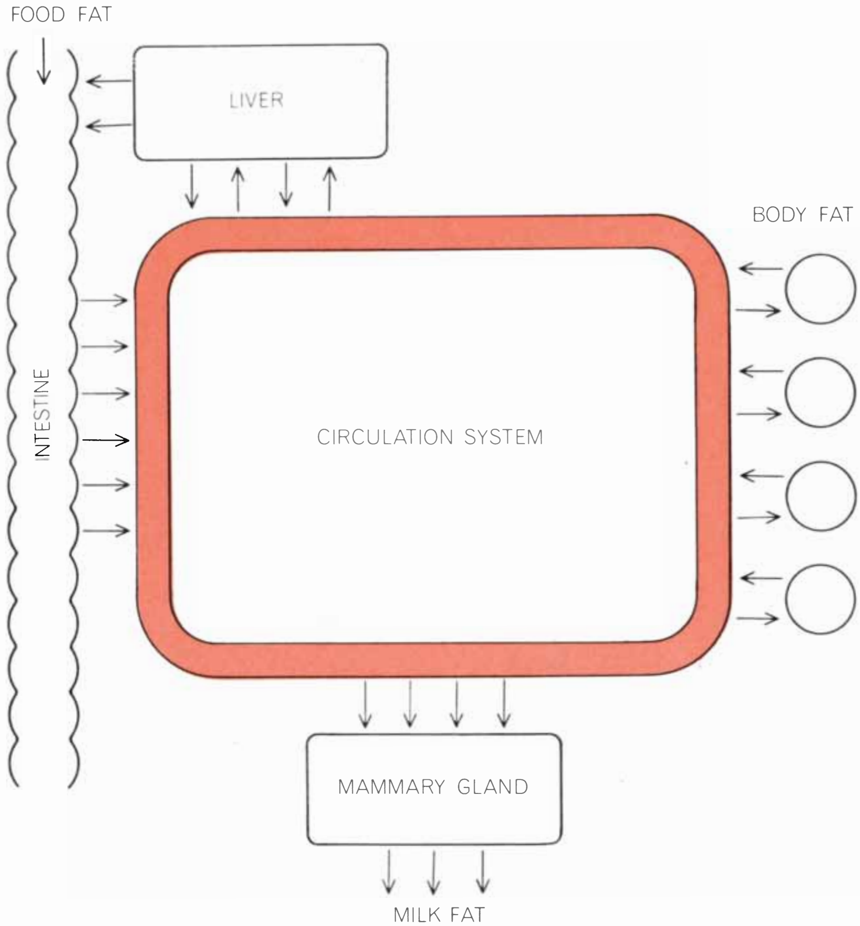
In sum, the synthesis of lactose depends on enzymes, and the synthesis of the enzymes depends in turn on several hormones, which ultimately are also regulating the synthesis of the other components of milk. It is particularly interesting that lactose synthetase not only figures in the synthesis of lactose but also is present in the milk. This is evidence for my earlier observation that in milk production the factory becomes to a certain extent the product.

The Lactating State

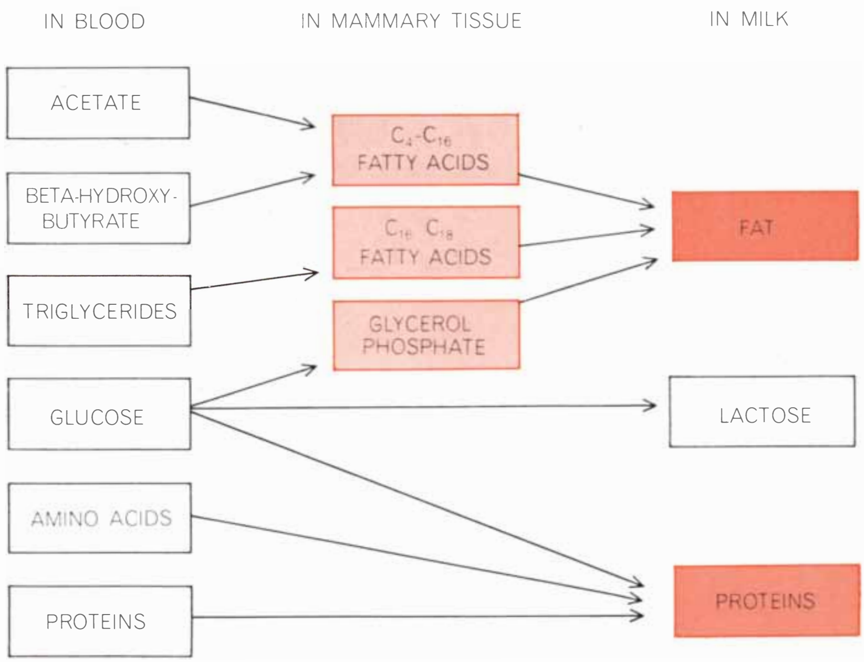
In considering the synthesis of milk it is necessary to recognize that the process is related to all the other processes going on within the animal. It is an integral part of the animal's total metabolism. A case in point is the relation of milk fat to the other fats in the animal. Milk fat is immediately derived from two main sources: lipids circulating in the blood and synthesis from simple metabolites in the mammary gland. The origin of the simple metabolites traces back to the blood, to various sites in the body and ultimately to the food. The lipids circulating in the blood arise from all the many locations of lipid synthesis, transformation and storage in the body [*see top illustration on page 64*].

It is also necessary to consider metabolic activity at the cellular level. Clearly the lactating mammary cell, which is continuously turning out fat, protein, carbohydrate and many other substances, is not a resting cell—a cell that is simply maintaining itself. It is a busy place, with substances constantly moving in through the basal parts of the cell and out through the secreting parts. Some of the substances are used to maintain the cell and others are merely transported through the cell, but most of them are used by the lactating cell in the synthesis of the major constituents of milk.

Another consideration in the cow is the rumen, which is in effect a large fermentation tank ranging in capacity from 30 to 60 gallons depending on the size of the animal. Plant materials eaten by the cow are broken down in the rumen by a large and highly diverse population of bacteria and protozoa. The changes in the food are of major importance. Cellulose, which man cannot digest, is readily broken down in the rumen, and the products—acetate, propionate and butyrate—are prime metabolites in the bovine metabolic economy. Another sig-



PATHWAYS OF FAT in the body indicate the sources of the fat in milk and thereby the mechanisms by which milk is synthesized. Fat from food enters the bloodstream through the intestines and also from the body's reserves of fat and from the liver. The mammary gland draws on these sources of raw material for the synthesis of the droplets of fat in milk.



RAW MATERIALS of milk are depicted in a scheme showing the materials from the blood that are used by the mammary tissue in the synthesis of milk. Information on the materials going into the synthesis is obtained with radioactive tracers and by measuring changes in concentration of a substance between arterial and venous blood in mammary gland.

nificant change taking place in the rumen involves lipids. The lipids of plants are highly unsaturated, meaning that they have many free bonding sites where they can add more hydrogen molecules or form new chemical compounds. In the rumen the fatty acids are released enzymatically from such feed lipids and are then hydrogenated, so that they are converted into saturated fatty acids (mainly palmitic acid and stearic acid). These acids are subsequently absorbed and become part of the lipids of both meat and milk, which is why meat, milk and milk products of the ruminant animal contain saturated fats. In contrast, the milk fat of animals with a single stomach (such as human beings) will readily reflect dietary unsaturated fatty acids.

Another interesting fact about the rumen is that the microorganisms involved in fermentation become part of the milk as a result of subsequent digestion. Mark Keeney of the University of Maryland has estimated that at least 10 percent of the fatty acids of bovine milk are derived from the bacteria and protozoa in the rumen. Similarly, the amino acids used in the synthesis of milk proteins originate partly with microbes in the rumen.

Lactogenesis, the process that sets in motion the synthesis and secretion of milk, depends on the action of hormones. Hormonal changes in the female following conception lead to proliferation and differentiation of certain mammary cells. The organelles of the cell increase in size and quantity. Enzymes required to synthesize the various milk constituents appear in the cells, some gradually and some rather suddenly at about the time the animal gives birth. It is probably conservative to say that 100 enzymes are newly formed or greatly intensified in activity during the lactogenic transformation of tissue.

The mode of action of a hormone at the molecular level has not been established with certainty. As a result of work by Yale J. Topper and his colleagues at the National Institutes of Health, however, considerable progress has been made in determining what hormones are involved in lactogenesis and what effects they have at the cellular level. Working in vitro with mammary tissue from virgin mice, Topper's group has shown that the hormones insulin, hydrocortisone and prolactin, acting synergistically, are required to stimulate the synthesis of milk by the mammary tissue.

The hormone progesterone has an inhibitory effect on the differentiation of

Domain Wall Structure and Nuclear Relaxation in Iron

Domain walls—in which electronic spins gradually shift their orientation over a region of a few hundred atomic positions—separate the domains of complete magnetization in ferromagnetic materials.

At Ford Motor Company, we have been conducting experiments in pulsed nuclear magnetic resonance that provide us with a new model for the structure of this magnetic "domain wall" in metallic iron.

By varying the length or frequency of a fixed-strength radio-frequency pulse, we are able to observe the tipping caused by these variations. Thus it is possible to study the nuclear spin dynamics and, from this, infer the domain wall motion. The interpretation of these experiments requires detailed analysis, since the nuclear spin system and the electronic spin system are tightly coupled.

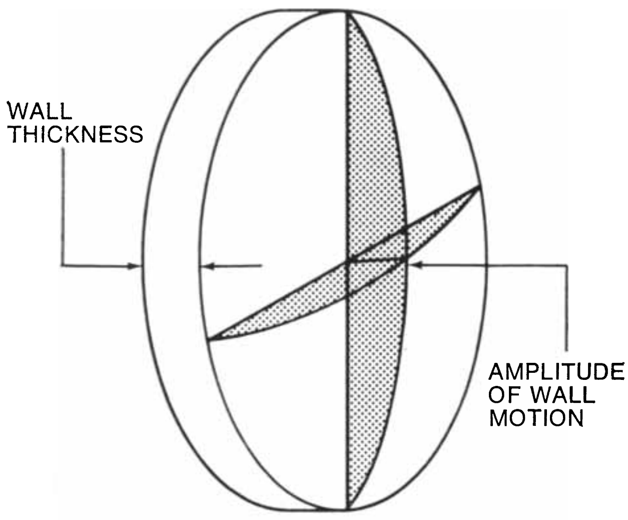
We know from our experiments that the domain walls move like vibrating membranes or drumheads. (See Figure). Although the nuclear spins on the periphery of the domain wall are not able to tip at all, those near the center of the drumhead are able to move with ease. And the nuclear spin orientations, which we measure in this experiment, reflect the orientations and motion of the electronic spin system of the wall. The latter actually characterizes the domain wall.

The experiment also provides information about the size distribution of the drumheads within an iron sample. Since nucleation processes favor smaller-sized regions, there are, predictably, more smaller-size drumheads than large ones.

When we measure the recovery of spin tipping as a function of time in this experiment, we are able to obtain information relating to the mechanism whereby nuclear spins relax back to their equilibrium orientations. That is, nuclear spins relax by interacting with the electronic spin system—through the emission or absorption of spin waves (magnons).

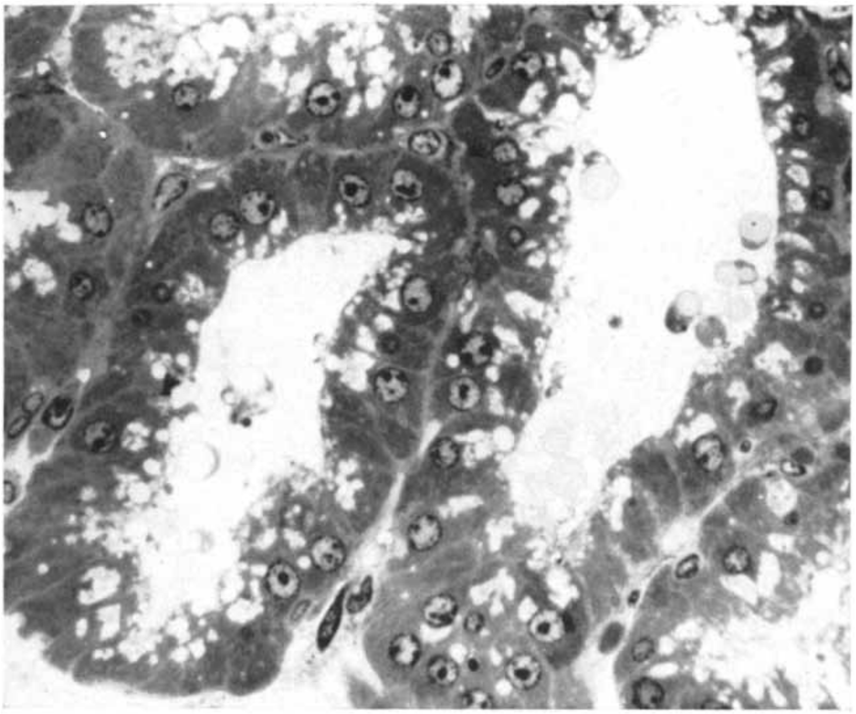
When we measure at various temperatures, we further learn that relaxation rate in natural iron varies in a linear fashion with temperature. This indicates that the magnons causing the relaxation are from the bulk domain regions. Since only the wall

MODEL OF A MAGNETIC DOMAIN WALL



nuclei are readily observable in the experiment, however, it is evident that there is coupling between the bulk magnons and the domain walls.

This research represents only one aspect of Ford Motor Company's continuing study of the fundamental properties of matter. It's a small part of our never-ending search for better materials and better devices to help us build the best products possible today.



TWO ALVEOLI in the mammary gland of a lactating rat appear in a photomicrograph made by C. W. Heald in the laboratory of R. G. Saacke at the College of Agriculture of the Virginia Polytechnic Institute. The light areas are the lumens, which are surrounded by lactating cells. Between the two alveoli is a capillary. The enlargement is 2,500 diameters.

mammary tissue and the secretion of milk. Thus lactogenesis results in part from suppression of the activity of progesterone. Another important regulator of milk synthesis and secretion is the removal of milk from the mammary gland. Unless the milk is removed regularly, synthesis stops.

The Synthesis of Milk

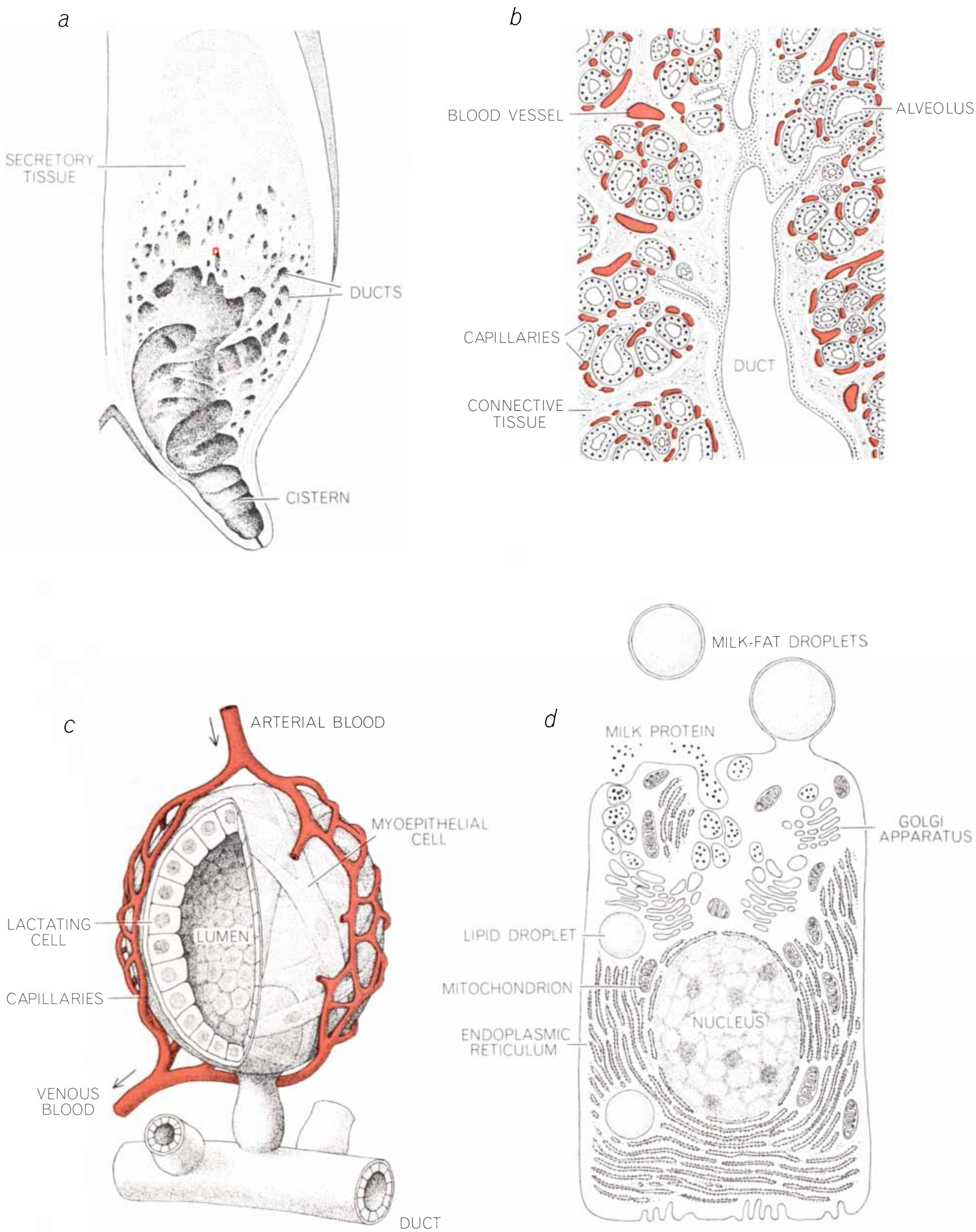
Milk is produced by the vast number of cells that make up the mammary gland. The cells are formed into billions of pear-shaped, hollow structures called alveoli [*see illustration on opposite page*]. Each cell in an alveolus discharges its milk into the lumen, which is the hollow part of the structure. When an alveolus is full, its outer cells contract under the influence of the hormone oxytocin, causing the alveolus to discharge its milk into a duct system that carries it to the cistern, or sac, that is the main collecting point.

In the present state of knowledge little more can be said about the precise mechanisms taking place within the lactating cell. It is possible, however, to describe to a certain extent the raw materials the cell draws from the blood and how they get from the blood into the cell. Much of the knowledge about the raw materials or metabolites comes from painstaking experiments by John M. Barry of the University of Oxford and J. L. Linzell and E. F. Annison of the British Agricultural Research Council's Institute of Animal Physiology. The principle of their work has been that any compounds being used by the mammary gland will show a drop in concentration between the entering arterial blood and the departing venous blood. The British workers have measured such arteriovenous differences and also have amplified their findings through use of radioactive tracers. The metabolites include acetate, triglycerides, glucose, amino acids and proteins.

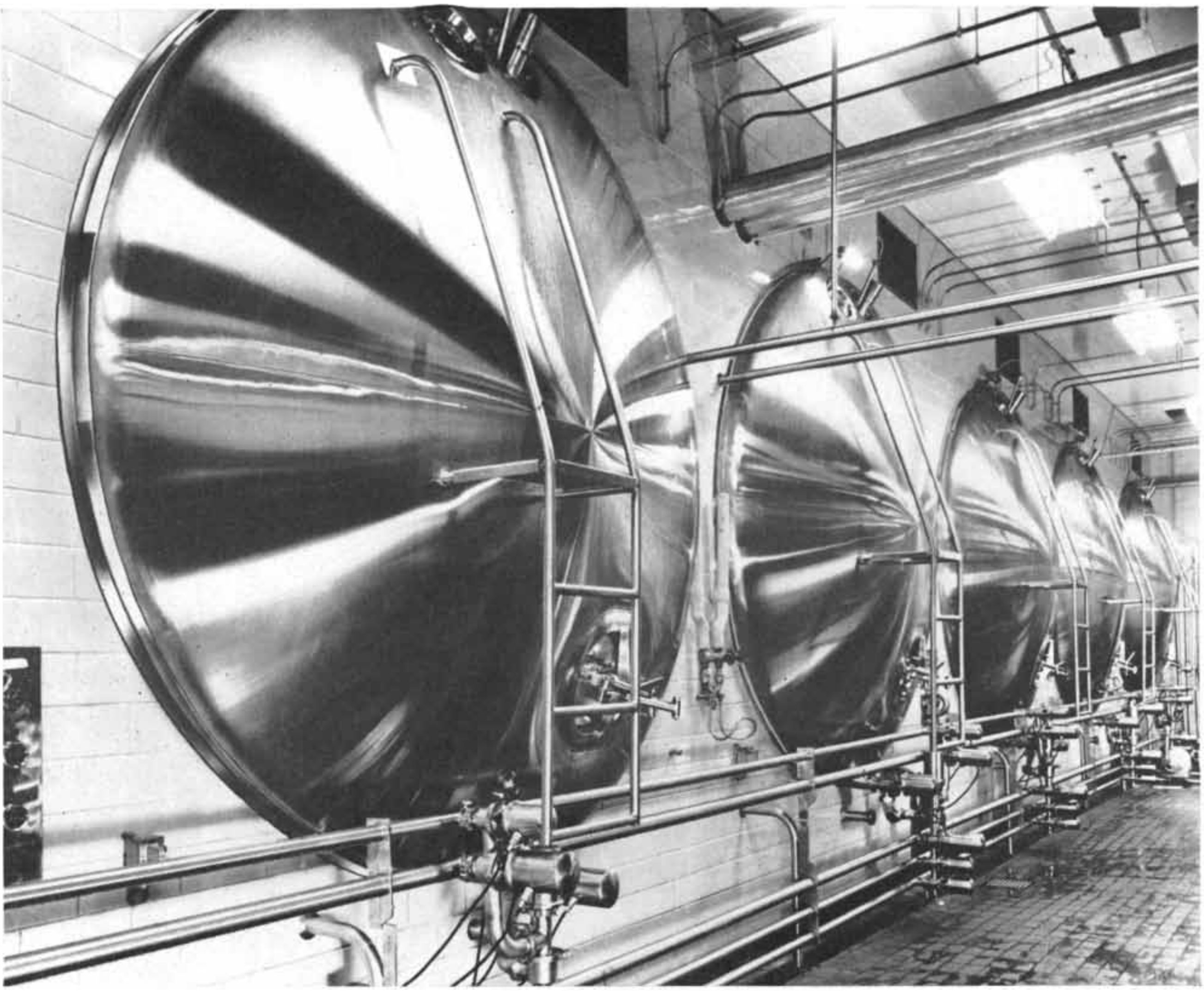
In order to reach the cell the metabolites must move through the walls of the blood-carrying capillaries, across the endothelium lining the capillaries, through intercellular spaces and into the alveolar epithelium where the milk is synthesized. For the transport of small ions from the blood there is a selective system, as is shown by the fact that compared with the blood serum milk is much reduced in sodium and chloride ions and much elevated in potassium ions. Molecules such as the amino acids, glucose and acetate could in principle simply diffuse through the system. In the light of the rapid, selective and continuing uptake of these substances, however, it seems likely that here too there are special transport systems. The same is true for certain large molecules of protein that appear to pass unchanged from the blood into the milk. They include serum albumin and the immune globulins. Unless there are extremely large discontinuities in the cellular structure all the way from the blood to the milk, one is almost obliged to invoke special transport mechanisms for these large molecules. (Most of the milk proteins are made within the cell by the usual method of transcription by ribonucleic acid on the ribosomes of the cell.)

This question of how large particles can migrate through cell membranes without destroying the integrity of the cells arises for the exports of the lactating cells as well as for its imports. Indeed, the fat droplets steadily secreted by the cell are at times nearly as large as the cell itself. The first evidence of the remarkable biophysical mechanisms required for this task was supplied in 1959 by electron microscopy done in Germany by Wolfgang L. Bargmann and his coworkers at the University of Kiel. From their micrographs of mouse and hamster mammary tissue it was deduced that the fat droplets are secreted as a result of being progressively engaged in and enveloped by the limiting membrane at the apex of the cell [*see illustration on page 58*]. When a fat droplet is completely surrounded by the membrane in this way, it is effectively displaced from inside the cell out into the lumen of the alveolus. All that remains for completion of its secretion is for the slender membrane bridge to be pinched off. From our calculation of the sizable forces (as much as 100 atmospheres) involved in the attraction of the membrane to the surface of the droplet it is possible that once the droplet makes a close approach to the membrane it is quickly and forcefully snapped through.

Bargmann and his colleagues reported that their electron micrographs suggested the existence of milk-protein granules inside cell vacuoles that arise from the Golgi apparatus [*see illustration on opposite page*]. According to the German workers the contents of the vacuoles were secreted by being emptied through the cell membrane. Our group believes the membrane processes in the two mechanisms of secretion (for fat droplets and protein granules) are related. The membrane around the Golgi vacuole carrying protein granules becomes continuous with the cell membrane at the time the vacuole empties its contents into the



MILK-PRODUCING TISSUE of a cow is shown at progressively larger scale. At *a* is a longitudinal section of one of the four quarters of the mammary gland. The boxed area is reproduced at *b*, where the arrangement of the alveoli and the duct system that drains them is apparent. A single alveolus (*c*) consists of an elliptical arrangement of lactating cells surrounding the lumen, which is linked to the duct system of the mammary gland. A lactating cell (*d*), similar to the one in the electron micrograph on page 58, is shown as it discharges a droplet of fat into the lumen. Part of the cell membrane apparently becomes the membranous covering of the fat droplet. Dark circular bodies in the vacuoles of Golgi apparatus are granules of protein, which are discharged into the lumen.



STORAGE TANKS in a milk and ice cream plant of the Borden Company in West Allis, Wis., hold 48,000 quarts each. Raw milk delivered to the plant from dairy farms is stored in the tanks at a temperature of about 37 degrees Fahrenheit until it is processed. The five slender pipes at bottom are used in loading and unloading the tanks. An inspection port and a gauge are at top of each tank.

lumen. The cell membrane then is engaged by the milk-fat droplet and becomes the membrane around the secreted milk-fat globule. Evidence from both electron microscopy and biochemical studies is tending to substantiate these mechanisms of secretion for the lipids and proteins of milk, but many questions of both a gross and a refined nature remain to be answered.

Further Questions

The basal portion of the lactating cell, as distinguished from its apical, or secreting, end, contains extensive membranous processes known as the endoplasmic reticulum. The evidence is convincing that these membranes are the sites of synthesis for the major constituents of milk: triglycerides, proteins and lactose. The means whereby the components are gathered for secretion is not known. For example, it is not understood how all the triglyceride molecules are gathered into a droplet.

The precise operation of the Golgi apparatus is not established. The apparatus is defined as an organelle that accomplishes the differentiation of membranes and the "packaging" of materials for secretion, but just how it does these things in the lactating cell is unclear. It is now a reasonable assumption that alpha-lactalbumin, the *B* protein of lactose synthetase, joins the *A* protein in the Golgi apparatus, thus allowing the synthesis of lactose at that site. The lactose, milk protein and other constituents of milk serum are then packaged into Golgi vacuoles for secretion. One wonders, however, if the Golgi vacuoles are the vehicle of secretion for all the milk proteins. Electron micrographs show clearly that the granules the vacuoles contain have the appearance of casein micelles. Perhaps the other proteins are also present in the vacuoles but are not evident because they are transparent to electrons. We have suggested that these vacuoles, since they must carry some of the fluid of milk, may provide the vehicle for the secretion of milk-serum constituents such as lactose. Investigations of these questions and inferences are needed.

In sum, the lactating mammary cell, like all cells, is an almost incredible unit of organization and action. We are beginning to gain an understanding of this cell, which is so important to mammalian life, but the detailed revelation of its elegant mechanisms is still to come. The findings may lead to more and better food products. At the very least they will mean a deeper understanding of cellular processes and of life itself.

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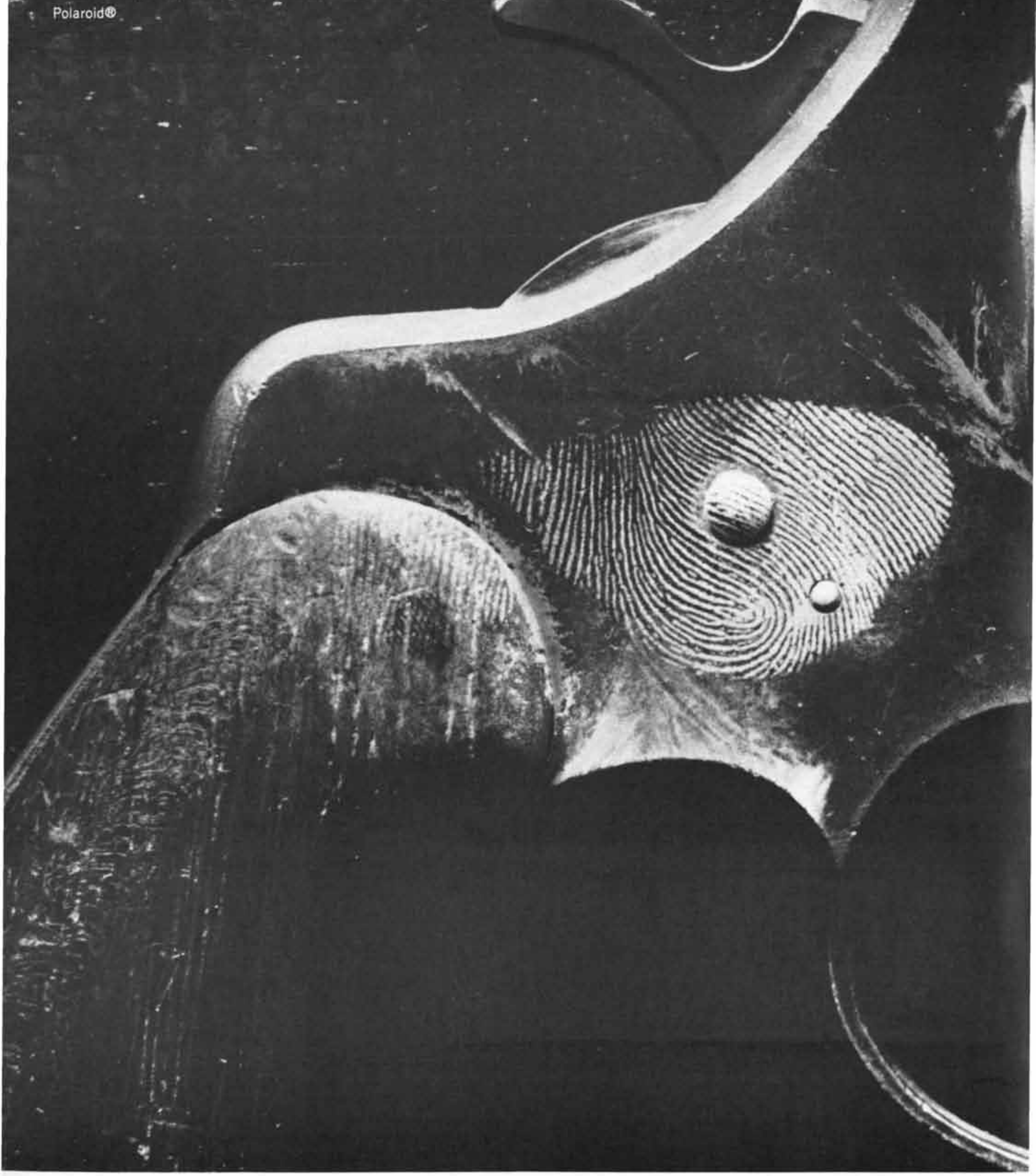


Recent Supreme Court decisions, relating to the Fifth and Sixth Amendments, have markedly increased the importance of physical evidence in obtaining convictions in criminal cases.

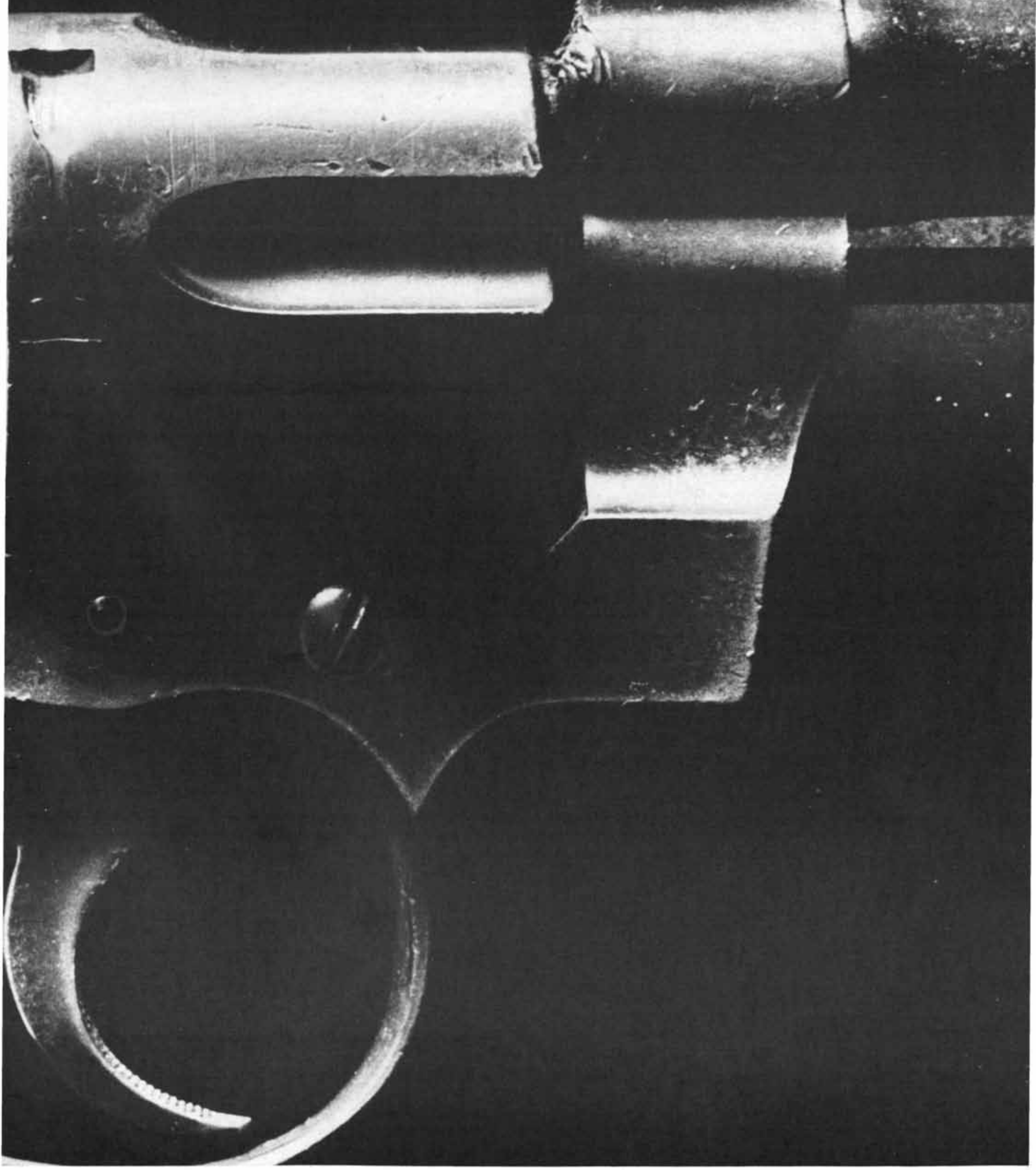
The safest method of retaining fingerprints is to photograph them immediately, *in situ,* thus eliminating the danger that they will be accidentally damaged or destroyed. But, according to one police source, producing acceptable photographs has been a matter of "50% knowledge and 50% luck." And, to make matters worse, camera malfunctions and film failures have narrowed that margin to *one* satisfactory fingerprint record for every *four* cases investigated.

In this situation, the Polaroid CU-5 Land camera has become almost indispensable for recording fingerprints.

Because he gets a finished black-and-white photograph in 15 seconds (color in 60 seconds), the investigating officer can see his print while he is still on the premises. If his first print isn't perfect, he can shoot another one on the spot.

But with the CU-5, re-shooting is seldom necessary. Because the camera's operation is highly simplified.

It has a frame and lens which automatically give a sharp 1:1 reproduction of fingerprints (or other types of evidence).



Perfect lighting is provided by a built-in electronic ring light, powered by a portable battery pack.

The speed and simplicity with which the CU-5 produces photographs of fingerprints provides two additional benefits:

The speed allows the police to check out prints minutes after they are photographed (instead of the hours which are required by conventional photo lab processing procedures). This means that the hunt for known suspects can begin before they get a chance to leave the area. It also means that suspects who are eliminated can be released promptly.

As for simplicity, not long ago the taking of photographs was restricted to a few experts. And these men could only go out on the most important cases. But the CU-5 is so easy to operate that police can be trained to use it in a matter of minutes. So more police are gathering fingerprints. And more cases are being solved.

The Polaroid CU-5 Fingerprint Camera

LIQUID METALS

Their liquid properties can be adequately explained in terms of the classical kinetic theory of matter, but their metallic properties yield only to the insights of modern quantum theory

by N. W. Ashcroft

Everyone knows how to liquefy a metal: you heat it and eventually it melts. But what does it mean to call the result a liquid metal? Exactly how does a substance such as mercury (which happens to be molten at room temperature) behave as a liquid, and how does it behave as a metal?

The surprising fact is that until quite recently relatively little attention was paid to the particular condensed state of matter represented by liquid metals. Late in 1966 an international conference on the properties of liquid metals was held at the Brookhaven National Laboratory. The published proceedings run to more than 600 pages. Obviously liquid metals are now beginning to attract widespread scientific interest. In the circumstances it seems reasonable to ask what is so interesting about them and what is the present state of our understanding of their properties, both liquid and metallic. I shall attempt to provide broad answers to these questions here.

First it will be necessary to touch on a variety of more general topics, including the microscopic structure and microscopic dynamics of liquids, and the nature of the forces between their atoms or ions. This information will be related in particular to the properties of the abundant "free" electrons that characterize many metals. We shall then be in a position to examine other properties of liquid metals that depend on their free electrons. Finally we shall compare some simple physical properties of liquid metals with those of other liquids and other metals.

A solid metal can be loosely defined as an opaque, malleable, typically lustrous substance with high thermal and electrical conductivity. Liquid metals certainly conform to this gross description, although apart from their malleability they do not perform quite as well as their solid counterparts. It is interesting to note that there are actually some elements that display metallic properties *only* in the liquid state. Silicon and germanium, for example, are quite good metals (almost as good as mercury) in their molten form but are semiconductors in their crystalline form. All told, some 70 elements are classified as metals [*see illustration on pages 74 and 75*]. All of them remain metallic when they are molten; alloys, or mixtures, of many of them are also metallic. All are characterized in varying degrees by a high concentration of conduction electrons, which are in fact responsible for their metallic properties.

Perhaps the simplest way to begin comparing a liquid metal and a "common" liquid such as water is to consider the "number density" of their particles just above their respective melting points. At 4 degrees Celsius one cubic centimeter of water contains about 3.4×10^{22} molecules. At -38 degrees C. the corresponding number density of mercury (which is 13.6 times more dense than water) is 4.1×10^{22} ions per cubic centimeter. The two numbers are remarkably close, an agreement that is by no means limited to water and mercury. Indeed, approximate constancy of the number density of most liquids is a well-established and important fact; from it one can immediately deduce that atoms in any liquid are on the average only two or three angstroms apart. (An angstrom is a hundred-millionth of a centimeter.)

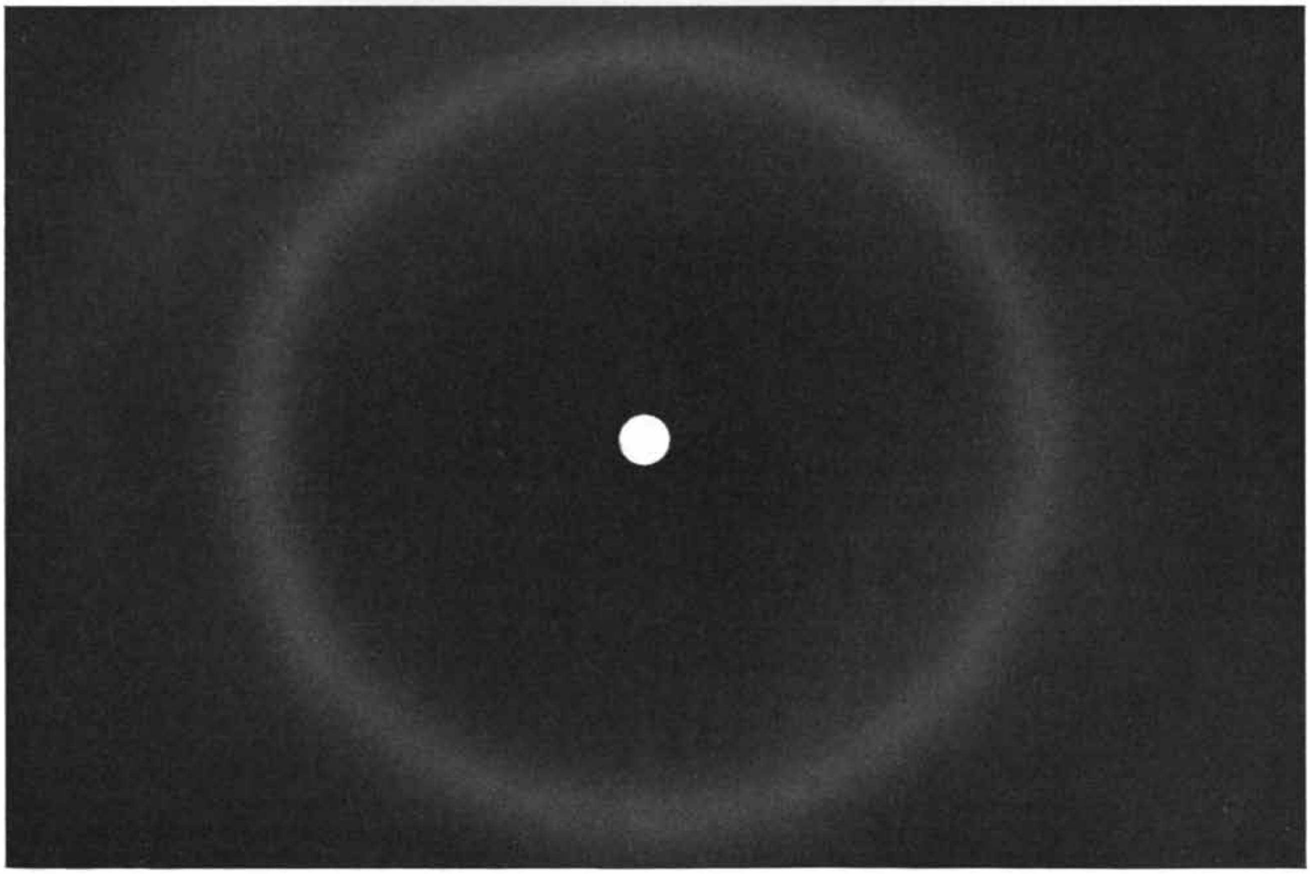
Since as a rule little change of volume is observed in the melting process (only about 3 percent or less), it follows that the number densities of solids and liquids should also be quite similar. Although it turns out that this is very much the case, the structural differences between solid and liquid metals are quite striking. Solid metals tend to crystallize with their atoms situated "on the average" at the intersections of a regular three-dimensional network, or lattice [*see illustration at upper left on page 76*]. One must say "on the average" because even at very low temperatures the atoms in a solid vibrate around their lattice sites, their excursions becoming progressively larger as the temperature rises.

A molten metal exhibits no such pristine microscopic order; its atoms are not located about fixed positions in space but rather move around in a seemingly random fashion [*see illustration at upper right on page 76*]. The atoms of a liquid do not, however, move independently of their neighbors. Their motions are inhibited by strong interatomic forces and are "sympathetic" in the sense that an excursion of any one atom is sensed by its neighbors (and vice versa). If we had a microscope capable of seeing individual atoms, the difference between a solid and a liquid would be revealed quite clearly: in a sample of solid metal the arrangement of atoms would appear highly symmetric; in a liquid metal there would be no apparent symmetry on the average.

What does the ubiquitous kinetic theory of matter have to say about the properties one might expect from such a disordered structure? This theory, largely a heritage of the 19th century, has had its greatest success with gases, where even today it requires only minor modifications of the early results. It has also been applied with varying degrees of success to the study of liquids and, as we shall see, it can be quite useful as a guide in comparing liquid metals with other liquids.

Gases are of course comparatively dilute, having number densities on the order of 10^{19} particles per c.c. This means

X-RAY DIFFRACTION PATTERNS produced by a sample of gallium just below its melting point (*top*) and just above its melting point (*bottom*) are compared. The periodic crystal structure of the solid metal is revealed by the symmetrical array of spots in its X-ray pattern. This characteristic spot pattern is lost in the phase change from solid to liquid. It is replaced by a diffuse ring indicating the average spherical symmetry of the liquid. This intensity pattern can be analyzed to yield information about the average structure of the liquid metal. Photographs were supplied by Boris W. Batterman of the Materials Science Center of Cornell University.



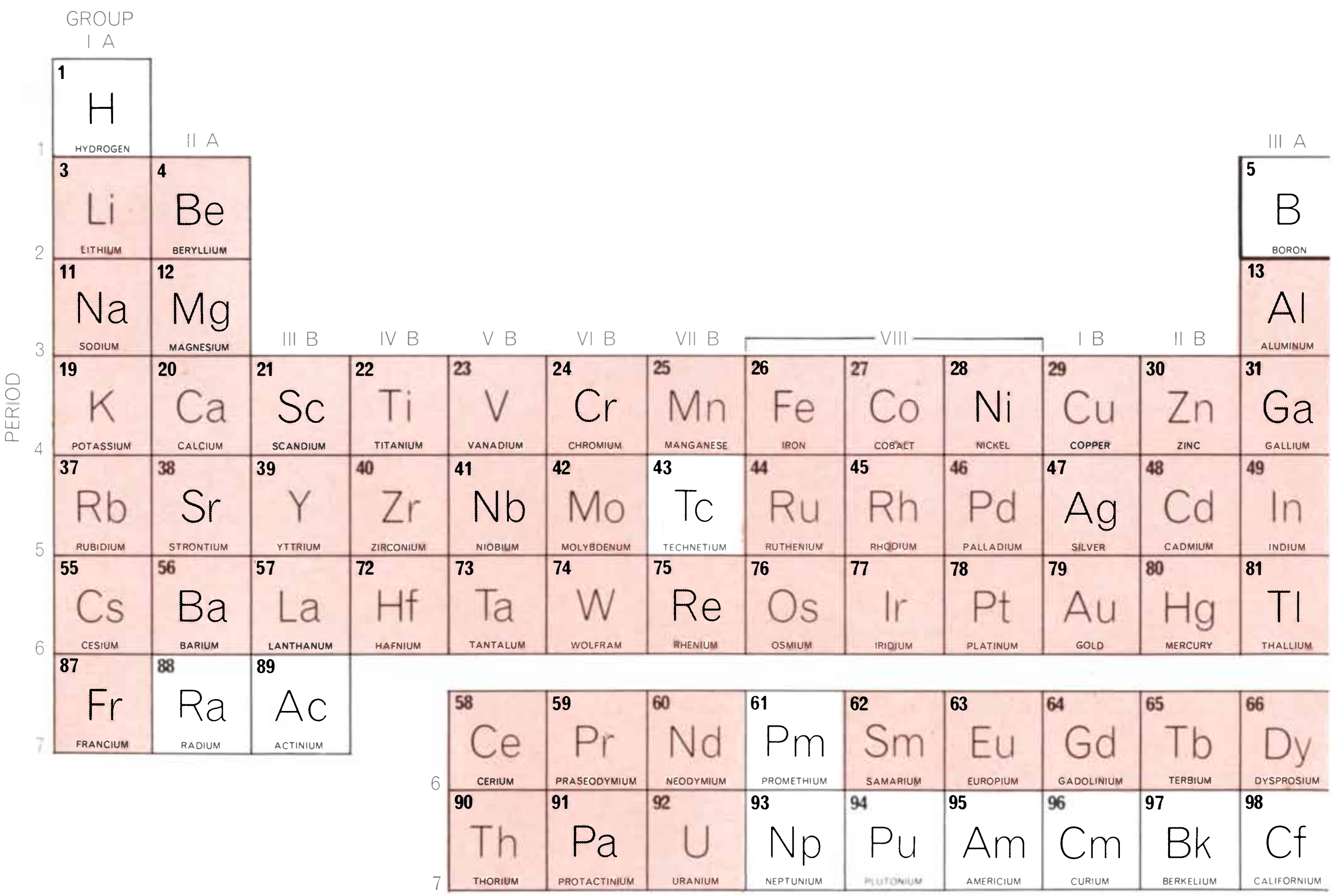
that on the average atoms are about 10 times farther apart in a gas than they are in a liquid. The fact that the separation of atoms in a gas is very much greater than atomic diameters (which are typically a couple of angstroms) is at the heart of the success of the kinetic theory of gases.

Crystalline solids are at the other extreme. We now know that many properties of solids are best described by the quantum concepts of wave mechanics. The fact that solids crystallize in regular lattices has been crucial to the development of successful theories of the solid state; the periodicity of the atomic array, perhaps more than any other notion, has been the foundation for the great analytical strides made in solid-state physics over the past few decades.

Compared with the kinetic theory of gases and modern solid-state theory, the present theory of the liquid state is still in its infancy. There are no sweeping, simplifying principles comparable to those that flow either from the relative sparseness of atoms in a gas or from the periodicity of the atomic arrangement in a solid. In many respects this is why liquid metals are so interesting. They present challenging unsolved problems to the physicist: how to describe dense disordered systems, and how to account for the properties of "free" electrons in these systems.

In order to gain perspective on the complexity of the first of these problems, consider the following analogy to the liquid state. Suppose all the people in the world (some three billion of them) were to be assembled on a flat square of land measuring about 25 miles on a side. Surprisingly, it turns out that on the average each person would be an arm's length from his closest neighbors. Each one is given a single instruction: to move, and to keep moving, as fast as possible, regardless of direction. Not unexpectedly the result will be chaos. People will mill about in an agitated fashion trying (but failing) to avoid running into one another. This, apart from the lack of a third dimension, is roughly analogous to the chaotic motion of a large number of atoms in a liquid. How does one analyze such a motion?

We begin by taking an imaginary snapshot of the liquid, so that all the atoms are stopped at particular positions in space; to each of these positions we ascribe a particular position vector, r, which is measured from some arbitrary point of origin [*see illustration at lower left on page 76*]. Specifying the values of all these vectors describes what we may call a configuration of the system. Moving along in time, we notice that the thermal agitation of the atoms causes their positions to fluctuate constantly. How fast do the atoms move? Elementary arguments involving the equation of kinetic and thermal energy of an atom indicate that the average speed of atoms in a liquid is roughly 1,000 meters per second. As I mentioned above, this motion is not free and rectilinear but is hindered by the presence of neighboring atoms. Each atom (or ion in the case of a liquid metal) moves in a "cage" formed by its immediate neighbors; the motion of each particle is somewhat analogous



MOST ELEMENTS ARE METALS in their solid state at normal pressures, as indicated by the light-colored squares in this periodic table. The dark-colored squares denote those few elements that become metallic only when molten. In addition certain other elements (including hydrogen, phosphorus, carbon and boron) may become metallic at high pressures. Each element is represented to that of a harmonic oscillator whose center (in this case the center of the cage) moves around [*see illustration at lower right on next page*].

We can readily estimate the extent of the cage; it must contain a volume roughly equal to the average volume per atom in the liquid. This is easily calculated from the atomic mass, the density of the liquid and Avogadro's number (the number of molecules in a gram molecule of the liquid). At metallic densities the radius of the cage is also about an angstrom or two; this means that the atoms can be thought of as oscillating in the cage with a frequency of about 10^{13} cycles per second. Thus every second the atom makes some 10^{13} attempts to change its position.

There are at least two important consequences arising from the foregoing line of reasoning. The first concerns a principle involved in the calculation of the properties of all liquids, including liquid metals. Imagine that we perform a measurement of some characteristic property of a liquid metal, say its electrical resistivity. The measurement of a sample's resistivity is normally accomplished on what must be regarded as a macroscopic time scale (times on the order of, say, seconds). Compared with the time scale of the atomic oscillation (about 10^{-13} second), this measurement takes an immense span of time, during which the liquid has progressed through an enormous number of different configurations. In effect the motions of the ions in the liquid are averaged over, and in many respects it is these "configurational averages" that allow progress to be made in the study of the liquid state.

The second consequence of the rapidity of atomic motion in liquids is the tendency for the neighbors of an atom (that is, the atoms forming the cage) to move or diffuse. Actual large-scale motion of the atoms is a phenomenon observed in liquids, in contrast to solids, where (except over enormous times) it is inhibited by the bonds of the crystal.

Although the caged ion has some 10^{13} chances a second to change its position, we know from experiments in which neutrons are diffracted by liquids that it is successful in only about one out of 10 efforts. This means that for very short time spans (on the order of 10^{-13} second) the ions are actually located in fleetingly fixed positions, about which they oscillate a few times before moving on. For this kind of time scale one can actually talk about a type of geometric liquid structure. It is not regular in the sense that a crystal is regular, but as the British physicist J. D. Bernal has demonstrated [see "The Structure of Liquids," by J. D. Bernal; SCIENTIFIC AMERICAN, August, 1960], some definite order in the ions can be discerned in the plethora of geometric patterns. On much longer time scales, however, the picture is one of atomic chaos.

The disorderly movement of atoms through the volume of a liquid is one of the requirements of the kinetic theory, to which we now return. One of the key elements of this theory is the "mean free path," a concept first introduced by Rudolf Clausius in 1857 to describe the average distance traveled by atoms between collisions with one another [*see illustration on page* 77]. In a gas the collision was thought of as an elastic process much like two billiard balls bouncing off each other (but of course in three dimensions). The mean free path in a gas at normal pressures is a few hundred angstroms. In liquids it is only a few angstroms. For atoms always in range of one another the very concept of a mean free path loses some of its power. The concept does, however, enable us to pursue the comparison between the simple properties of liquid metals and common insulating, or "classical," liquids.

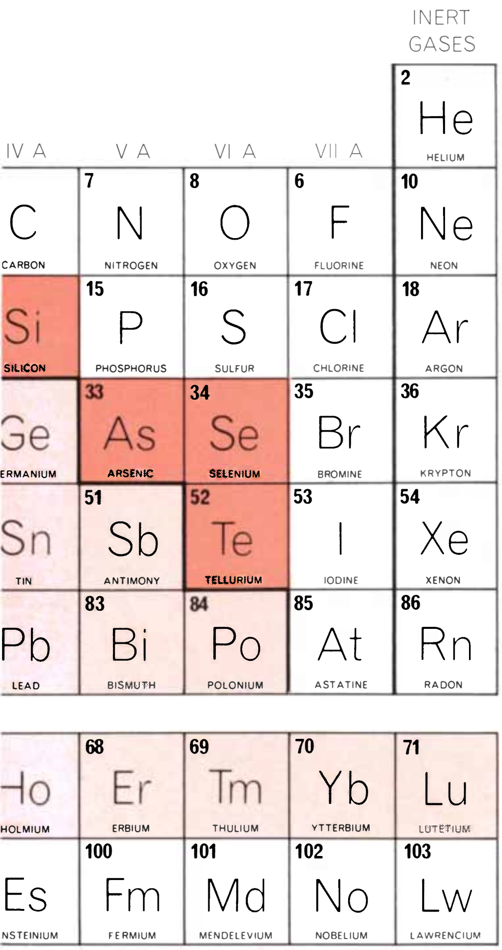
Other important parameters of the kinetic theory are the number density and the mean square velocity of the atoms. The number density, as we have seen, varies little among liquids (and indeed is roughly constant for the condensed state as a whole); the mean square velocity can be estimated from the thermal energy of the atoms and basically depends on the atomic mass and the temperature. Thus we are left ultimately with a calculation of the atomic mean free path, a quantity that by its very definition depends on the nature of atomic collisions.

When atoms collide, there are substantial forces acting between them; normally these forces are represented by means of the potential-energy function. Liquids whose atoms have similar potential-energy functions and similar densities would surely be expected to have similar atomic mean free paths. As indicated above, this is one possible and convenient starting point for comparing the properties of liquid metals and other liquids. In order to proceed further, however, it is clear that we need to inquire more deeply into the microscopic details of interatomic or interionic forces and their bearing on macroscopic properties.

One of the manifestations of these forces is the "average structure" of the liquid, that is, the property of the liquid that in a statistical sense reflects the mean atomic distribution as measured on a macroscopic time scale. Put in terms relevant to our mob scene on a 25-mile-square lot, we could ask two questions. First, what is the average occupancy of any square yard? Second, what is the occupancy of a given square yard always measured at a certain distance from one particular person? The answer to the first question is merely the average density of people (about one per square yard). The answer to the second (and its extension to real liquids) is more complicated and more interesting.

The determination of the average arrangement of atoms in the liquid state is a difficult problem in statistical mechanics. On the other hand, some of the underlying physics is not too hard to unravel. In many liquid systems the total force on an atom can simply be regarded as the sum of all possible forces exerted on it by near and distant neighbors. The dynamics of a given liquid are controlled by these forces and by the laws of statistical mechanics.

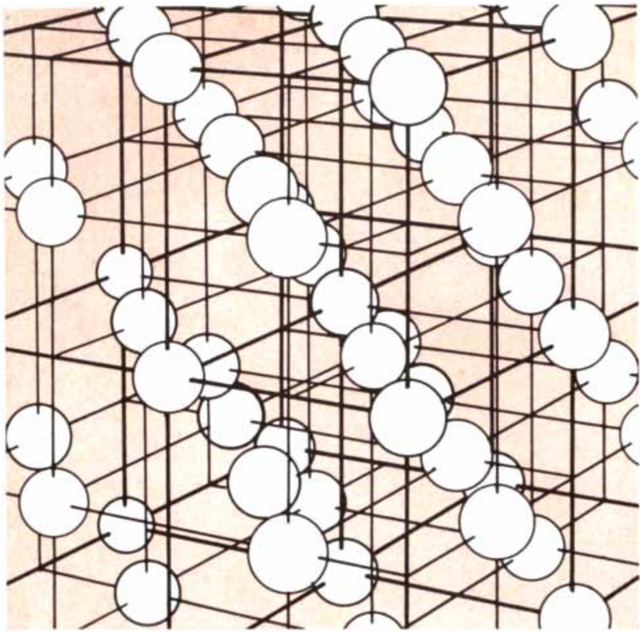
One popular and quite illuminating



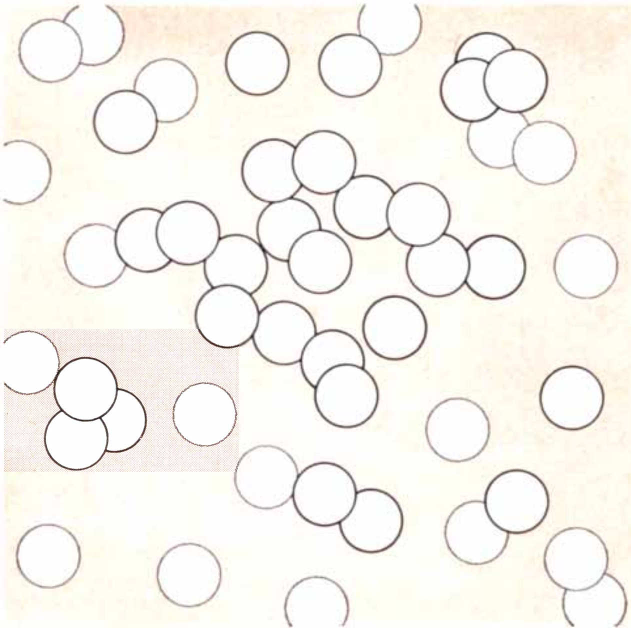
here by its name, symbol and atomic number (the number of positive charges in its nucleus or the number of bound electrons).

method for studying classical liquid structures is to perform computer experiments in which the computer is programmed to represent a small number of particles placed in a box; a force between them is assumed, and the system is observed to develop in time under the laws of simple Newtonian mechanics. Positions and velocities can be computed and followed at any stage. In particular, one might ask the machine to compute the chance, on the average over the configurations, of finding a particle at a given distance from another particle. This probability is described in terms of a radial-distribution function, $g(r)$. It is much like a contour map for the density of particles around a given particle.

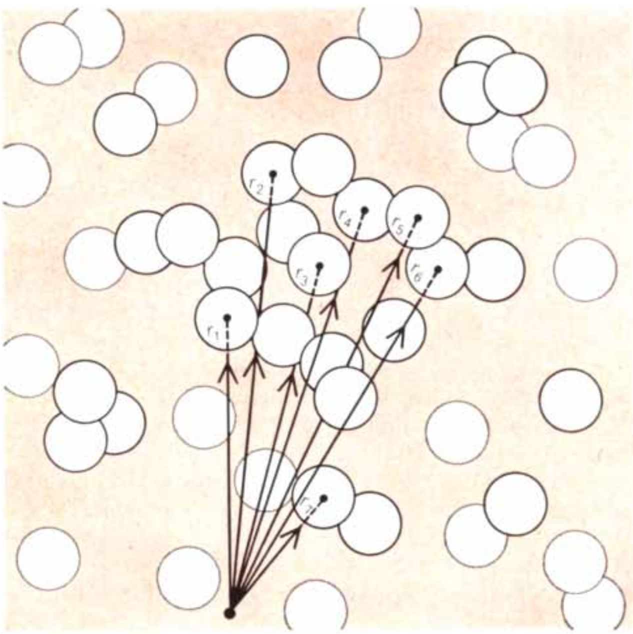
The radial-distribution function is very important in the microscopic theory of liquids and in theories of electron



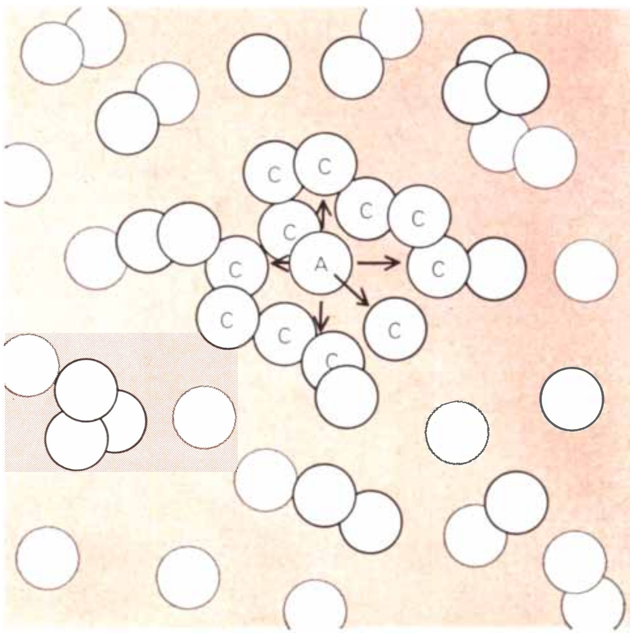
SOLID METAL is characterized by a regular three-dimensional crystal lattice. The particular metal shown here has a "face-centered cubic" structure, with ions on the average occupying the cube corners and the center of every face. In most solid metals the region between the ions is filled with "free" electrons (*color*).



LIQUID METAL, in contrast, exhibits no such pristine microscopic order. Its ions are not located about fixed positions in space but rather move around in a seemingly random fashion, inhibited only by strong interatomic forces. As in the case of a solid metal, the volume not occupied by the ions is filled with free electrons (*color*).



IMAGINARY SNAPSHOT of the instantaneous atomic structure of a liquid metal shows the positions of the ions as measured from an arbitrary fixed origin in space. The particular position vectors are designated r_1, r_2 and so on. The sum of the position vectors at a given instant constitutes one configuration of the system.



NEIGHBORING IONS in a liquid metal form a "cage" in which the central ion vibrates rapidly. (The central ion also participates in the cages of its neighbors.) The frequency of the vibration is so high that ions have about 10^{13} chances per second to change their position. Only about 10 percent of these forays are successful.

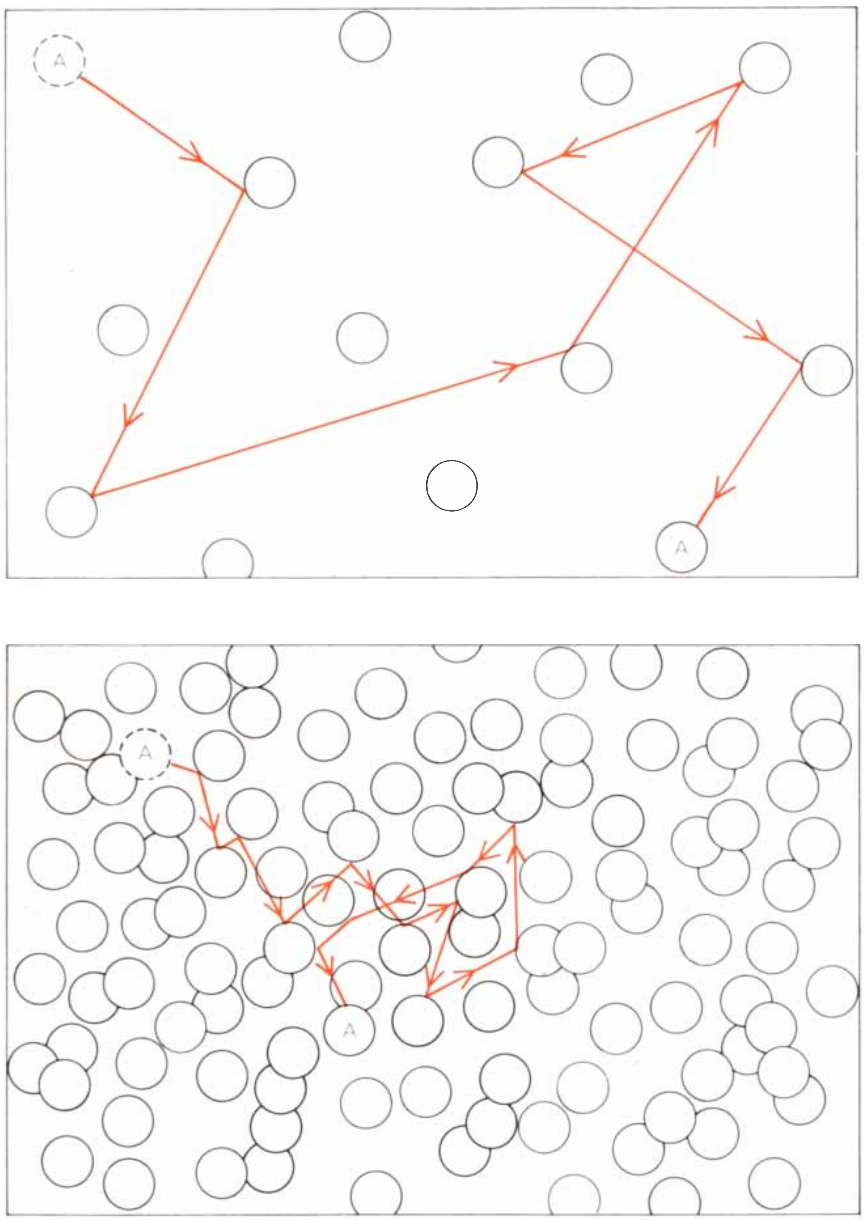
states in liquid metals. It clearly reflects the average structural arrangement of atoms and ultimately the forces between atoms. The question naturally arises: Is there any way of experimentally probing the structure of liquids and liquid metals? If there is, then the possibility arises of working back from experiment to elucidate the nature of the atomic forces. The answer is of course yes. For almost 50 years the techniques of X-ray diffraction have been used with remarkable success in the study of matter, most prominently in determining the structure of crystalline solids. Wavelengths of X rays are on the order of a few angstroms. Since interatomic spacings in solids are about the same, X rays are strongly and characteristically diffracted by the atoms on their regular sites. Beyond the fact that X rays are scattered by the atomic electrons, we need not go much into the details of the particular mechanisms by which the X rays are deflected. The interest centers on the pattern that emerges at the detector: a symmetrical array of spots that is characteristic of the structure of the solid [*see top illustration on page 73*].

But X rays are also strongly diffracted by liquids; the pictures produced, however, are radically different. During the macroscopic time it takes to obtain a scattering pattern the atoms in the liquid will have executed countless changes in configuration; the pattern we see corresponds to an average state of the system. "On the average," however, the properties of a liquid clearly do not depend on the choice of direction. The system is spherically symmetrical, and the spherical symmetry is reflected in the X-ray diffraction pattern [*see bottom illustration on page 73*].

Intensity patterns of this type can be plotted (in terms of the deflection angle) for a solid along a line of spots from the center, and for a liquid along any radius [*see illustration on next page*]. When we compare such results, it is apparent that the peaks of the liquid diffraction pattern are in a sense a remnant of the spots in the solid. As it turns out, however, the average interference pattern of X rays scattered from liquids also depends very sensitively on the relative separation of the scatterers; this important dependence was first pointed out in 1915 by Peter J. W. Debye.

It is perhaps fairly obvious that since it is the electrons that scatter X rays, the resulting patterns must also reflect in some way the distribution of these electrons within and between the atoms themselves. Putting it another way, suppose we have two hypothetical liquids in which the interatomic forces are identical. From what we have recounted already it is clear that at equal temperatures the mean structure of the two liquids would also be identical. Suppose for argument's sake that the atoms of the two liquids have different electron arrangements; then clearly they must differ in their ability to scatter X rays, and the two intensity patterns will not be identical. Each pattern contains in it information on the liquid structure and information on the electron distribution. In fact, the resulting pattern is a very simple combination of these two factors. From quantum-mechanical considerations we can actually calculate the electron distribution, and by combining it with experiment we can deduce the liquid structure. The diffraction of slow neutrons can also be used to investigate liquid structure, and recent results from both X-ray and neutron measurements show a pleasing overall agreement between the two methods.

The information on the average liquid structure contained in such diffraction patterns is actually related to the radial-distribution function by a straightforward mathematical transformation; as a consequence, with sufficient information



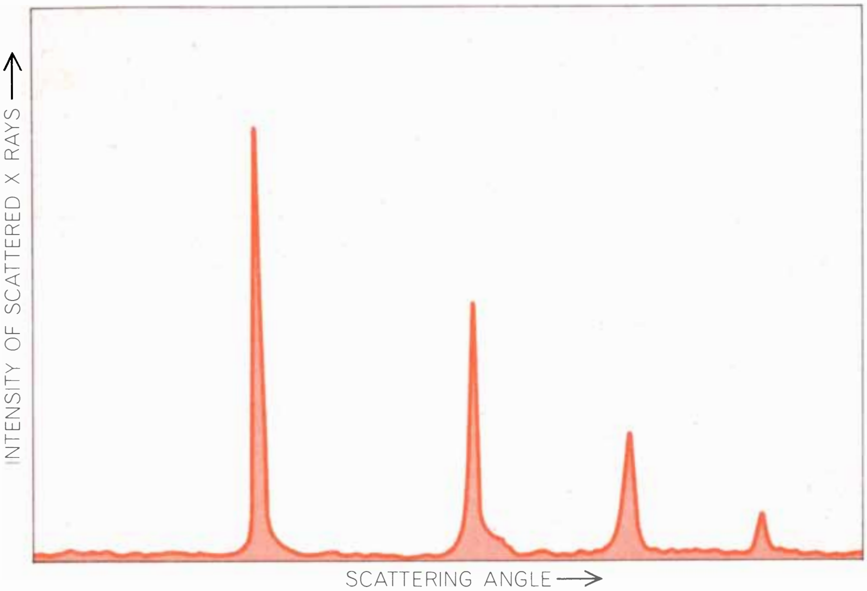
MEAN FREE PATH is used in kinetic theory to describe the average distance traveled by atoms between collisions with one another. In a gas (*top*) the mean free path may be as large as a few hundred angstroms, or much larger than the size of the atom itself. In a liquid (*bottom*) the mean free path is only a few angstroms, or comparable to the atomic size.

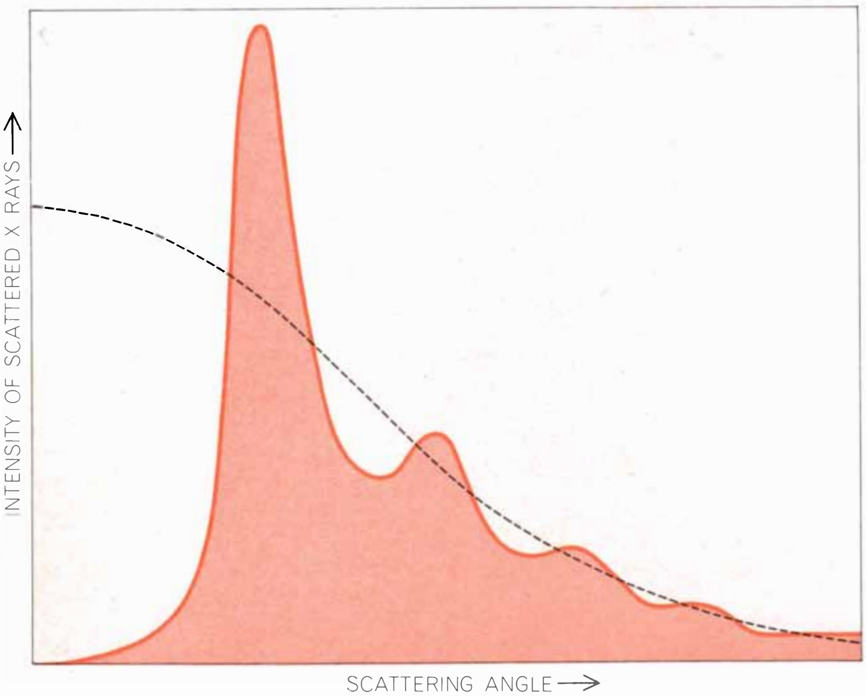
from experiment, this function can be found numerically. The ultimate step is the following: From the laws of statistical mechanics we can build up approximation equations that relate $g(r)$ to the forces between particles. Although it is a complex numerical task, interatomic and interionic forces (and their potentials) can be extracted from the basic scattering information.

Although difficulties still remain in formulating theories that connect the density contours and the forces, the theoretically calculated potentials are not much different from those derived from experiment. One such experimental potential curve, for liquid sodium, is shown on the opposite page. Notice that it exhibits some rather striking features, particularly when it is compared with the potential curve for liquid argon on the same page. The two curves are quite similar: both have a steep slope at small interparticle separation. For the argon-argon potential the physical origin of this region (which corresponds to strong repulsion) is well known. Argon, being an inert element, has a "closed shell" electron system [*see illustration on page 80*]. The outer shell of such an atom, unlike that of a metal atom, is complete and cannot accommodate any more electrons. Suppose, however, we try to push two of these neutral argon atoms close together so that the outer shells are forced to overlap. By Pauli's exclusion principle, the shells (which are filled) are not allowed to take any of the electrons we are attempting to impose on them. Inevitably the electrons tend as the only recourse to seek permitted empty states, which of course are at much higher energies. In other words, the deliberate overlap of filled electron shells costs a great deal of energy, and as a result the interaction is strongly repulsive. Put in terms of potentials, we would say that when the separation between atoms diminishes to characteristic atomic dimensions, the potential energy rises steeply, rather like the effect of pushing two rigid elastic spheres together.

At larger distances it turns out that the force between two argon atoms is in fact attractive. The reason for this is also well known: the charges on one atom tend to influence those on the other. At any instant this causes a separation of the centers of positive charge (the nuclei) from the centers of negative charge (the electrons), which are normally found coincident in neutral, well-separated atoms. Slightly separated charges, however, constitute an electric dipole, and two dipoles (such as we have on the pair of atoms) may now attract each other. Elementary arguments on the "fluctuating dipole" effect explain the long-range part of the classical potential-energy curve for argon. It is important to reemphasize that the short-range part is extremely steep. Moreover, the fact that the argon atoms do find each other relatively impregnable, and that the fluctuating-dipole effect is found to be comparatively small, suggests that the widely used approach of regarding the atoms simply as rigid spheres (as in the kinetic theory) is a reasonable physical approximation.

Evidently the ion-ion potential curve for a metal is similar in shape to the potential curve for neutral atoms in a classical liquid. But why is this so? To give an answer we need now to begin to analyze the metallic state more closely.





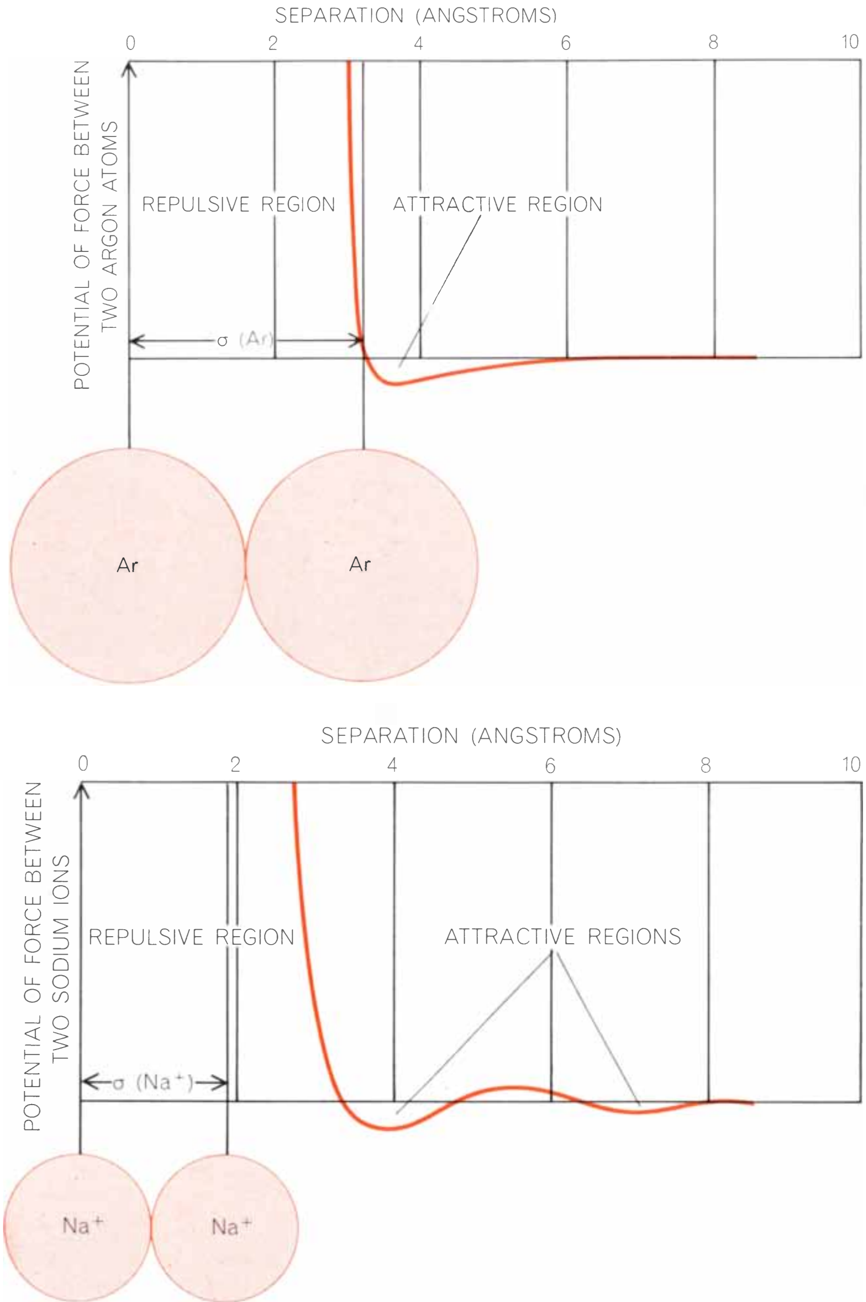
INTENSITY OF SCATTERED X RAYS can be plotted for a solid along the line of spots emanating from the center of the pattern (*top*) and for a liquid along any radius (*bottom*). The smooth peaks of the liquid diffraction pattern correspond to the sharp peaks of the solid pattern; the main liquid peak corresponds to the bright ring in the X-ray photograph at the bottom of page 73. The broken curve at bottom summarizes the information contained in the patterns about the distribution of electrons in the atoms. Evidence about the structure of the sample is obtained by dividing the unbroken curves by the broken curves.

What is the peculiar character of metals that distinguishes them from other states of matter? It is, of course, the fact that the outer valence electrons of metallic atoms are almost completely detached when the atoms are in the condensed state. All the originally loosely bound valence electrons are in a sense shared by all the ions. Furthermore, we know that the distribution of electrons in some metals is hardly affected by interactions among electrons or between electrons and the positive ions they have deserted. These are often called the "nearly-free-electron-like metals." Since we find experimentally that the density of the liquid metal is only a few percent different from the density of the solid, it would not be unreasonable to suppose the electron distribution in the liquid metal is not drastically different from the distribution in the solid. Although this point is difficult to justify theoretically, it has recently received some confirmation from studies of the actual generation of X rays in both solid and liquid metals.

One of the central problems we are faced with now is to estimate the nature of the forces between two positively charged ions in the presence of a high density of macroscopically uniform conduction electrons. This is a complicated problem to work out in detail, but again the main physical points are easy to make. The electrons are very light charged particles; they delight in moving and responding to applied forces, such as are produced by electric fields. We know from classical electrostatics that when charges in a neutral system are disturbed by a field, an internal polarization, or separation of charges, is produced. The polarization of the charges in a medium gives rise to a contribution to the dielectric constant.

Indeed, in a hypothetical situation where all charges were inhibited from moving or responding to applied fields, we should expect the dielectric constant to be unity, as it is in a vacuum. We know also that inside the medium the applied field is modified by the dielectric constant, which for continuous homogeneous mediums is in fact almost a true constant. Not so in a metal, however. Consider the field around a positive charge q on an ion that in the absence of any electron gas (or in the presence of a "frozen" electron gas) produces by Coulomb's law a potential energy $-qe/r$ at a distance r, where $-e$ is the charge of the electron [*see part "a" of illustration on page 81*]. Introducing the electrons (or "unfreezing" them if they are already present) gives rise to the following situation: The electrons near the charge respond at first enthusiastically and converge on it. In doing so they contribute negative charges of their own around the potential center, so that electrons farther out see a diminished total charge and react to it in a somewhat less spirited fashion. The result when the system stabilizes is a nonuniform distribution of negative electron charge around the ion [*see part "b" of illustration on page 81*]. As a consequence the "dielectric constant" in such a medium is not in fact constant.

Suppose we now fix our attention on one of the ions. It is surrounded by a cloak of electrons. We bring up a second ion. It also tends to attract electrons around it, and in discussing the forces between them we have to take into account the interaction of two positive ions each with its retinue of negative charges [*see part "c" of illustration on opposite page*]. Although we cannot pursue the analogy very far, it is somewhat helpful



POTENTIAL-ENERGY CURVES for two neutral argon atoms (*top*) and two positively charged sodium ions (*bottom*) are compared. At small interparticle separations both curves have steep slopes, corresponding to strong repulsion. For argon, a "classical" liquid, the onset of the steep repulsive region equals approximately the closest approach distance. For sodium, a liquid metal, the repulsive region is farther out than the diameter of the ion. At larger separations the potential functions for both liquids show small attractive regions.

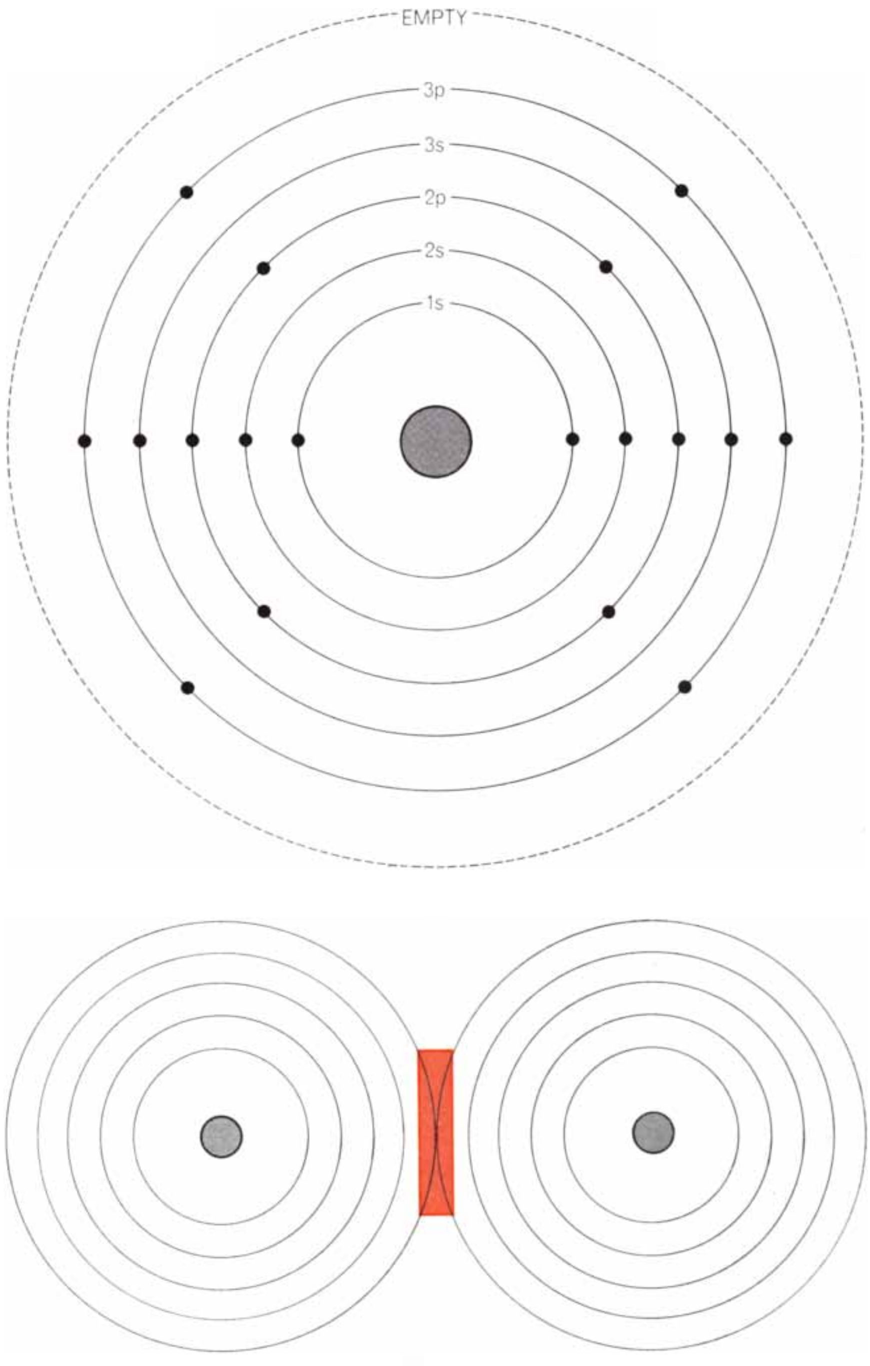
to view this process again in terms of the interaction of the atom with the electrons in the shells around it rather than with its fellow travelers. We have already observed that this can lead to steep potentials between atoms in classical liquids; similar conclusions can be drawn about ions with their nearby electron clouds. Moreover, under certain circumstances attractive (or negative) regions in the potential may also be found.

The sum total now is an ion-ion potential with a repulsive inner region and an outer region that for some metals is attractive. It is clear, however, that the repulsive part of the potential has more to do with the outer electron charge and does not necessarily arise from the remaining inner closed electron shells in the ion itself. This statement must be qualified for two reasons. First, at sufficiently high densities (or short ion-ion separations) we must ultimately consider this region just as we did in the case of the argon-argon potential, but at normal densities in the nearly-free-electron metals the steep part is due to the conduction electrons. Second, there are certain metals, such as the transition metals found in the center of the periodic table, that basically have two "classes" of electron states: (1) those for which the electrons are spread over the whole of the sample and are essentially similar to the physical situation we have been describing, and (2) those that, although not exactly like the electron states of atoms, are still typically much more localized around the ions than the detached electrons are. For these metals it turns out that the ion-ion potentials are again dominated by the equivalent of the shell-shell interactions; their potential curves are also reminiscent of the argon-argon type.

For the nearly-free-electron metals, however, the repulsive region is about an angstrom farther out than the inner hard-sphere sizes of the electron shells would suggest. The reason for this lies in the range of the electron charge piled up around the positive ion. This range is typically an angstrom, so that the effective size of an ion with its screening electrons in the liquid metal is reasonably close to the size of a free metal atom with its outer valence electrons in shells.

The important conclusion that can be drawn from all of this is that since the gross sizes of atoms in the periodic table do not differ greatly, it must follow that the corresponding probabilities of their encounters do not vary substantially. We can now see that the mean free paths used in kinetic theory should vary only by a small amount between classical insulating liquids and liquid metals. Moreover, after accounting for the differences in atomic mass and temperature, basic properties normally connected with liquids (such as viscosity, surface tension and diffusion) should be comparable within small numerical ranges. This is in fact often the case, and for these properties liquid metals are by no means anomalous. The dramatic differences between liquid metals and other liquids are in properties such as thermal and electrical conductivity, optical reflectivity and compressibility, all of which are uniquely related to specific metallic properties of the liquid metal.

Apart from the obvious change of



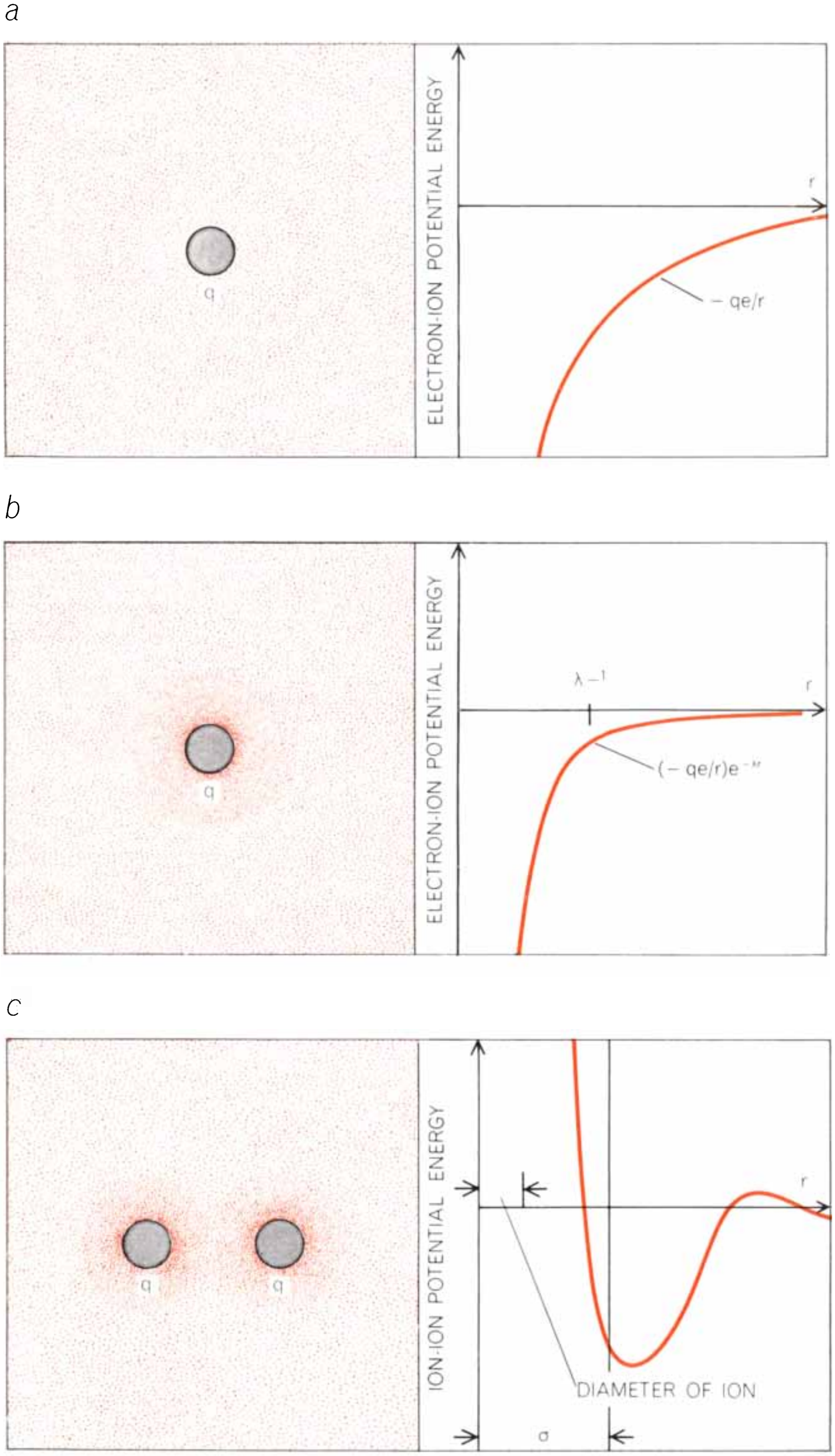
IN LIQUID ARGON the steep repulsive region in the potential-energy curve arises from the fact that argon, being an inert element, has a "closed shell" electron structure (*top*). The numbering of the filled electron shells is derived from spectrographic terminology. When two such atoms are pushed together so that the filled outer shells are forced to overlap (*bottom*), these shells are not allowed to take on any more electrons. Therefore the electrons seek permitted empty states, which are at higher energies. The net result is a strongly repulsive interaction, rather like the effect of pushing two rigid elastic spheres together.

state, how different is a metallic liquid from a metallic solid? The detailed answer here naturally depends on the properties being compared, but an overall impression is that the differences are not great. Take the change in electrical resistivity as an example. On melting, the resistivity of gallium metal goes up by about a factor of two, which is not a striking change. In mercury and sodium the change is about the same.

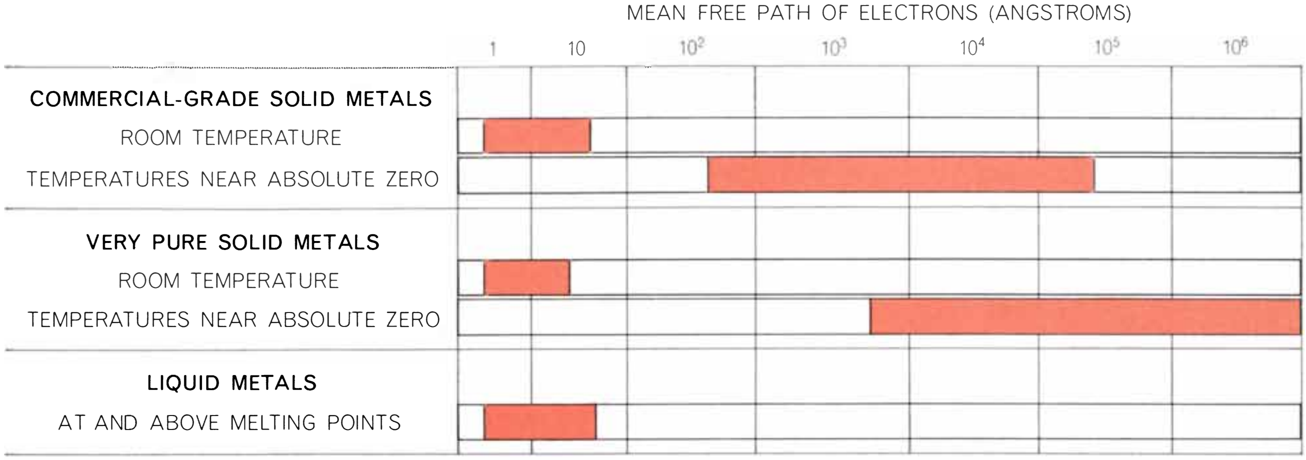
Now, the electric currents in metals are carried in the main by the detached electrons; they drift along in response to applied electromagnetic forces or temperature gradients. If there were no obstacles to impede this drift, then the resistance to the flow would be zero. This is not the case; the electrons seem to be required to pick their way through a dense collection of ions whose own electric fields scatter and deflect them. In a liquid metal the electrons suffer collisions with ions; drawing on our experience with kinetic theory, it makes sense to try to describe the electron scattering by the concept of a mean free path. An obvious intuitive guess would be that the distance between successive collisions suffered by an electron would be something like the spacing between scattering centers, that is, two or three angstroms. In many metals, however, this is quite wrong, the mean free paths estimated from their resistivities being much longer.

Reading through the history of metal physics, one realizes that this difficulty has a familiar ring to it. It is precisely the problem that was encountered by physicists in the 1920's in their attempts to explain the resistivities of solid metals. If extremely low temperatures and perfect metal crystals had been available in those days, mean free paths for the electrons as high as 10 million lattice spacings would have been discovered! This problem was finally resolved by the use of wave mechanics for the electrons. It predicts that electrons represented by waves are not scattered at all by atoms arranged in perfect crystalline solids. Electron waves are only weakly scattered by the ions in some liquid metals. In this context it is quite illuminating to compare the mean free paths of electrons in solid and in liquid metals [*see illustration on next page*].

At high temperatures the deviation from perfection (in the form of ionic vibrations that increase with the temperature) are the root cause of resistance in otherwise perfectly crystalline metals. At low temperatures the ionic vibrations diminish and other imperfections (such as



IN LIQUID SODIUM the steep repulsive region in the potential-energy curve arises from the nonuniform distribution of "free" electrons around the two neighboring ions. These electron "cloaks" are made up of electrons that have been detached from the outer valence shells of the ions. The drawing at left in *a* shows a positive charge *q* on an ion embedded in a "frozen" distribution of electron charge; this situation results in a potential field that is described by the potential-energy curve at right in *a*. The drawing at left in *b* shows the same positive charge *q* embedded in an "unfrozen" distribution of electrons, which are now free to respond to its potential field. The electron charge piles up around *q*, producing the nonuniform potential field described by the potential-energy curve at right in *b*. The drawing at left in *c* shows two neighboring ions with their cloaks of electron charge in contact. As the corresponding potential-energy curve at right in *c* indicates, these cloaks are similar in their effects to the fixed electron shells of neutral atoms.



MEAN FREE PATHS OF ELECTRONS in solid and liquid metals are compared in this table. At high temperatures resistance in pure metals is caused primarily by the large mean free paths of the ionic vibrations. At low temperatures the ionic vibrations diminish and other imperfections begin to dominate the resistivity. In liquid metals the electrons are scattered by the disordered array of ions. Near the melting point, however, the ability of both solid and liquid metals to deflect the conduction electrons is comparable.

the presence of impurities or crystalline defects) begin to dominate the resistivity. This shows up in the fact that metals of varying purity have about the same room-temperature resistivity but their low-temperature resistivities can vary by many orders of magnitude.

In a liquid metal, electrons are scattered by the disordered array of ions. Near the melting point, however, the ability of both solid and liquid metals to deflect electron waves turns out to be comparable, the liquid winning by about a factor of two. Moreover, physicists are now beginning to understand not only why liquid metals are conductors at all but also why they are such good conductors. During the past few years John M. Ziman of the University of Bristol has developed a relatively simple theory for the resistivities of liquid metals involving only the mean structure of the ions (available from experiment) and the basic scattering of electrons from individual ions (available from our knowledge of solid metals). His approach has been remarkably successful and has encouraged others to develop and extend his basic ideas.

A new and exciting development is the study of the effects of imminent phase changes and phase separations on the transport properties of liquid metals and alloys. We know that in general metals solidify when they are cooled below their melting points. We also know that some mixtures of metals are completely miscible above a certain temperature and immiscible below it. Just before these transitions the ions must begin to exhibit "critical fluctuations" in their motion, or excursions that mirror the onset of the phase changes. As a result the transport phenomena must also exhibit these effects; such "critical phenomena" are proving to be an interesting field of study in the liquid metallic state.

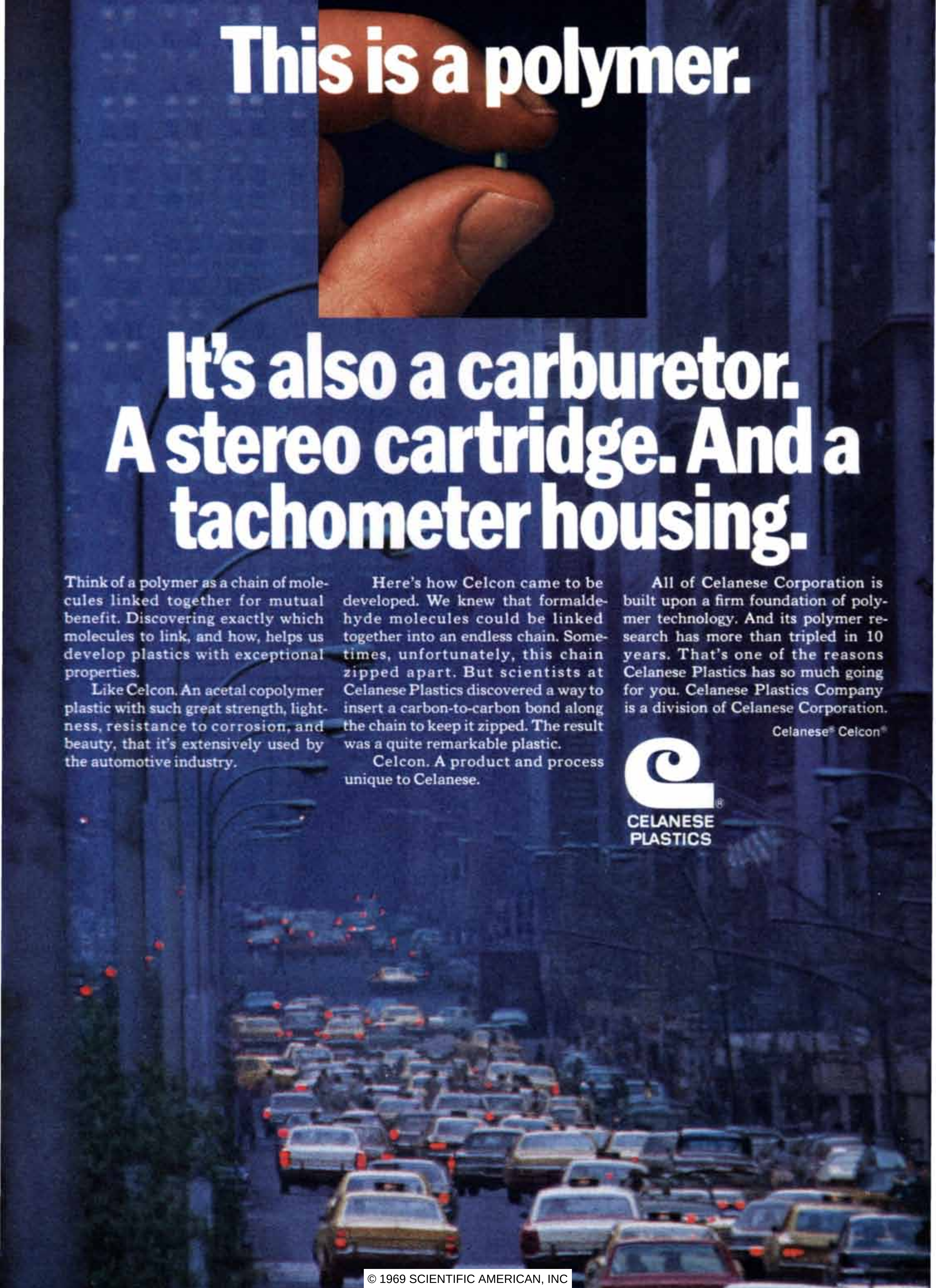
The explanation of the transport properties of liquid metals exposes a fundamental distinction between metallic and liquid properties. The liquid properties can be reasonably well accounted for by the methods of classical physics. To explain the metallic properties, however, we need quantum theory. This remains true even in those metals whose electron mean free paths turn out to be just two or three angstroms. This particular problem—the nature and distribution of electronic states in strongly scattering systems—is one that is receiving considerable theoretical attention.

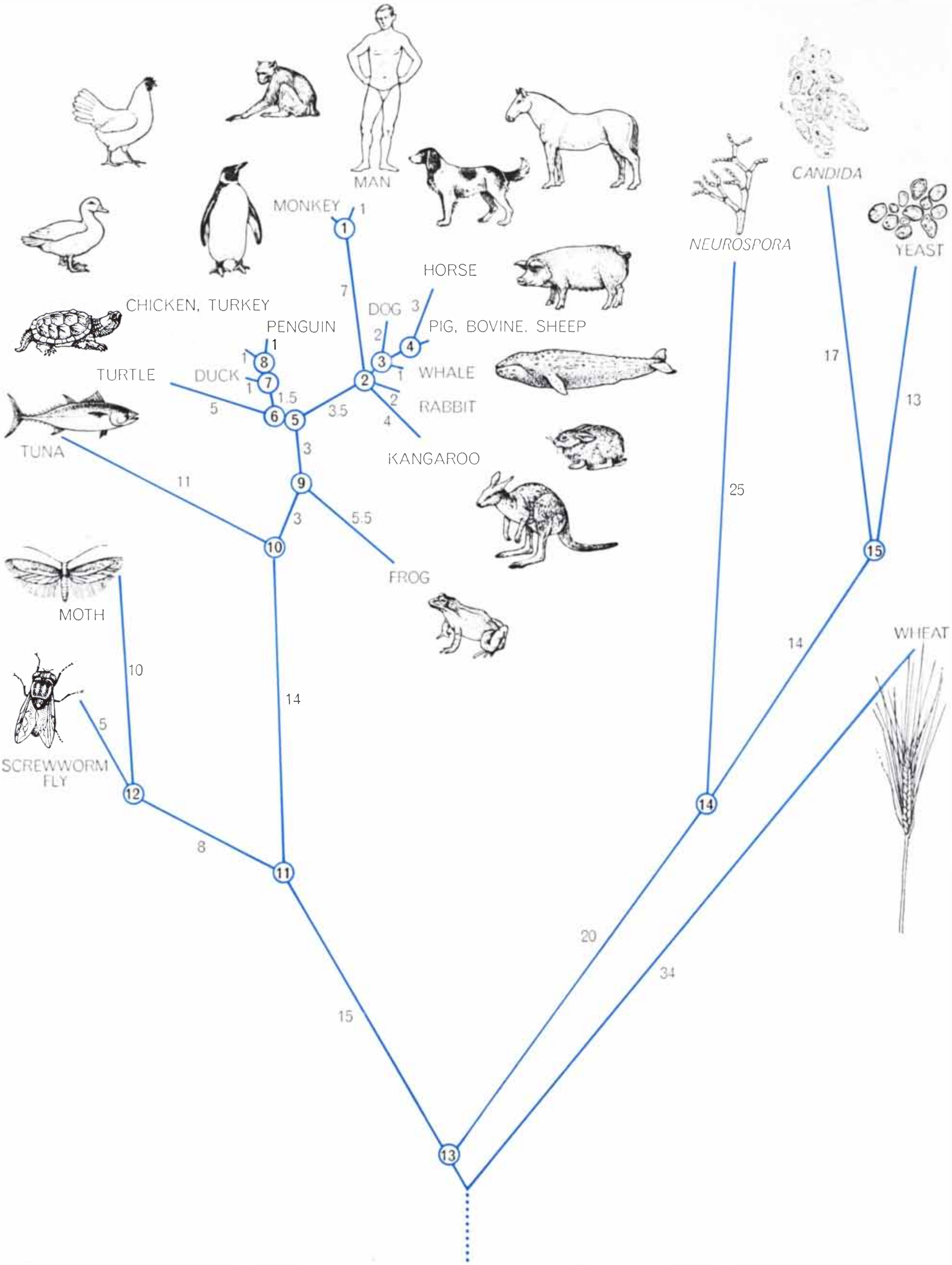
Just as it is very difficult to compress solid metals, it is also difficult to compress liquid metals, and for the same reason, namely that in reducing the volume of both we are attempting to crowd the "free" electrons into a smaller space. They resist this crowding because large numbers of such electrons in a confined space tend to have substantial kinetic energies that increase with increasing density. Liquid metals are much more incompressible than other liquids. It follows directly from this fact that the velocity of sound in liquid metals is usually higher than in other liquids.

Solid metals are capable of sustaining fairly high shear stresses. Liquid metals are unable to sustain static shears, as is true of most liquids. There is, however, an interesting exception. Certain very-high-frequency ultrasonic waves are observed to propagate in liquid metals as shear disturbances. Shear waves propagate easily in solids; in a sense the observation of shear waves in liquid metals indicates the effects of the instantaneous structure of the atoms coming into play. This in turn is linked to the ion-ion forces and hence in part to the electrons.

As for thermal properties, it has been known for more than a century that the thermal conductivity of a substance is proportional to its electrical conductivity and the temperature. The changes in conductivity (the inverse of the resistivity) at melting are small, and this must also be the case for the thermal conductivity of a liquid metal. Because the free electrons carry most of the heat current, liquid metals have much higher thermal conductivities than insulating liquids. Moreover, some liquid metals combine their substantial thermal conductivity with high heat capacity. These particular properties make liquid metals useful to the thermal engineer as materials that efficiently transport heat to and from heat exchangers. Perhaps the most thoroughly studied of all liquid metals are sodium and potassium. These have reasonably low melting points, and they have been used either separately or as alloys to facilitate the flow of heat from nuclear reactors.

I have in this article confined my comments to simple monatomic liquid metals. There are more complex systems, such as liquid tellurium and liquid selenium, that apparently collect their ions into bunches and sometimes rings. An enormous amount of data is also available now on alloy systems. Progress is slowly being made toward an understanding of their properties both from the standpoint of multicomponent fluids and as part of the general problem of the behavior of electrons in dense disordered systems. Like pure liquid metals, complex liquid metal systems challenge the ingenuity of both the theorist and the experimentalist.


This is a polymer.
It's also a carburetor. A stereo cartridge. And a tachometer housing.
Think of a polymer as a chain of molecules linked together for mutual benefit. Discovering exactly which molecules to link, and how, helps us develop plastics with exceptional properties.
Like Celcon. An acetal copolymer plastic with such great strength, lightness, resistance to corrosion, and beauty, that it's extensively used by the automotive industry.
Here's how Celcon came to be developed. We knew that formaldehyde molecules could be linked together into an endless chain. Sometimes, unfortunately, this chain zipped apart. But scientists at Celanese Plastics discovered a way to insert a carbon-to-carbon bond along the chain to keep it zipped. The result was a quite remarkable plastic.
Celcon. A product and process unique to Celanese.
All of Celanese Corporation is built upon a firm foundation of polymer technology. And its polymer research has more than tripled in 10 years. That's one of the reasons Celanese Plastics has so much going for you. Celanese Plastics Company is a division of Celanese Corporation.
Celanese® Celcon®
CELANESE PLASTICS



PHYLOGENETIC TREE showing the derivation of present-day organisms was constructed on the basis of a computer analysis of homologous proteins of cytochrome *c*, a complex substance that is found in similar versions in different species. The sequence of the amino acids that constitute the homologous protein chains is slightly different in each of the organisms shown at the ends of the branches (*see illustration on pages 88 and 89*). Analysis of the differences reveals the ancestral relations that dictate the topology of the tree. The computer programs determine the sequences of the unknown ancestral proteins shown at the nodes of the tree (*numbered circles*) and compute the number of mutations that must have taken place along the way (*numbers on branches*).

Computer Analysis of Protein Evolution

Amino acid sequences of similar proteins in different organisms contain information on relations among species. This information is analyzed to reconstruct in detail the history of living things

by Margaret Oakley Dayhoff

The protein molecules that determine the form and function of every living thing are intricately folded chains of amino acid units. The primary structure of each protein—the sequence in which its amino acid units are linked together—is governed by the sequence of subunits in the nucleic acid of the genetic material. The proteins of an organism are therefore the immediate manifestation of its genetic endowment. From a biochemical point of view a fungus and a man are different primarily because each of them has a different complement of proteins.

Yet human beings and fungi and organisms of intermediate biological complexity have some proteins in common. These homologous proteins are quite similar in structure, reflecting the ultimate common ancestry of all living things and the remarkable extent to which proteins have been conserved throughout geologic time. Because of this conservation the millions of proteins existing today are in effect living fossils: they contain information about their own origin and history and about the ancestry and evolution of the organisms in which they are found. The comparative study of proteins therefore provides an approach to critical issues in biology: the exact relation and order of origin of the major groups of organisms, the evolution of the genetic and metabolic complexity of present-day organisms and the nature of biochemical processes. A new discipline, chemical paleogenetics, concerns itself with such studies [see "The Evolution of Hemoglobin," by Emile Zuckerkandl; SCIENTIFIC AMERICAN, May, 1965]. In order to exploit the possibilities of this new field we have developed a computer technique for analyzing the relations among protein sequences.

The body of data available in protein sequences is something fundamentally new in biology and biochemistry, unprecedented in quantity, in concentrated information content and in conceptual simplicity. The data give direct information about the chemical linkage of atoms, and that linkage determines how protein chains coil, fold and cross-link—and thus establishes the three-dimensional structure of proteins. Because of our interest in the theoretical aspects of protein structure our group at the National Biomedical Research Foundation has long maintained a collection of known sequences. For the past four years we have published an annual *Atlas of Protein Sequence and Structure*, the latest volume of which contains nearly 500 sequences or partial sequences established by several hundred workers in various laboratories. In addition to the sequences, we include in the *Atlas* theoretical inferences and the results of computer-aided analyses that illuminate such inferences. This article is based in part on that material, to which contributions have been made by Chan Mo Park, Minnie R. Sochard, Lois T. Hunt and Patricia J. McLaughlin, and by Richard V. Eck, now of the University of Georgia.

Basic metabolic processes are similar in all living cells. Many identical structures, mechanisms, compounds and chemical pathways are found in widely diverse organisms; even the genetic code is almost the same in all species. It is by this code that the sequence of nucleotides, or nucleic acid subunits, that constitutes a gene is translated into the amino acid sequence of the protein derived from it. It is therefore not surprising that a large number of proteins have been found to have identifiable counterparts in most living things. These homologues appear to perform the same functions in the organisms in which they are found, and they can often be substituted for one another in laboratory experiments. Being complex substances, they are only rarely identical, but in the past 15 years homologous proteins have been shown to have nearly the same amino acid sequences and quite similar three-dimensional structures.

One such protein whose amino acid sequence has been established for a number of species is the protein of cytochrome *c*, a complex substance that in animals and higher plants is found in the cellular organelles called mitochondria, where it plays a role in biological oxidation. Twenty different sequences of cytochrome *c* have been identified and analyzed by a number of investigators, including Emil L. Smith of the University of California at Los Angeles, Emanuel Margoliash of the Abbott Laboratories and Shung Kai Chan and I. Tulloss of the University of Kentucky. Recently Karl M. Dus, Knut Sletten and Martin D. Kamen of the University of California at San Diego found a clearly related protein in a bacterium, *Rhodospirillum rubrum*, which lacks mitochondria.

The correspondence in amino acid sequence among these proteins is clear when the sequences are arrayed below one another [*see top illustration on next two pages*]. There are differences in length, reflecting additions or deletions of nucleotides in the corresponding genes. These changes are at the ends of sequences except for the internal deletions or additions revealed by the bacterial protein. Once the sequences have been adjusted to allow for these changes there is no question about the correct alignment. In man and the gray kangaroo, for example, the amino acids are the same in 94 out of 104 positions; in the less similar human and baker's yeast sequences, 64 positions conform, or some

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                               10        20        30        40
                      1234567890123456789012345678901234567890123456789
HUMAN                 --------GDVEKGKKIFIMKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
RHESUS MONKEY         --------GDVEKGKKIFIMKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
HORSE                 --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
PIG, BOVINE, SHEEP    --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
DOG                   --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
GRAY WHALE            --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
RABBIT                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
KANGAROO              --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLNGIFGRKTG
CHICKEN, TURKEY       --------GDIEKGKKIFVQKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
PENGUIN               --------GDIEKGKKIFVQKCSQCHTVEKGGKHKTGPNLHGIFGRKTG
PEKIN DUCK            --------GDVEKGKKIFVQKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
SNAPPING TURTLE       --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLNGLIGRKTG
BULLFROG              --------GDVEKGKKIFVQKCAQCHTCEKGGKHKVGPNLYGLIGRKTG
TUNA                  --------GDVAKGKKTFVQKCAQCHTVENGGKHKVGPNLWGLFGRKTG
SCREWWORM FLY         ----GVPAGDVEKGKKIFVQRCAQCHTVEAGGKHKVGPNLHGLFGRKTG
SILKWORM MOTH         ----GVPAGNAENGKKIFVQRCAQCHTVEAGGKHKVGPNLHGFYGRKTG
WHEAT                 ASFSEAPPGNPDAGAKIFKTKCAQCHTVDAGAGHKQGPNLHGLFGRQSG
FUNGUS (NEUROSPORA)   ----GFSAGDSKKGANLFKTRCAECHGEGGNLTQKIGPALHGLFGRKTG
FUNGUS (BAKER'S YEAST)---TEFKAGSAKKGATLFKTRCELCHTVEKGGPHKVGPNLHGIFGRHSG
FUNGUS (CANDIDA)      --PAPFEQGSAKKGATLFKTRCAECHTIEAGGPHKVGPNLHGIFSRHSG
BACTERIUM (RHODOSPIRILLUM)
                             EGDAAAGEKVSK-KCLACHTFDQGGANKVGPNLFGVFENTAA

NODE 1                --------GDVEKGKKIFIMKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 2                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 3                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 4                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 5                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 6                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 7                --------GDVEKGKKIFVQKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 8                --------GDIEKGKKIFVQKCSQCHTVEKGGKHKTGPNLHGLFGRKTG
NODE 9                --------GDVEKGKKIFVQKCAQCHTVEKGGKHKVGPNLHGLFGRKTG
NODE 10               --------GDVEKGKKIFVQKCAQCHTVE GGKHKVGPNLHGLFGRKTG
NODE 11               ----  PAGD EKGKKIFVQ CAQCHTVEAGGKHKVGPNLHGLFGRKTG
NODE 12               ----GVPAGD EKGKKIFVQRCAQCHTVEAGGKHKVGPNLHGLFGRKTG
NODE 13               ----  PAGD  KGAKIFKT CAQCHTVEAGG HKVGPNLHGLFGRK G
NODE 14               ---- F AGDAKKGA LFKTRCAECHTVE GG HKVGPNLHGLFGRK G
NODE 15               ---  F AGSAKKGATLFKTRCAECHTVE GGPHKVGPNLHGIFGRHSG
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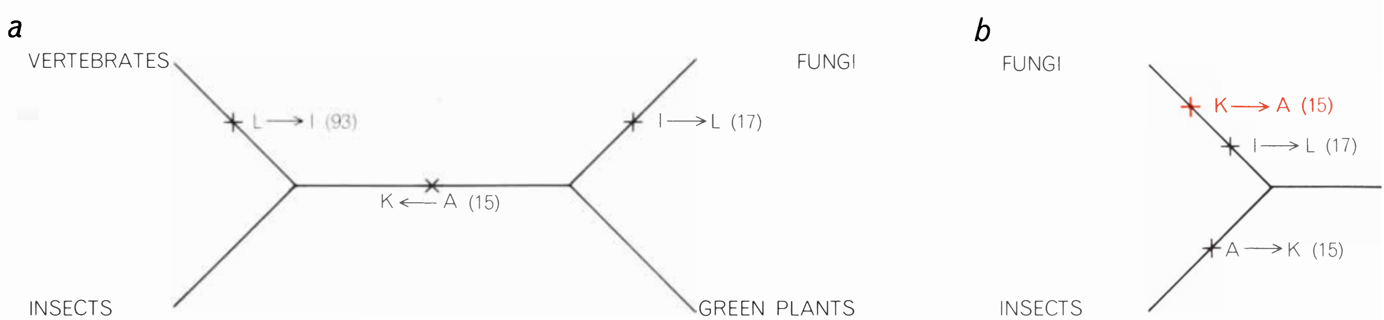
A ALANINE
C CYSTEINE
D ASPARTIC ACID
E GLUTAMIC ACID
F PHENYLALANINE
G GLYCINE
H HISTIDINE
I ISOLEUCINE
K LYSINE
L LEUCINE
M METHIONINE
N ASPARAGINE
P PROLINE
Q GLUTAMINE
R ARGININE
S SERINE
T THREONINE
V VALINE
W TRYPTOPHAN
Y TYROSINE

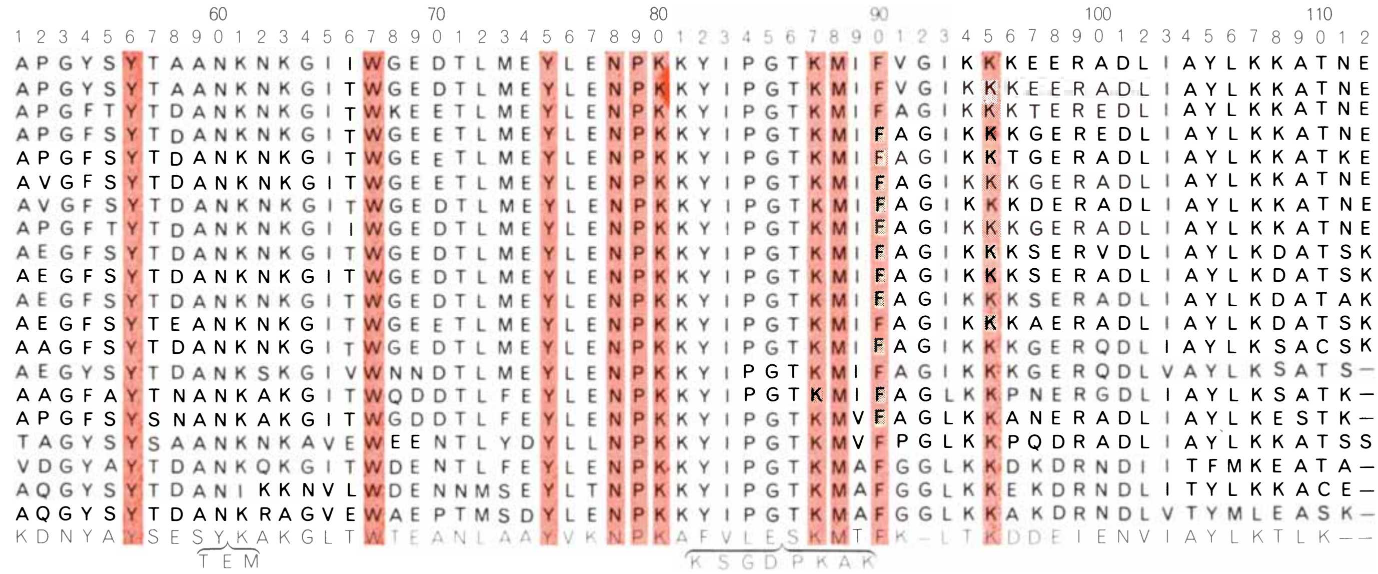
AMINO ACID SEQUENCES of 20 cytochrome *c* proteins and of a related bacterial protein are arrayed below one another. For the purposes of the computer each amino acid is represented by a single letter (*see key at left*) instead of the usual three-letter symbol. The proteins differ in length, and dashes have been inserted in order to preserve the correct alignment; these differences come at

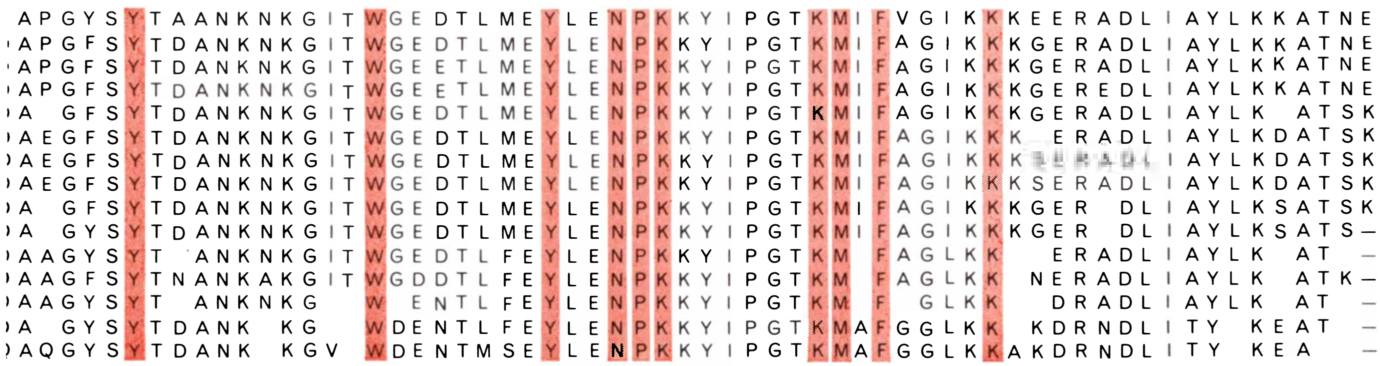
three-fifths of the total length. All 21 sequences, including the bacterial one, have the same amino acid in 20 positions. When the amino acids at a given position are not the same, they usually have similar shapes or chemical properties.

Such similarity of sequence is impressive testimony to the evolution of all these organisms from common ancestors, confirming earlier morphological, embryological and fossil evidence. The alternative to common ancestry—that the similar cytochrome *c* proteins originated independently in different organisms—is not plausible. Consider the probability of duplicating the sequence of amino acids in just one chain 100 units long. Since any of 20 amino acids can occur in every position, the number of different possible chains is 20^{100}. With so many possibilities it is improbable that two unrelated organisms would happen independently to have manufactured—



LINEAGES of major groups are constructed from the evidence at three positions in the sequences in order to illustrate the principles involved in constructing a phylogenetic tree. At Position 15 vertebrates and insects have a *K* (lysine); fungi and wheat have an *A* (alanine). This suggests that a single lineage connected the animals and plants and that a single mutation from *A* to *K* took



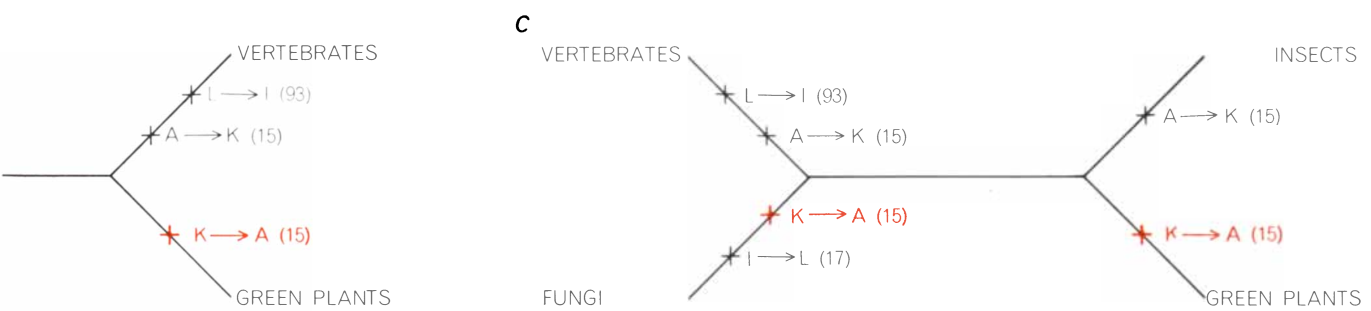


the ends of sequences except in the case of the bacterium, where there are internal differences in length. The amino acid positions are numbered according to the wheat sequence, which has 112 amino acids. At 20 positions (*color*) the same amino acid is found in all the sequences, and the degree of identity is far greater among related species. These observed sequences constitute the raw data that are fed into the computer. The computer determines the ancestral sequences that can best account for the relations among observed sequences. These ancestral sequences establish the nodes: locations at which the branches of the phylogenetic tree diverge. Node 1, for example, is the ancestor of the primates, Node 2 is the mammalian ancestor and Node 10 is the vertebrate ancestor.

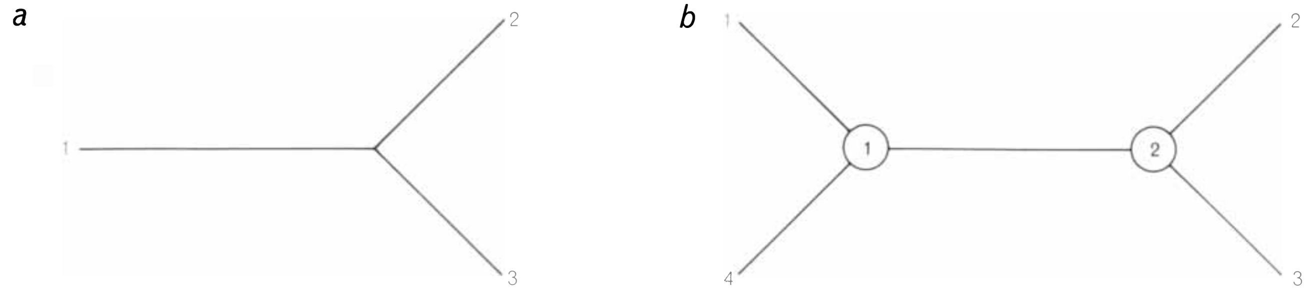
and to have preserved through natural selection—such similar structures. On the other hand, gradual evolution from a common ancestor through millions of generations provides a convincing explanation for both the similarities and the differences among present-day cytochrome sequences.

The evolutionary process is made possible by mutations: errors in the copying and passing along of genetic material from generation to generation. The most frequently accepted mutation within a gene is the exchange of a single nucleotide for another, which may yield a protein that has one amino acid changed.

A second kind of error is the duplication of a portion of a gene. This can yield an elongated gene or, often, two almost complete copies of the original genetic material that proceed to mutate independently. Finally, nucleotides can be deleted or inserted, resulting in a protein of altered length.



place between them. This reasoning, together with similar reasoning from evidence at Position 17 and Position 93 (*see text*), suggests a certain topological relation of lineages (*a*). It includes three mutations. There are two other possible configurations (*b, c*) but they each require four mutations, two of which have alternative forms (*color*). The first topology is therefore the most probable one.



COMPUTER PROGRAM 2 builds an approximate topology by beginning with three observed sequences, which can only be related by a simple three-branch topology (*a*). It then adds a fourth sequence to each of the three original branches in turn, establish-

Over billions of years many such errors have occurred in individual organisms. A few have been selected as beneficial and perpetuated in the species; most have been deleterious and have been eliminated. One pressure against their selection is the biochemical conservatism that results from the interdependence of the various cell components. A protein must automatically fold into a precise three-dimensional shape when it is synthesized, and the shape is predetermined by the sequence. Each protein becomes adapted to performing a particular function in which it must interact with other components, whether through its chemical action, through the complexes it forms, through the rate at which its reactions proceed or through its structural properties. Moreover, all these capabilities must be little disturbed by changes or extremes in the environment.

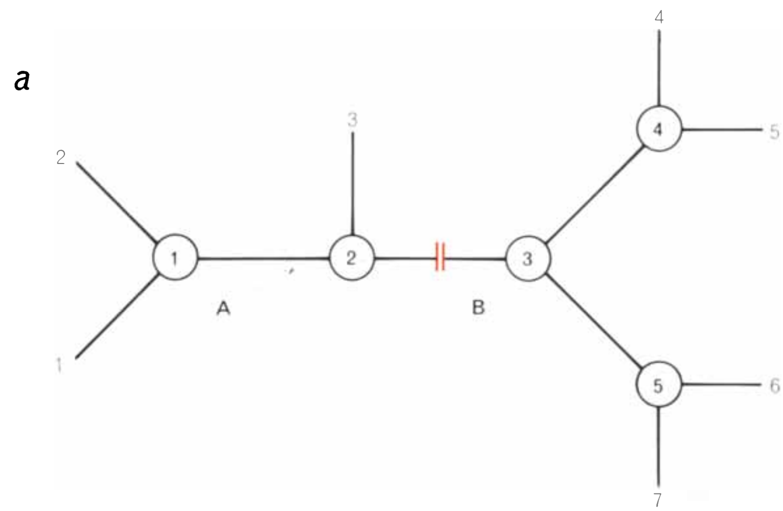
Under such circumstances as these, most changes in protein sequence—even if they are advantageous for a particular function—are likely to disturb so many other interactions as to be almost always deleterious on balance. So severe are these constraints that an identical sequence of each protein is found in most individuals of a species, and a given sequence may be predominant in a species for several million years. Occasionally a minor variant may be tolerated, persist and eventually become preferable because of a change in other cell components or in the external environment. In other cases a rarely occurring error may immediately prove to be beneficial. Sometimes the environmental circumstances are so strained or the beneficial error is so profound that two separate populations or even two species develop. Subsequent changes arise independently in the two separate groups.

The degree of difference among present-day species and the order of their derivation from common ancestors are commonly represented by a phylogenetic tree. It is possible to derive such a tree from protein-sequence data. The basic method is to infer from observed sequences the ancestral sequences of the proteins from which they diverged, and thus to establish a series of nodes that define the connections of twigs to branches and of branches to limbs. Then all the observed and reconstructed sequences and the topology, or order of branching, that connects them are considered at once, and the configuration that is most consistent with the known characteristics of the mutational process is chosen. Within the limitations of the small quantity of data available so far, a tree constructed in this way has the same topology as trees that have been derived from conventional morphological or other biological considerations. When the structure of a large number of proteins has been worked out, there will be enough evidence to establish the order of divergence of the major living groups of organisms and even a relative time scale for these divergences. The detailed nature and order of acceptance of mutations that occurred in the distant past may then become clear.

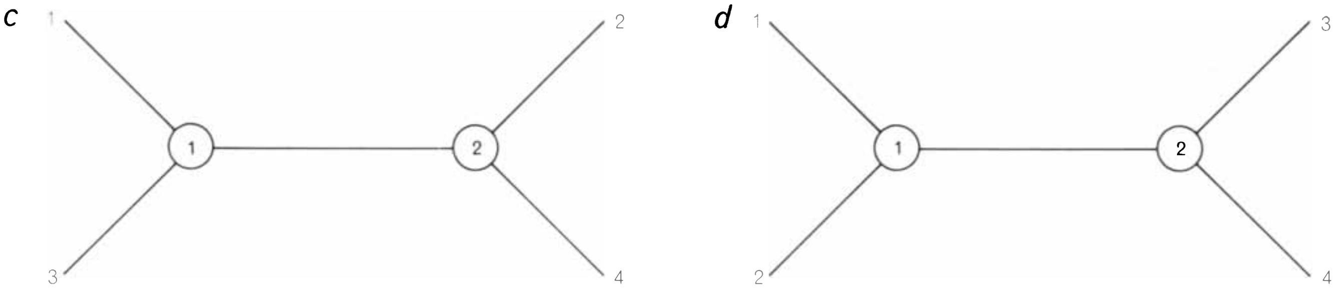
Each point on a phylogenetic tree derived from protein sequences represents a definite time, a particular species and a predominant protein structure for the individuals of the species. For any such tree there is a "point of earliest time"; radiating from this point, time increases along all branches, with protein sequences from present-day organisms at the ends of the branches. The location of the point of earliest time—the connection to the trunk of the tree—cannot be inferred directly from the sequences; it must be estimated from other evidence.

To illustrate some of the general considerations in building a phylogenetic tree let us consider just three amino acid positions in the cytochrome *c* sequences (excluding the bacterial one). It is clear, first of all, that biologically similar organisms tend to have the same amino acid in a given position. In Position 15 the plants all have the amino acid alanine (*A*), whereas the animals have lysine (*K*). In Position 17 the fungi (*Neurospora*, yeast and *Candida*) have leucine (*L*), whereas the wheat and most animal sequences have isoleucine (*I*); only a fish (the tuna) has threonine (*T*). In Position 93 the insects and plants have leucine, whereas the vertebrates have isoleucine.

Changes arise so seldom that an observed change almost always reflects a mutation in a single ancestral organism.



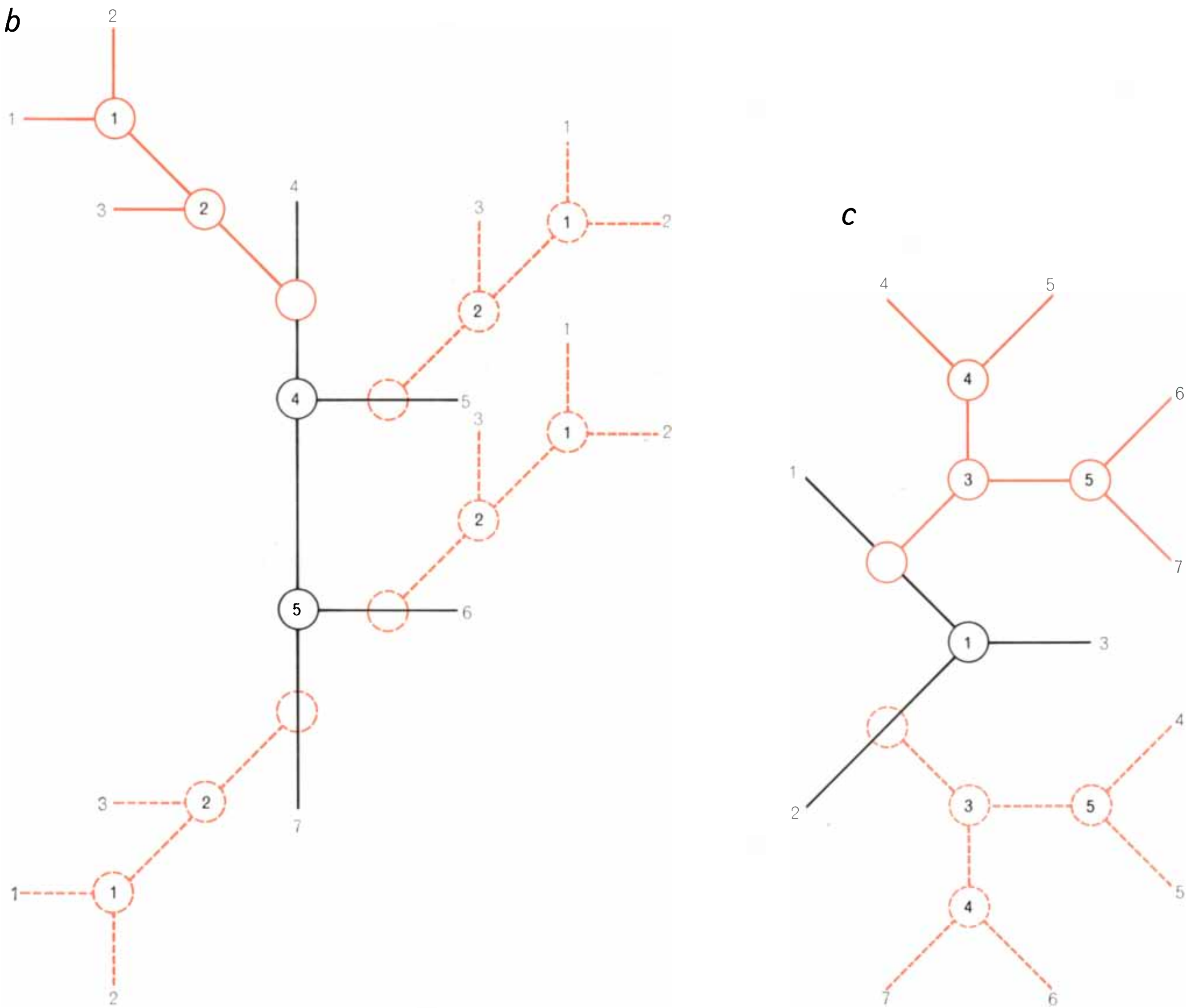
PROGRAM 3 improves on the topology established by Program 2 by trying alternative configurations. It does this by cutting each branch of the tree and grafting the resulting pieces



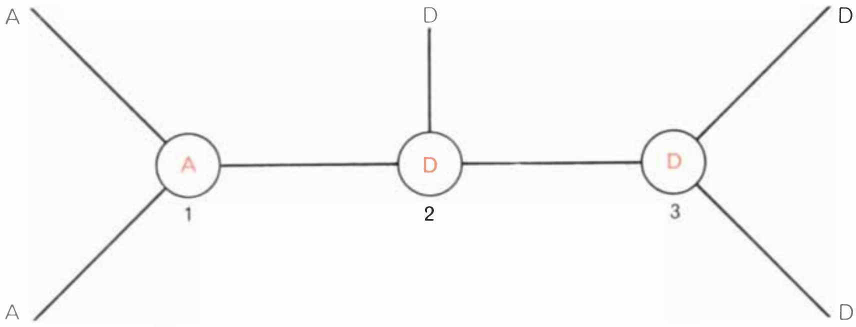
ing three possible topologies for a four-branch tree (*b, c, d*). Program 1 establishes the sequences for the nodes (*numbered circles*) and evaluates each topology. The best one is accepted. In this way all the sequences are added until a complete tree has been formed.

The evidence at Position 15 favors the hypothesis that there was a single mutation in a single lineage connecting the animal group with the plant group. The mutation at Position 17 indicates a single lineage between fungi and the other species; the one at Position 93 indicates a single lineage between vertebrates on the one hand and insects and plants on the other. Taken together, these pieces of evidence yield a topology that accommodates all the information from the three sites and requires that only three changes occurred in three ancestral organisms. There are two other possible topologies, but they require that at least four changes must have taken place [*see bottom illustration on pages 88 and 89*]. Since changes in sequence are so rare, we assume that the first configuration is the one most likely to be correct.

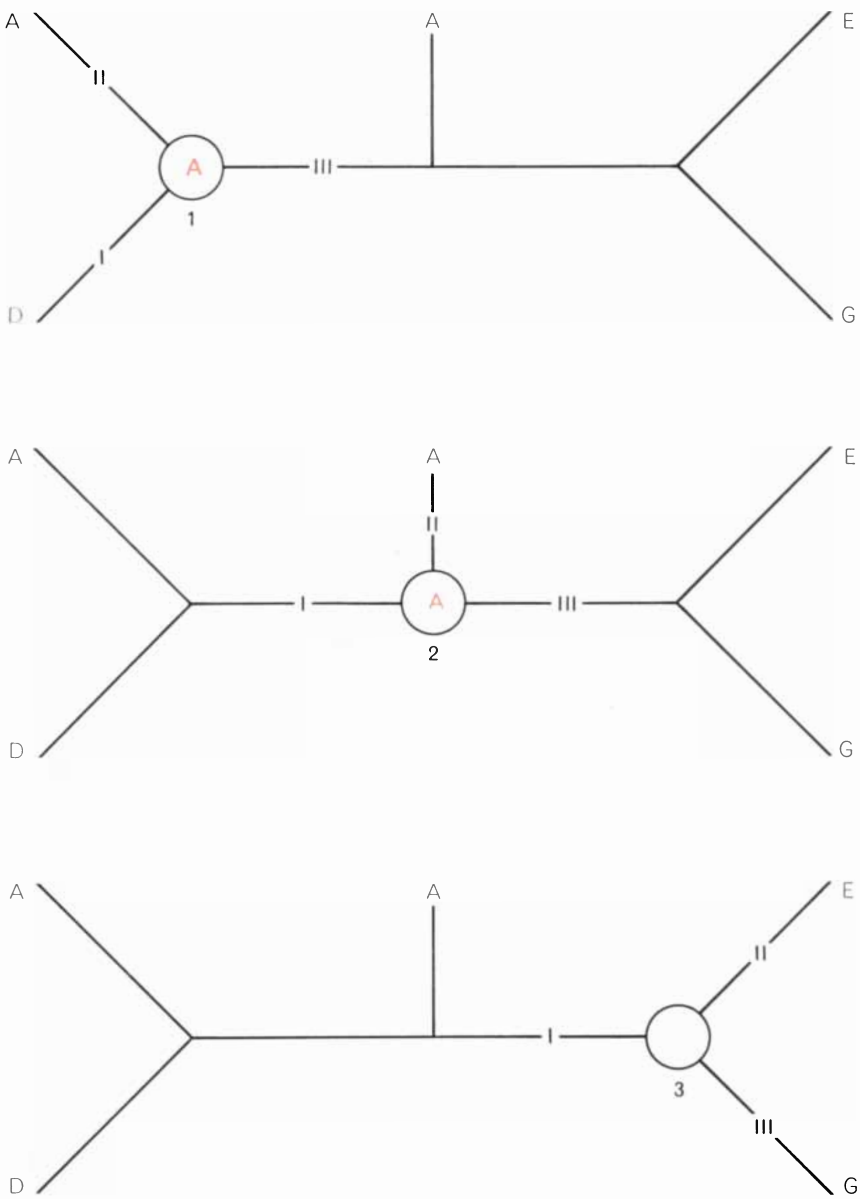
It is necessary, of course, to consider all the evidence, not just that found at three amino acid positions. Evidence



in different ways. In this example a small tree (*a*) is divided into parts *A* and *B*. Four new topologies are created (*b*) when *A* is grafted to *B* at four points (*color*). Two new structures result (*c*) when *B* is grafted to *A*. The procedure is repeated for each branch.



PROGRAM 1, which evaluates topologies, infers the ancestral sequences at each node. It does this one amino acid at a time. In this tree the amino acids at a certain position in five observed sequences are shown (*black letters*). From this information the amino acids at that position in ancestral sequences at Node 1, Node 2 and Node 3 are inferred (*color*).



PROCEDURE followed by the computer is to make a list, for each node, of the amino acids on each branch (*Roman numerals*). The amino acid that is on more lists than any other one is assigned to the node. Here the lists would read, for Node 1, *D*, *A* and *AEG* (*top*); for Node 2, *DA*, *A* and *EG* (*middle*); for Node 3, *DAA*, *E* and *G* (*bottom*). Amino acid *A* appears on two lists for Node 1 and so it is assigned to the node. For the same reason it is assigned to Node 2. No amino acid is clearly the best for Node 3 and so it is left blank.

from a number of other positions confirms the choice of the first topology described above, but occasionally there is conflicting evidence. For example, at Position 74 there is evidence that wheat and *Candida* are in one group that is connected by a single lineage to all other species. Since this is contrary to the weight of all the other evidence, we must assume that in this position there were two distinct mutations, in two different groups, that by coincidence yielded the same amino acid.

In constructing a phylogenetic tree the quantity of data to be considered is so large and objectivity is so essential that processing the information is clearly an appropriate task for a computer. Our approach is to make an approximation of the topology and then try a large number of small changes in order to find the best possible tree. We have developed three computer programs to do this. Program 1 evaluates a topology. It does this, as I shall explain in more detail below, by first determining the ancestral sequences at all the nodes in a given topology and then counting the total number of amino acid changes that must have occurred in order to derive all the present-day sequences from the ancestral ones. The lower the number, the better the topology is assumed to be. The other two programs use Program 1 to build an approximate tree and then to improve it.

Program 2 starts with three observed present-day sequences, which can only have a simple three-branch topology. It then adds a fourth sequence to each of the three branches in turn [*see top illustration on preceding two pages*] and applies Program 1 to evaluate each resulting topology. The best one is chosen. Then a fifth sequence is added, and then, one at a time, the rest of the sequences. Since each placement is decided without regard to the sequences to be located later, at least one wrong decision is very likely to be made, producing a tree that is almost but not quite the best one. Program 3 is therefore applied to shift each of the branches to other parts of the tree, thus testing all likely alternative configurations. This can be done systematically by cutting each branch or group of branches and grafting it to every other branch or limb of the tree [*see bottom illustration on preceding two pages*]. Again the resulting topologies are evaluated by Program 1, and the best one is finally chosen.

Program 2 and Program 3 are straightforward in logic, although they were intricate programming problems. Our major decisions were made in designing Program 1, which evaluates the topologies proposed by the other two programs.

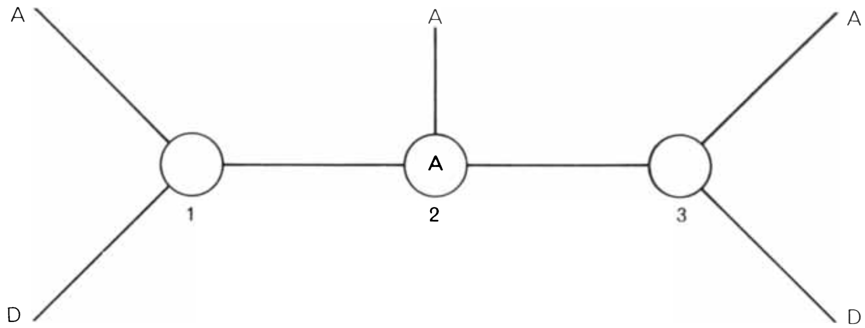
Program 1 begins by making inferences about the ancestral sequences to be assigned to the nodes. It does this by considering, one at a time, the amino acid positions along the chain. Where only one amino acid is found in all the observed sequences, almost certainly it was present in all the ancestors at all times. In less clear-cut situations a number of reasonable conjectures can be made regarding the ancestral sequences. Consider the case of the amino acids at a certain position in five sequences connected by a definite topology [*see top illustration on opposite page*]. What was the ancestral amino acid at that position in the three nodal sequences? At Node 1 it is most likely to have been *A*, and at Node 2 and Node 3 it is most likely to have been *D*. There was, then, one mutation between Node 2 and Node 1. Any other assignment of amino acids would require two or more mutations.

Let us now see how the computer handles such a problem in practice. The computer must treat all possible topologies, not just one particular case. For this purpose any tree can be thought of as being made up entirely of nodes connecting three branches [*see bottom illustration on opposite page*]. More complex branching simply involves two or more such nodes with zero distance between them. Each of the three branches connects the node either with an observed sequence or with another node and, through it, ultimately with two or more other observed sequences. The computer makes a list of the amino acids that lie on each branch. For example, the lists for Node 1 would show *D* on Branch I, *A* on Branch II and *A*, *E* and *G* on Branch III. Then the amino acid that is found on more lists than any other is assigned to each node. If no single first choice exists, the position is left blank. By this procedure *A* would be selected for Node 1 and Node 2; Node 3 would be left blank.

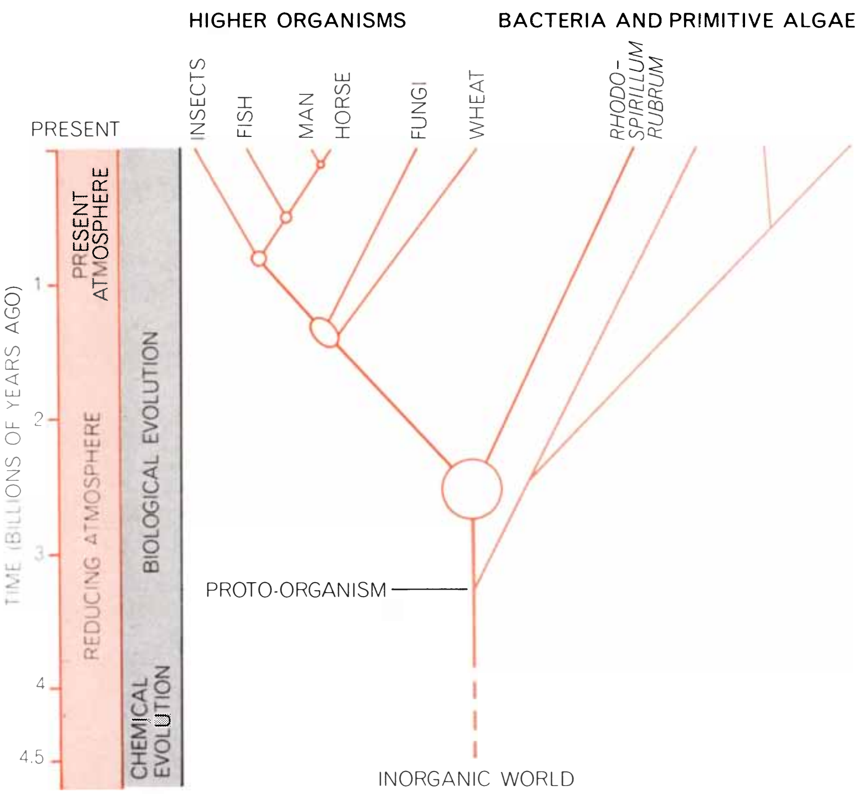
In a number of situations this simple program gives an equivocal assignment when it need not [*see top illustration on this page*]. The procedure I have described would assign blanks to Node 1 and Node 3 although it is intuitively clear that the choice of *A* for all three nodes is best, necessitating two independent mutations from *A* to *D*. Any other choice would require at least three mutations, a less likely history.

We therefore added further steps to enable the computer to fill in unnecessary blanks. The first assignment of nodal amino acids is examined. If at least two of the three positions adjacent to a blank node contain the same amino acid, that amino acid can be inferred also for the blank node. This second assignment may supply the information required to fill in other blanks, and so the procedure is repeated until no more changes occur. Finally any node that does not have the same amino acid as two of its neighbors is changed to a blank. The entire process yields a definite assignment of ancestral amino acids wherever one choice is clearly preferable and leaves blanks where there is reasonable doubt. By applying these procedures to each position the program eventually spells out all the ancestral sequences.

The nodal sequences for cytochrome *c* are displayed along with the observed sequences [*see top illustration on pages 88 and 89*]. The very small number of blanks indicates how few of the positions remain doubtful. These computed ancestral sequences, incidentally, may take



FURTHER STEPS are required of Program 1 to avoid leaving unnecessary blanks. In this example the basic procedure would leave Node 1 and Node 3 blank (because at both nodes *A* and *D* would each appear on two lists. The program therefore examines the first nodal assignments and, if at least two of the three positions adjacent to a blank node (including another node) have the same amino acid, assigns that amino acid to the blank node. Thus *A* is assigned to Node 1 and Node 3. Ultimately each node must agree with two of its neighbors.



CYTOCHROME *C* TREE (*dark color*) is redrawn on an absolute time scale and in the context of earth history. The bacterial branch has been added and the "point of earliest time" is taken to be equidistant from the bacterial and the other present-day sequences (*see text*). The size of each node reflects the degree of uncertainty in determining its position.

on real meaning in view of the increasing possibility of synthesizing proteins in the laboratory. As investigators succeed in duplicating the sequences we may learn a great deal about the chemical capabilities of ancient organisms.

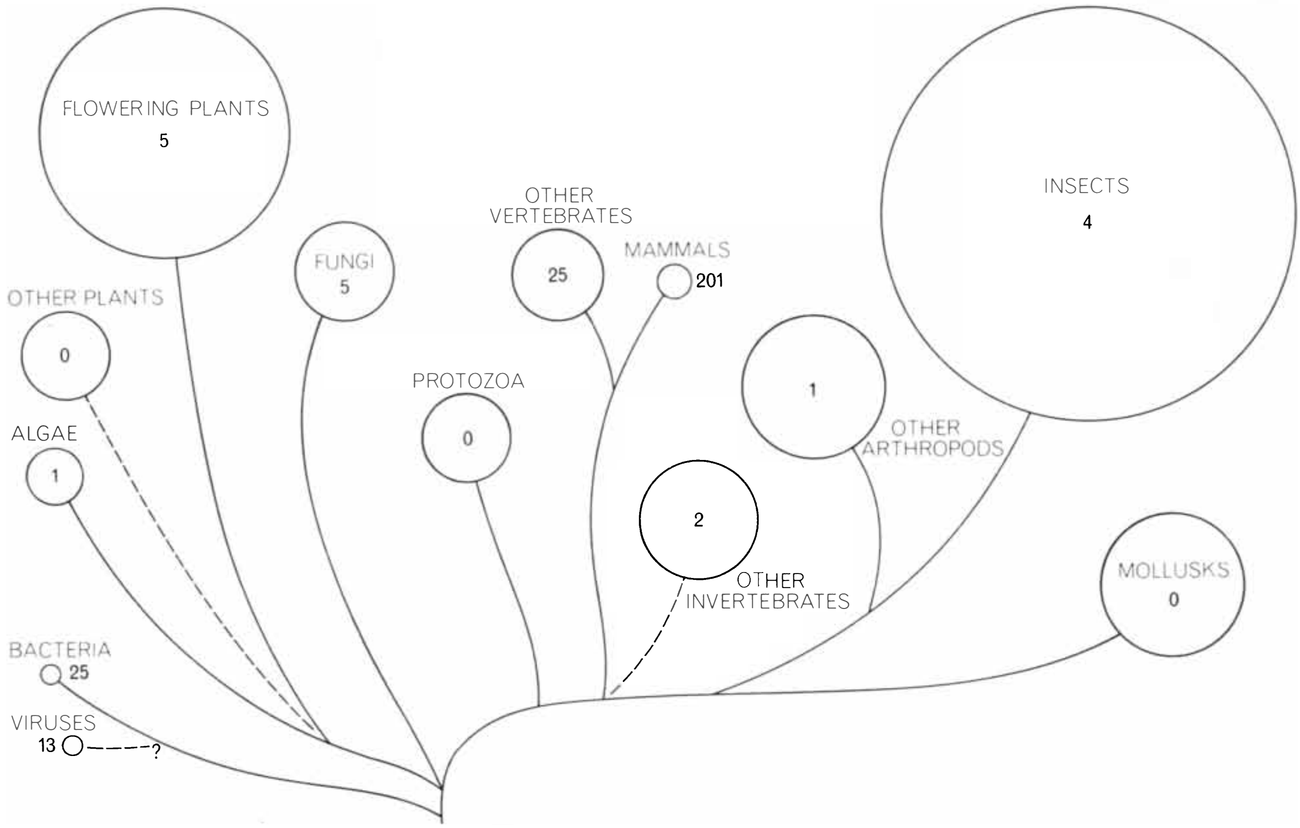
Once the ancestral sequences have been established, the amino acid changes along each branch of the tree are totaled. (Even when a position is left blank, it is possible to determine the number of changes that must have taken place there.) The sum, representing the total number of changes on the tree, is the final score for that tree. In this way each of the alternative topologies proposed by Program 2 and Program 3 is evaluated in turn.

To make the best topology into the best phylogenetic tree one needs a measure of branch length. We use the number of mutations between nodes. The figures for the observed amino acid changes, however, understate the actual number of mutations because mutations can be superimposed: in a long enough time interval, for example, an *A* might change to a *D* and the *D* to an *S* and the *S* to an *A*, eradicating the evidence of change. We correct for superimposed mutations by applying factors based on the known probability that any amino acid will change to any other given amino acid. That provides our unit of branch length: accepted point mutations per 100 amino acid positions (PAM's). Now it is possible to draw the tree [*see illustration on page 86*]. The major groups fall clearly into the topology shown, but some of the details are still uncertain. It is hard to establish the exact sequence of events in the short interval during which the lines to the kangaroo, the rabbit, the ungulates and the primates diverged. For some divergences, such as the one to the dog and the gray whale, the topology depends on a single amino acid position, and there is perhaps one chance in five or 10 that the branching point is incorrect by one unit. In time other protein sequences from these animals should clear up the uncertainties.

It remains only to establish a time scale for the tree and, by establishing a point of earliest time, to relate the history of cytochrome *c* to geologic time. Our impression is that a protein such as cytochrome *c*, once its function is well established, is subject to about the same risk of mutation in a given time interval no matter what species it is in. It may well turn out that this is not true—that the risk varies in major groups and that occasionally a species may undergo a large change. For the time being, however, we assume that the mutation rate is constant over long intervals, and we define a time scale in terms of the number of mutations.

The bacterial sequence provides information with which to establish the point of earliest time. Because the *Rhodospirillum* sequence is so different from the other sequences it is not shown on the cytochrome *c* tree. There is evidence for its placement, however. At Position 13 and Position 29 *Rhodospirillum* and wheat are different from all the other sequences but are like each other. This indicates that the bacterium should be attached to the wheat branch. Then the fungi and the animals must have diverged from each other after the line to higher plants diverged from the bacteria. To allow for its many differences, the bacterial branch must be very long—about 95 PAM's. That being the case, the point of earliest time must be well back on the bacterial branch.

Now it is possible to redraw the cytochrome tree in simplified form with a time scale in years. The translation frcm PAM's to years is derived from geological evidence, the best of which dates the divergence of the lines to the bony fishes and the mammals at about 400 million years ago. The cytochrome tree puts that divergence at 11.5 PAM's, on the aver-



SEQUENCE DATA are accumulating rapidly. The numbers indicate how many sequences of 30 amino acid positions or more have been determined in each biological group; the area of the circles is proportional to the number of species described in each group (except in bacteria and viruses, where species are not clearly defined). Data from a wide range of groups are needed for paleogenetics.

age. Therefore 11.5 PAM's corresponds to 400 million years. Now the major nodes can be plotted on the basis of the average number of mutations on the branches above each node. We assume, moreover, that the point of earliest time—the connection to the trunk of the tree—is equidistant from the bacterial and the other present-day sequences. Thus from one family of related proteins we can estimate the temporal relations for an extensive tree of life [*see bottom illustration on page 93*].

The tree is shown in the context of current theory from geological and other biochemical considerations. Elso S. Barghoorn of Harvard University has reported fossil evidence that at least two kinds of organism existed more than three billion years ago, one resembling a bacterium and the other a blue-green alga. Their common ancestor, the "proto-organism," must already have had a complex cell chemistry; it contained many related proteins presumably descended by evolutionary processes from fewer ancestral proteins. Before the time of the proto-organism there was an era of chemical evolution through which life emerged from an inorganic world [see "Chemical Fossils," by Geoffrey Eglinton and Melvin Calvin; SCIENTIFIC AMERICAN, January, 1967].

The rate of change over geologic time varies greatly from one protein to another. Cytochrome *c* protein is the most slowly changing one that has been studied so far in a wide variety of organisms; it appears to have changed at the rate of about 30 PAM's every billion years. The comparable figure for insulin is 40; for the enzyme glyceraldehyde-3-phosphate dehydrogenase, 20; for histones (proteins that are bound to DNA) only .6 PAM. On the other hand, hemoglobin has undergone about 120 PAM's per billion years, ribonuclease 300 and the fibrinopeptides, which are involved in the chemistry of blood clotting, 900. It seems likely that some of the slowly changing proteins will provide the best information on long-term evolution because they have undergone fewer superimposed mutations. Proteins that change more rapidly will provide higher resolution for sorting out closely related species.

Each protein sequence that is established, each evolutionary mechanism that is illuminated, each major innovation in phylogenetic history that is revealed will improve our understanding of the history of life. Surely insight into the biochemistry of man will be obtained from better understanding of his origins.

HIGH-TEMPERATURE PLASTICS

Many common plastics lose their shape at the boiling point of water. Ingenious chemical strategies can now provide such materials that survive at temperatures as high as 900 degrees C. (1,650 degrees F.)

by A. H. Frazer

Ordinary plastics consisting of synthetic polymers are remarkably resistant to tension, compression, abrasion, impact, repeated flexure, discoloration and the effects of sunlight and corrosive chemicals. They were designed, in fact, to withstand almost any destructive agent except intense heat; it was not anticipated that they would ever have to maintain their rigidity, shape and strength in aviation-fuel fires, curing ovens, industrial smokestacks and other high-temperature environments. To be useful a nylon fabric, for instance, needed only to be able to survive the heat of washing and ironing. Even insulation for electrical wiring and laminated structures for electric motors experienced only intermittent exposure to temperatures as high as 100 degrees Celsius—the boiling point of water. Today, however, the demand for light, strong and formable materials that can withstand temperatures considerably higher than that has led to the development of new families of polymers.

For the windshields, radomes, door seals and airframe adhesives of a Mach-2 aircraft materials are needed that can survive temperatures of 300 degrees C. Even aircraft tires must be quite heat-resistant: when an airplane lands at 200 miles per hour, friction can raise their temperature to 150 degrees. Electric motors also need sturdier polymer insulation, since it has been found that their efficiency increases as operating temperatures rise. Furthermore, certain kinds of protective clothing must withstand temperatures above 300 degrees, and aircraft companies are beginning to ask for polymers that can be made into the leading edge of wings for Mach-3 and Mach-4 aircraft that will maintain its strength at temperatures that for short periods may go as high as 1,000 degrees.

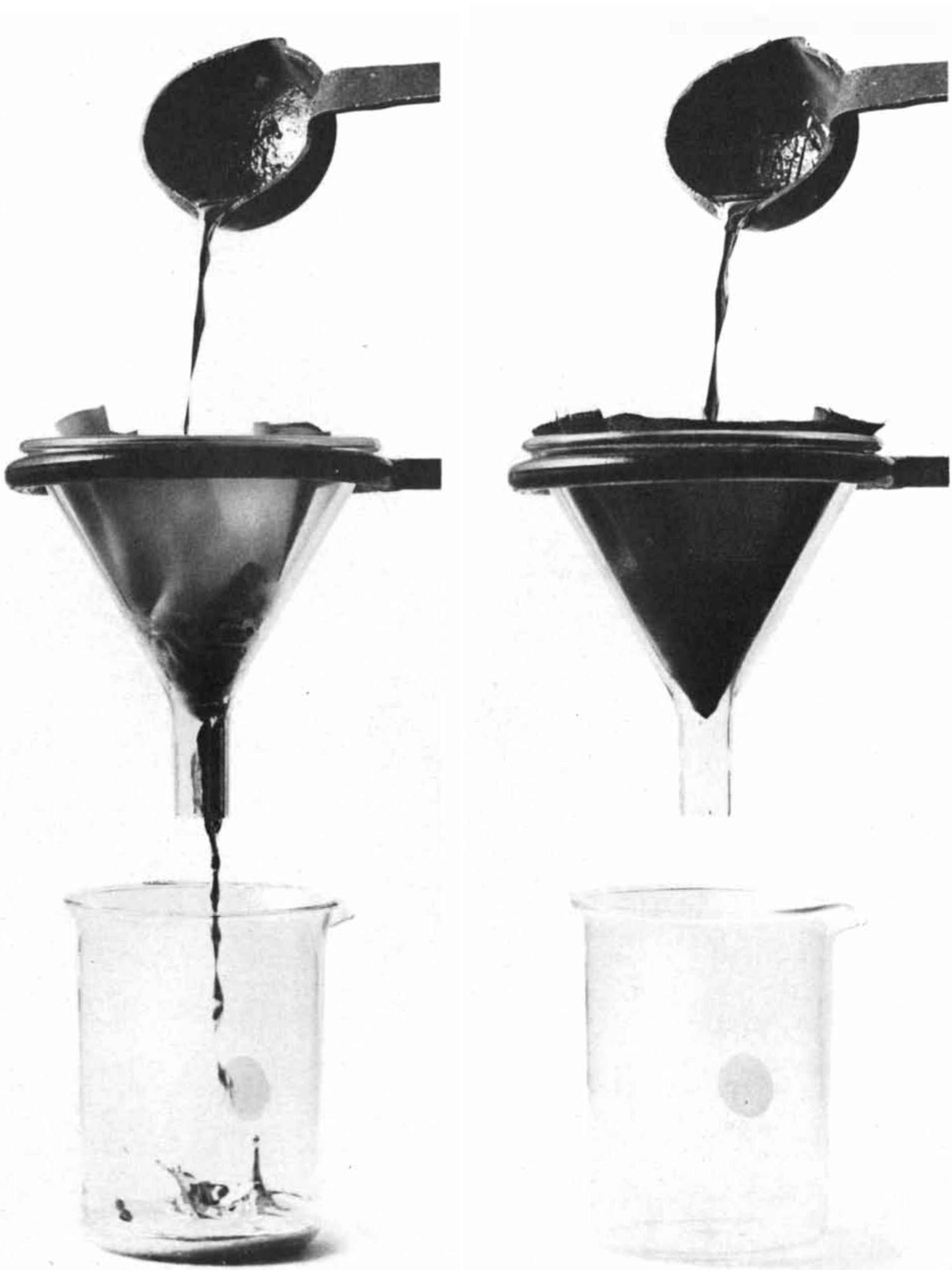
An ordinary polymer cannot maintain its rigidity, shape or strength at these high temperatures because the chainlike structure of its molecules is vulnerable to heat. In its simplest form such a molecule consists of hundreds of the segments called monomer units, joined end to end like the cars of a freight train. Heat agitates the individual monomer units so that they vibrate, and as the temperature increases, the vibrations become stronger until finally the bonds between the monomer units break. In organic polymers the temperature at which this happens is quite low, because the covalent bond that joins one monomer to another consists of two electrons shared by two carbon atoms, one at the end of each monomer. This kind of coupling is relatively weak. When the bonds break, the material disintegrates, but in some cases the ruptured molecules may then form cross-linked polymers. The nature of the material is, however, always irreversibly changed.

Sometimes the segments of the molecules continue to vibrate without breaking. In an amorphous polymer whose molecules are not arranged in regular, crystalline arrays this vibration can become strong enough (at a point called the glass-transition temperature) to cause the material to lose its rigidity and temporarily grow soft or rubbery. A crystalline polymer simply melts when it reaches a high enough temperature because the agitation caused by heat makes the tightly packed molecules bounce and slide over one another. Such changes are reversible; both the crystalline and the amorphous materials revert to their former state when the temperature falls.

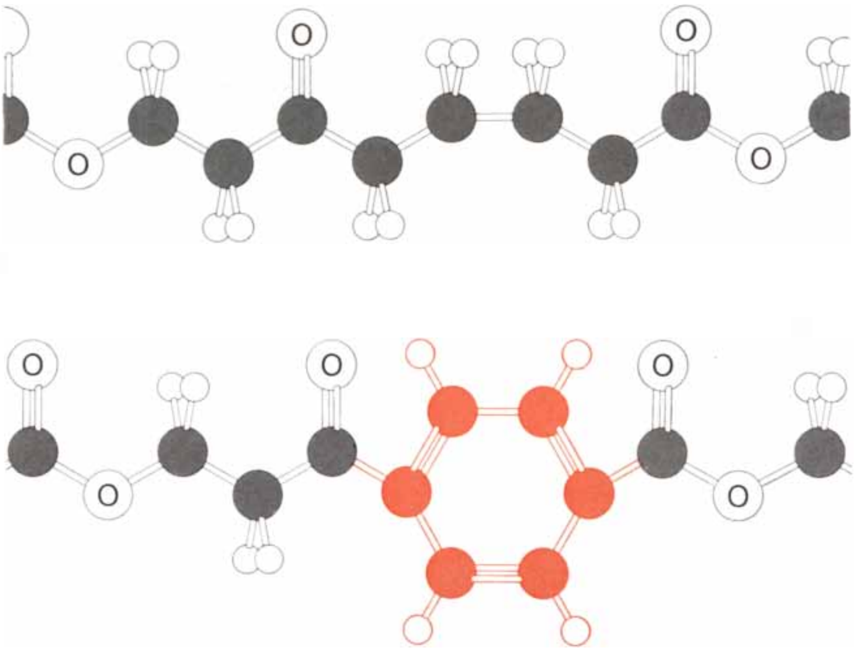
Both the irreversible and the reversible changes are "time-dependent," that is to say, a piece of material may be able to survive for a certain amount of time at any destructive temperature before losing its characteristic properties. Moreover, a chemist designing such materials must keep in mind the environmental as well as the thermal influences on his material. A plastic that will survive at a given temperature in an atmosphere of nitrogen, for example, may disintegrate in an atmosphere of air. Whether the change is reversible or irreversible, it happens suddenly at a characteristic and definite temperature.

In order to create heat-resistant plastics my colleagues and I at E. I. du Pont de Nemours & Company, and workers at the Celanese Corporation, the Monsanto Company and other firms, have been devising ways to stiffen polymer molecules so that they will be less vulnerable to the effects of vibration. This goal can be accomplished by (1) incorporating aromatic rings (ring structures whose main constituents are carbon atoms) into the polymer chain, (2) adding bulky side chains to the molecule, (3) cross-linking the molecules to one another and (4) inducing crystallization [*see illustrations on pages 98 and 99*]. Each of these structural modifications, or any one of them used in combination with another, will raise the temperature at which reversible changes occur.

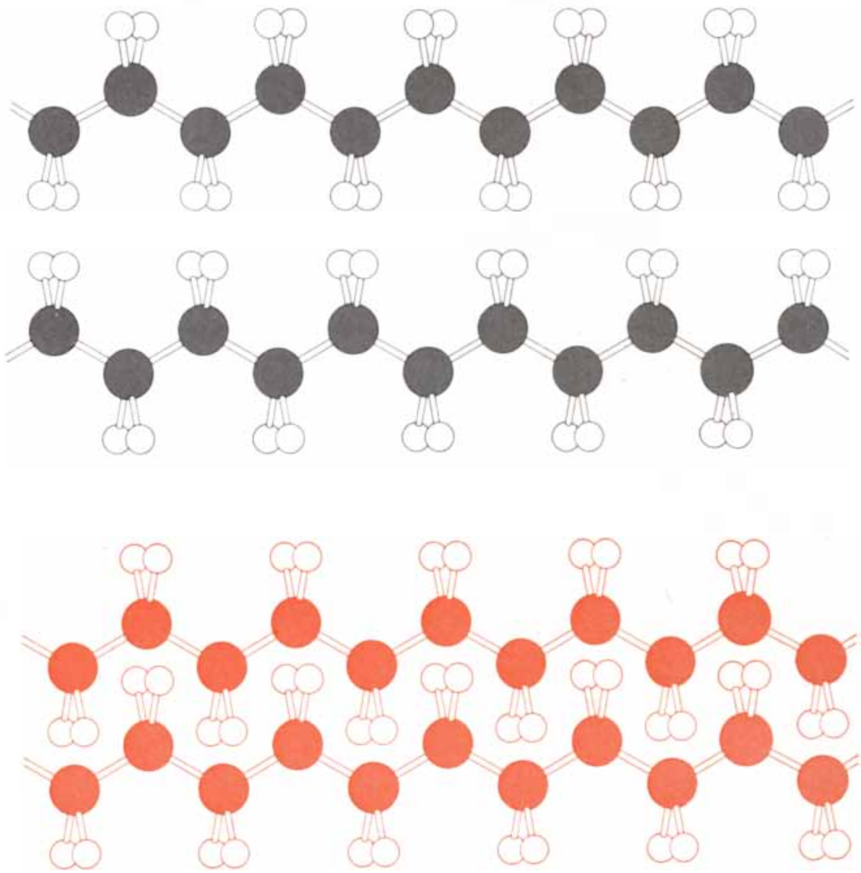
The addition of aromatic rings to a polymer in order to increase its resistance to heat is roughly analogous to fireproofing a building by incorporating comparatively incombustible materials into it. The single covalent bonds, consisting of two electrons shared by two carbon atoms, that normally hold a polymer together can be broken by heat of a certain intensity. The aromatic ring, however, has many double bonds with four shared electrons between its carbon atoms. Since more heat is required to disrupt a



RESISTANCE TO HEAT of a high-temperature polymer derived from ordinary nylon is demonstrated in these photographs. A cone of nylon fabric in the glass funnel at left disintegrates when hot solder pours into it from a crucible, allowing the molten metal to splatter into the dish below. A cone made from fibers of an aromatic polyamide (*right*) can, however, survive the heat of the molten solder (about 250 degrees Celsius) because the material retains at least 60 percent of its strength at a temperature of 285 degrees and loses all strength at 300 degrees. The photographs were made in the laboratory of J. K. Gillham of Princeton University.



AROMATIC RINGS, when added to the chainlike structure of polyethylene adipate (*top*), raise its melting point from 45 degrees C. to 250 degrees. Such a ring (*color*) contains strong double bonds and is inherently more rigid than a chain; therefore the aromatic rings damp the destructive vibrations caused by heat that would normally break up the polymer.



CRYSTALLIZATION of amorphous polyethylene (*top*) can increase its melting point from less than 100 degrees C. to 137 degrees. In this instance certain conditions of temperature and pressure are created so that the molecules that have identical structures can slip together into a crystalline pattern (*color*) that reinforces each molecule against vibrations.

double bond than a single one, the polymer containing an aromatic ring is less flammable or meltable. A ring is more stable for another reason: it is a geometrical form inherently more rigid than a chain. For these two reasons the resistance of a polymer to heat increases if aromatic rings are interspersed between its other monomer units. Aromatic rings also give a polymer greater resistance to oxidation and other chemical reactions because most of the available bonding sites on such a ring are already occupied.

In a crystalline polymer the chainlike molecules are mechanically interlocked in a mutually supporting, highly ordered pattern, like tiles in a mosaic. Furthermore, the attraction between chains called the van der Waals force acts to hold them together. Polymers will form a crystalline array, however, only if the individual chains have a highly regular structure in which the same sequence of units and their orientation to one another is precisely repeated. Such molecules must have sufficient mobility in the amorphous state so that when the temperature and other environmental conditions are right they slip into an ordered, crystalline array. The normal tendency of the molecules to slide over one another can be discouraged by the addition of side chains at regular intervals; the side chains interlock mechanically like gear teeth. Side chains that have an electric charge can also be attached to a polymer. Such chains will attract oppositely charged side chains on other molecules and promote crystallinity.

Bulky side chains have a similar effect. Here the side chains are electrically neutral, but their very bulk keeps the polymer chain from folding easily. Polymer chains can also be stabilized by introducing components that cross-link one chain to another. With such cross-links chains that are normally flexible become quite rigid. All these stratagems raise the melting point of the material and the temperature at which other destructive effects set in.

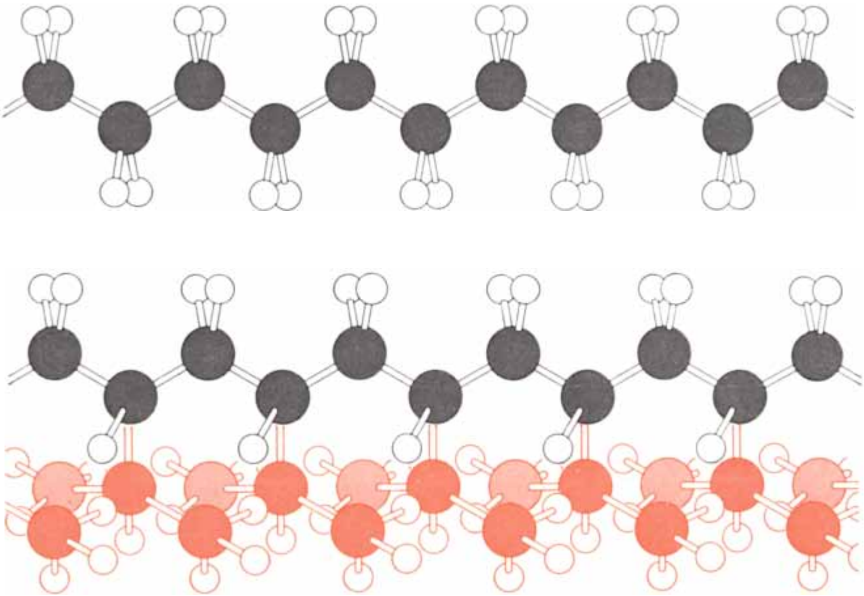
Three methods are widely used to quickly determine whether a polymer can survive a particular temperature and atmosphere. The first, differential thermal analysis, reveals the temperatures that induce reversible and irreversible changes in a material. This method involves heating a specimen and noting the temperature at which it absorbs or gives off heat, indicating some thermal reaction. Thermal analysis does not, however, directly indicate to what extent a material retains its strength or other properties at a given temperature, nor does it show the extent to which the material has disintegrated.

These questions can be partly answered by thermogravimetric analysis. In this technique the specimen is weighed as the temperature is increased. The amount of weight lost, it is assumed, reveals how much the material has decomposed. This method is not entirely reliable either. Some silicone polymers, for instance, can be completely degraded to silica with a weight loss of only 20 percent.

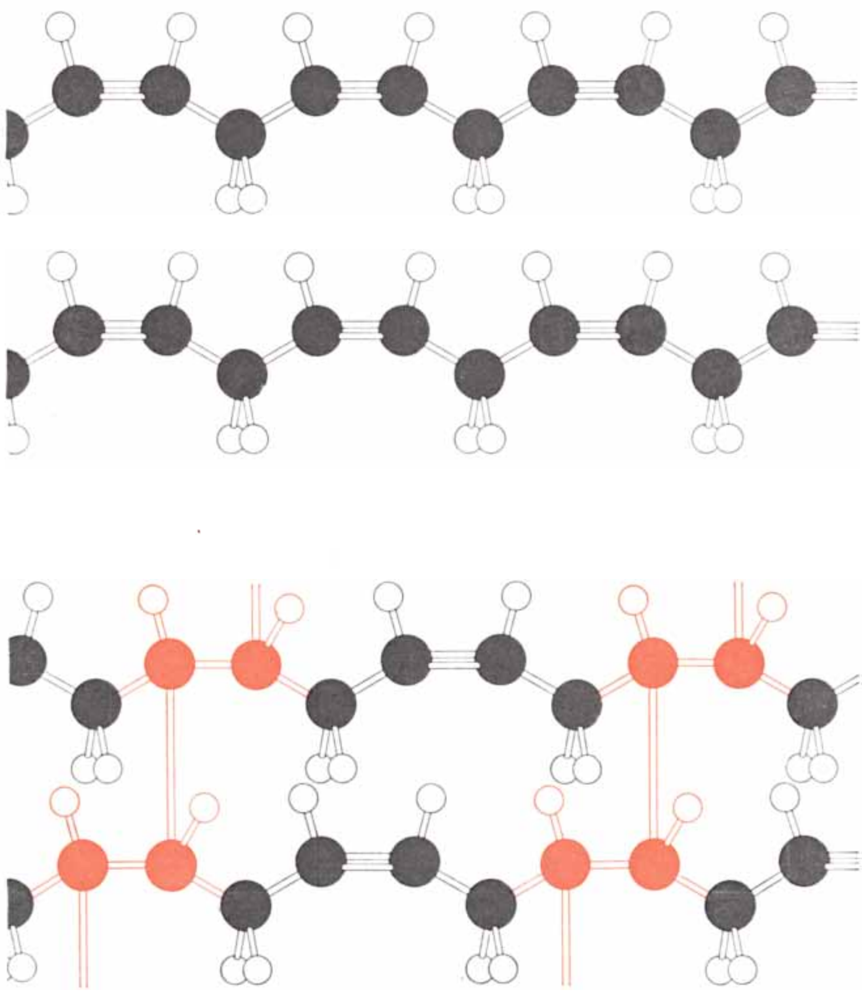
The third technique, the torsional-braid analysis developed by J. K. Gillham of Princeton University, eliminates the ambiguities implicit in these indirect attempts to measure the effect of heat on a polymer. First a string composed of glass fiber is dipped into a melt of the polymer to be tested. Then the entire specimen is twisted while being heated in a test oven. Since the properties of the glass-fiber string are well known, changes in the properties of the specimen at a given temperature can be attributed to the polymer. Torsional-braid analysis offers an additional advantage in that it does not require the preparation of large test batches of a polymer that is difficult to synthesize.

One of the most versatile polymer families developed by means of such design strategies and testing procedures is the aromatic polyamides. These polymers are the direct descendants of nylon. Aromatic rings have been incorporated into the nylon polymer chain, and the resulting polymers have a fairly high degree of crystallinity [*see illustration on next page*]. Under the trade name Nomex such a polymer has recently been marketed in the form of fiber and paper for applications involving exposure to temperatures up to 250 and 300 degrees C. A polyamide fiber can retain 50 percent of its room-temperature strength at 285 degrees, whereas conventional nylon fibers lose almost all their strength at about 225 degrees.

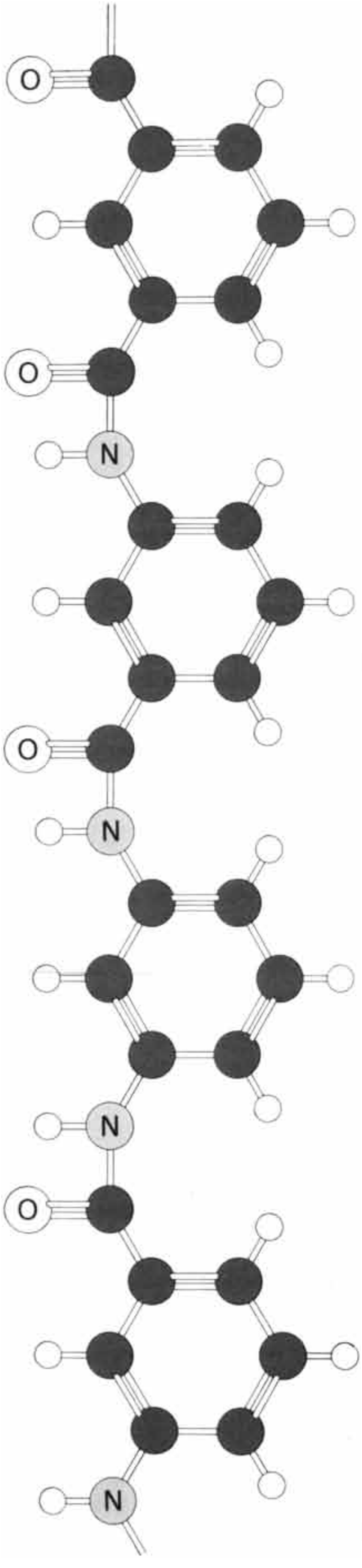
Aromatic polyamide fibers can be ignited only by prolonged exposure to direct flame, and the fire goes out as soon as the source of ignition is removed. This behavior has led to the development of highly effective protective clothing, as was demonstrated recently when a Navy helicopter lifting from a runway struck a nearby jeep and burst into flames. The three men aboard escaped the blazing wreckage. Two of them in conventional coveralls were severely burned on the arms and legs, but the third man, wearing coveralls of aromatic polyamide fiber



SIDE CHAINS (*color*), when added to the polymer poly-3-methyl-1-butene, prevent the molecule from bending and rotating by packing against one another. Thus heat vibrations are damped, and the melting point of the material rises from 137 degrees C. to 250 degrees.



CROSS-LINKS (*color*) between chains of the polymer cis-polybutadiene form between carbon atoms on each chain. These bonds unite all the polymers in a material into an infinite network. When polybutadiene is stiffened this way, its melting point rises to 250 degrees C.



(standard equipment for Navy and Marine fighter pilots) was unhurt. Nomex polyamide fiber can also be made into conveyor belts for carrying materials through high-temperature curing, baking or drying processes. Ovens equipped with such belts can be operated at temperatures that are 50 to 100 percent higher than would have been possible otherwise.

Electrical operating costs can be reduced by using polyamide insulation in motors, generators and transformers. Because of the material's ability to resist heat, motors can be run for long periods at temperatures up to 220 degrees, making possible greater operating efficiency. The temperature beyond which an electric motor protected by polyamide insulation cannot be run is usually determined not by the failure of the insulation but by the failure of metal components that begin to soften at these high temperatures.

Some of the other aromatic polymers that have been successfully developed are the aromatic polycarbonates, the polyethers and the polysulfones. Among the many products made from such materials are plastic scalpels and surgical saws, which have begun to replace stainless-steel ones in some operating rooms. These instruments are not only sharp, strong, stiff and sterilizable but also cheaper. High-tolerance gears and tubing for chemical-processing equipment, where temperature fluctuations can be quite severe, can also be made from the aromatic polymers.

Because aromatic polymers comprise the same vulnerable molecular chains as their parent compounds, however, even the sturdiest of them fail above 300 degrees C. At that temperature the stiffness provided by the aromatic rings cannot prevent the polymer chain from vibrating so intensely that it breaks up. To make polymers capable of withstanding still higher temperatures a new class of organic molecules, the aromatic heterocyclic polymers, has come into existence. Aromatic heterocyclic polymers are the logical next step in molecular design: if aromatic rings stiffen a polymer, it was reasoned, the polymer could be made still stiffer by making the parent molecule itself into a ring. Experimental work has shown that such a polymer can indeed be synthesized. It consists of aromatic rings that alternate with ring-shaped molecules of the parent compound, called heterocyclic rings because they contain a variety of atoms.

In order to make these molecules it is first necessary to synthesize high-molecular-weight or long-chain precursor polymers. By suitable chemical manipulation these polymers can then be converted into the desired heterocyclic and aromatic molecules. Many completely new families of aromatic polymers have been developed in this way, all of which are stable at 300 degrees, and for shorter periods at 400 degrees. One or two can even survive at higher temperatures. Aromatic polyimides, for instance, have a melting point of 900 degrees, and polyimide films have survived for more than a year without losing their shape or rigidity at a continuous temperature of 275 degrees.

Aromatic polyimides consist of two aromatic rings bracketing a heterocyclic ring. The heterocyclic ring includes a nitrogen atom and two pairs of carbon atoms. Because polyimides are almost impervious to solvents and flash radiation, they are now being marketed as varnish, coatings for glass fabrics, insulating enamel for wire, self-supporting films, laminating resins and precision parts. Polyimides can also be made into sleeve bearings, ball-bearing cages, vanes for rotary compressors, valve seats and piston rings that must function at high temperatures and in vacuums or other environments where lubricants cannot be used. As an example, compressor vanes for jet engines made from these plastics are stronger and resist wear better than vanes of graphite. Since polyimide film can maintain its shape at elevated temperatures, it can serve as a base for magnetic tapes and printed circuits where shrinkage would distort electrical signals.

Polyimide insulation allows electric motors to be built that are 100 percent more powerful than others of the same size. Since polyimide insulation is thinner than an equivalent amount of ordinary insulating material, the amount of power-generating copper in the motor can be increased without making the frame larger. As in the case of polyamide insulation, polyimide insulation can also withstand higher operating temperatures. This characteristic suits it particularly for service in engines such as those that drive electric locomotives, which

AROMATIC POLYAMIDE molecule is the basic unit of the most versatile of the high-temperature polymers synthesized. The molecule consists of aromatic rings that alternate with subunits of the nylon polymer. The material, which is also crystalline, melts at 300 degrees C., 75 degrees above melting point of nylon. This is also the upper temperature limit for aromatic polymers, which are held together only by covalent bonds.

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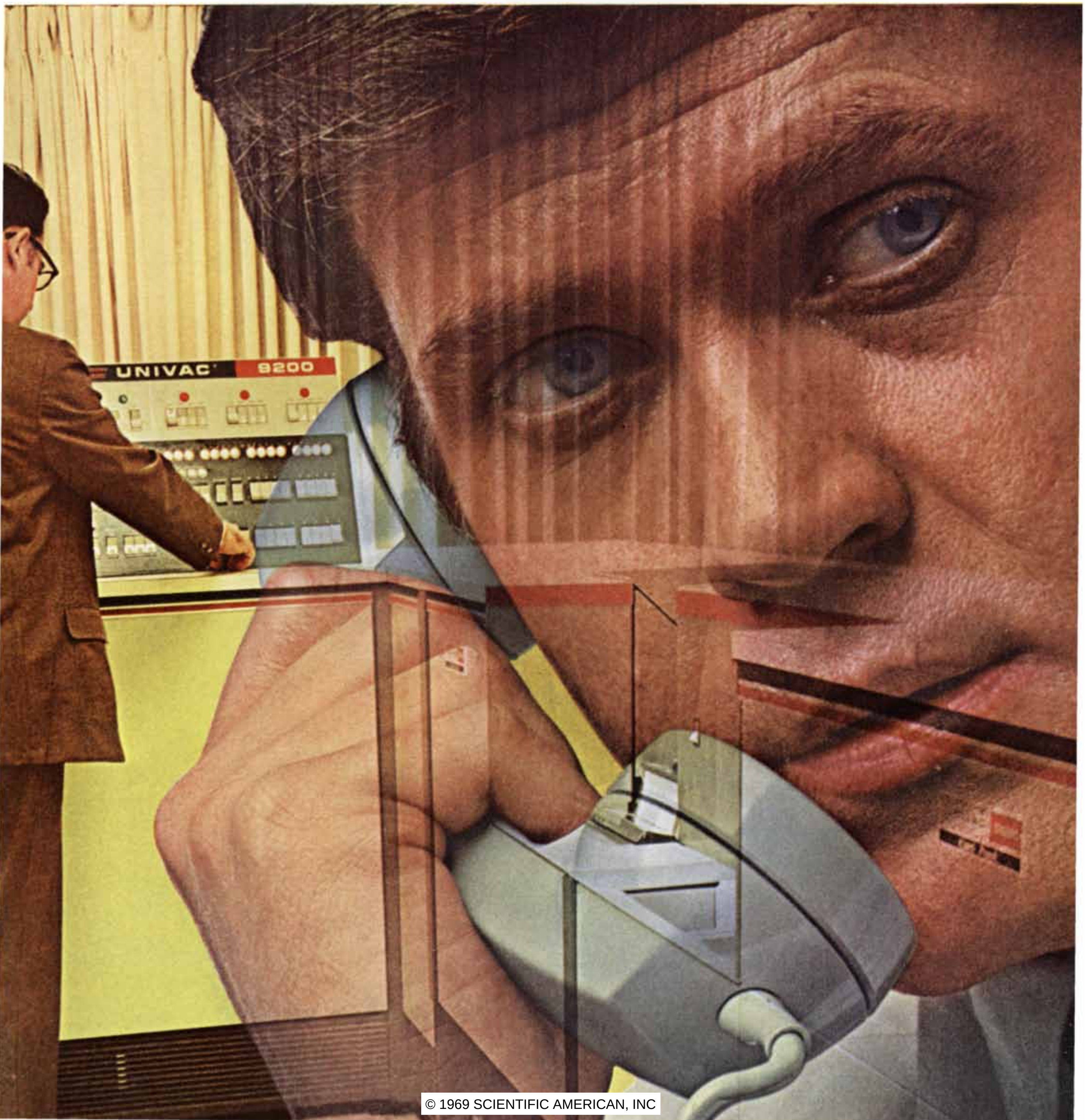

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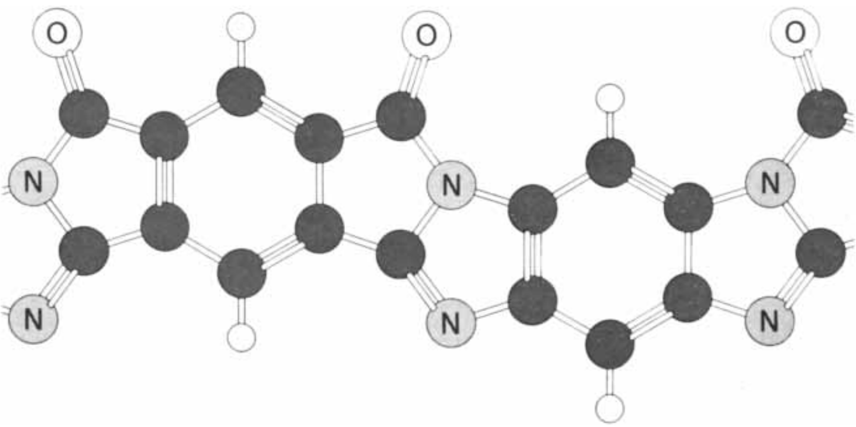
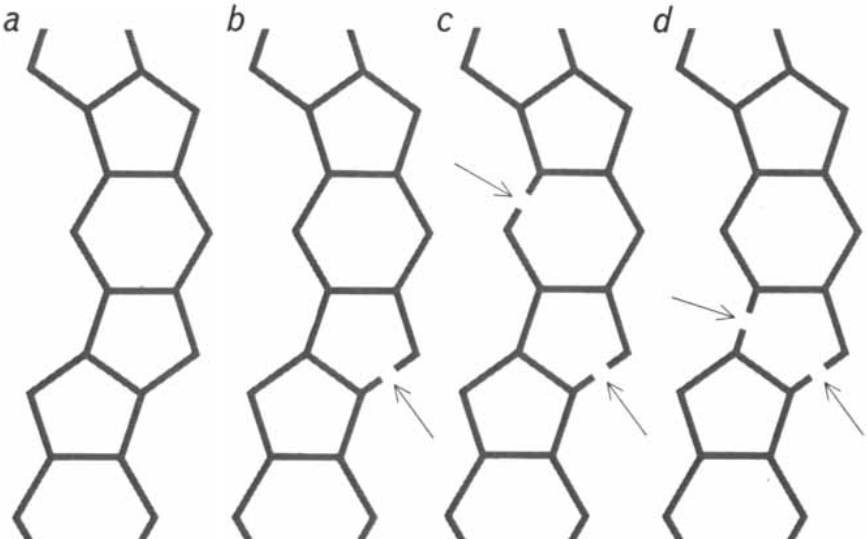
generate great surges of power and heat when starting up.

Polyimide coatings may someday protect the outer skin of Mach-3 aircraft. Radomes could be manufactured from polyimide binders and glass fibers or other high-temperature materials. Polyimides can also be made in the form of fibers, as laminating resins for high-temperature pressure vessels constructed from filament-wound, glass-impregnated materials and as adhesives for bonding metal to metal, film to film and film to metal in devices that must operate in a high-temperature environment.

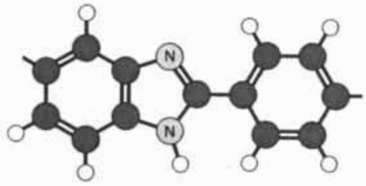
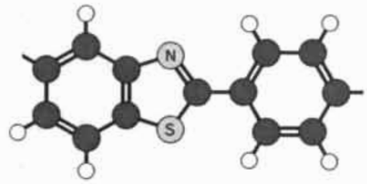
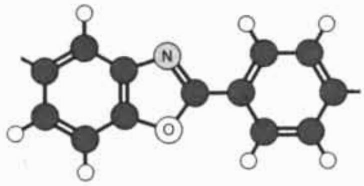
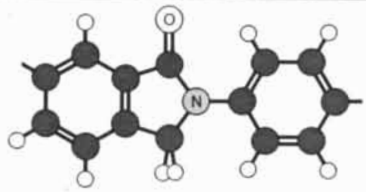
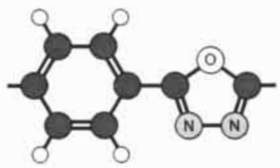
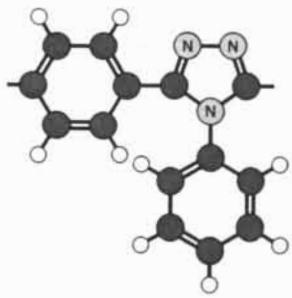
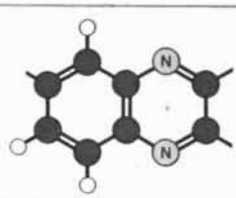
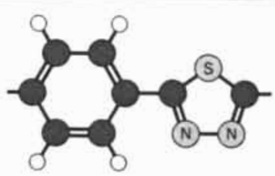
Polyimides may get some competition from the polybenzimidazoles. Like the polyimides, these polymers have good thermal stability and useful electrical and mechanical properties. They also have one significant property that is not shared by the other polyaromatic heterocyclic materials: solubility in com-



LADDER POLYMER such as poly(imidazopyrolone) shown here can resist temperatures well above 500 degrees C. because it consists of a series of aromatic and parent-molecule rings joined so that bonds between some atoms are "rungs" and other bonds form the sides of this rigid, ladder-like structure. The problems of economic production are formidable.



STRUCTURE of ladder polymer enables it to resist temperatures that would melt some metals. The ladder molecule (*a*) will not break if cut at one point (*b*), or even if cut at two points (*c*), because in both cases the overall structure remains intact. The "ladder" can only be broken when bonds are severed on either side between the same two "rungs" (*d*). In the case of single breaks or breaks between different pairs of rungs it is probable that the molecule will repair itself, since the rigid structure holds both sides of the break close together.

POLYMER	REPEATED SEQUENCE OF MONOMERS	MELTING POINT IN AIR (DEGREES CELSIUS)	WEIGHT LOSS IN AIR
POLYBENZIMIDAZOLE		590°	Moderate, up to 560°
POLYBENZOTHIAZOLE		600°	Moderate, up to 570°
POLYBENZOXAZOLE		600°	Moderate, up to 570°
POLYIMIDE		600°	Moderate, up to 600°
POLYOXADIAZOLE		Above 450°	Moderate, up to 450°
POLYPHENYLTRIAZOLE		Above 480°	Begins to lose weight at 425°
POLYQUINOXALINE		Above 600°	Moderate, up to 600°. Retains 80 percent of its weight at 800° in nitrogen.
POLYTHIADIAZOLE		Above 450°	Moderate, up to 600°

AROMATIC HETEROCYCLIC POLYMERS, because of their inherently rigid, ring-shaped monomer units and sturdy double bonds, can survive temperatures well above 300 degrees C. Several of the materials can, in the form of fibers or films, retain strength

OTHER REACTIONS TO HEAT	USES
	Aircraft skin coatings, other aerospace uses.
	Adhesives, laminating agents.
	Adhesives, laminating agents.
Film loses all strength at 600° in air, fibers retain toughness at 275° for more than a year.	Coating, fibers, insulation, tape and etched circuit bases, aircraft skin coating, compressor vanes.
Fibers disintegrate at 450° after one hour in air, film becomes brittle after two hours at 450°.	Fibers, fibrous materials, laminating agents, coatings.
Fibers lose all strength at 425° in air.	Fibers, fibrous materials.
	Coatings, films, adhesives, laminating agents.
Fibers maintain strength for more than 24 hours at 400°.	Adhesives, laminating agents.

and shape even when subjected to heat for several hours or even several months.

mon polymer solvents. This property allows them to be made into many shapes and forms. Other aromatic heterocyclic polymers are also being evaluated, including the polyoxadiazoles, the polyquinoxalines, the polybenzothiazoles, the polybenzoxazoles, the polythiadiazoles and the polyphenyltriazoles [*see illustration at left*].

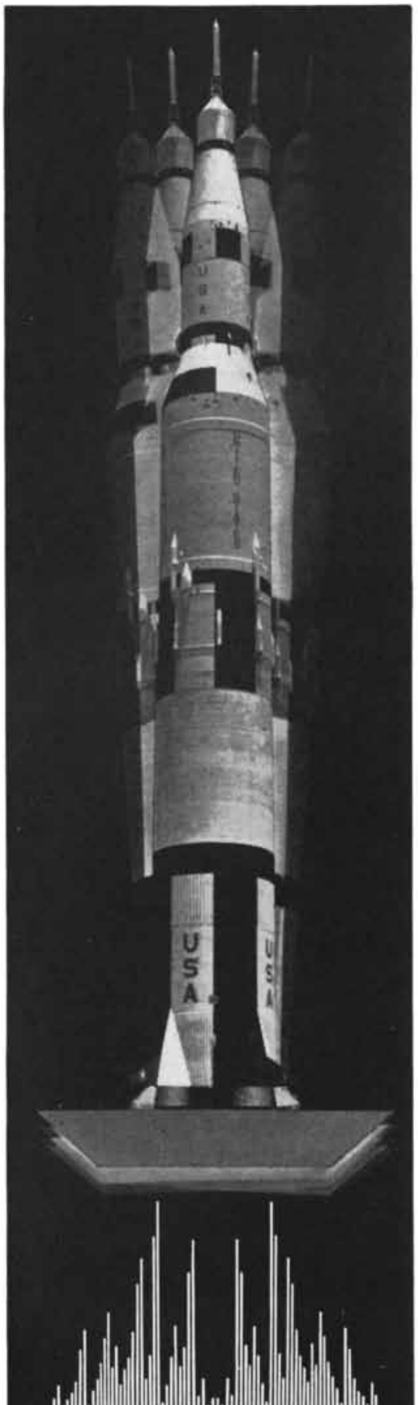
It is too early to tell which of these materials will be the most successful, but clearly they will offer designers and manufacturers in many fields advantages over existing materials. For example, some aromatic heterocyclic polymers have begun to approach and overlap the thermal properties of metals, exceeding the thermal stability of some (such as copper) and the mechanical integrity of others (such as aluminum). Like the aromatic polymers, however, the aromatic heterocyclic materials have a fundamental limitation on their ability to endure heat: their monomers too are linked by the carbon-carbon covalent bond. To create polymers that can withstand temperatures of 600 degrees or more and compete directly with metals more durable than copper or aluminum it may be necessary to take another step and modify or even abandon the covalent bond.

It might be possible, for instance, to synthesize entirely new kinds of organic ring. Unfortunately an imposing barrier stands in the way of chemists who would like to pursue this course. The theories that describe how molecules form and hold together oversimplify reality. As an example, theory predicts that a certain nitrogenous ring compound, tetraazapentalene, should explode if a large specimen is struck by a hammer, yet the compound is completely stable. Clearly our ideas about how patterns of chemical bonding affect stability are imprecise. So are some theories about the crystalline state in organic molecules. As long as theoretical knowledge remains inexact, it cannot be used to predict ways to synthesize radically new organic structures. A trial-and-error search would take far too much time.

Some workers feel that a new class of high-temperature polymers can be developed only if organic molecules are abandoned and new families of inorganic molecules are synthesized. According to what we know about bond energies there is no question that repeating units of silicon-nitrogen, boron-nitrogen and phosphorus-nitrogen would be much more durable than repeating units of carbon and hydrogen. Inorganic substances are stronger than organic ones because they are held together not by covalent bonds but by ionic bonds. When two atoms form an ionic bond, one of them actually captures an atom from the other. Consequently one atom is positively charged and the other negatively. The two atoms then attract each other electromagnetically while being held together by the captured electron. The strength of such bonds can be estimated from the fact that one boron polymer has a melting point of 2,300 degrees C. Unfortunately, however, no one has yet developed an economic way to synthesize inorganic polymers. Furthermore, when these compounds break down, they either disintegrate completely or rearrange themselves in patterns that make the material worthless. For example, a silicon polymer, if it is heated sufficiently, will suddenly re-form into a series of large rings. Inorganic polymers are also susceptible to attack by water and oxygen.

In my view the most promising approach is one suggested by Carl S. Marvel of the University of Arizona. He proposes that the next generation of polymers be derived from "ladder molecules." These molecules could be made from chains of aromatic and heterocyclic molecules cross-linked as the sides of a ladder are joined by the rungs between them [*see upper illustration on page 103*]. This structure would give the molecule added strength in two ways. First, each ring joins the other at two points instead of at just one, creating an extremely rigid and therefore heat-resistant structure. Second, the ladder molecule cannot be broken simply by severing a single bond, or even by severing two bonds. After all, one cannot divide a real ladder in two parts by cutting it between the second and third rungs on the right side and the fifth and sixth rungs on the left side; intervening rungs would still hold the ladder together. To sever the ladder—or a molecule—completely it would be necessary to cut both sides between the same pair of rungs. Such a molecule might also repair itself: even after a bond is broken the rigid structure holds the two atoms so closely together that recombination is probable [*see lower illustration on page 103*]. In our laboratories and in others chemists are now working on the formidable problems of synthesizing this kind of polymer. No matter how difficult it proves to be to create a third type of high-temperature polymer, the effort will be well rewarded, since the diverse and useful properties of plastics cannot be found in any other kind of material.

Frequency measurements mean a safe launch for Saturn. A pinpoint re-entry for Apollo. A man's life in Boston.



Shaking the life out of a Saturn V.

Imagine a vibrating platform like the one you stand on for a foot massage. Except this one's 50 feet by 50 feet. And on it stands a rocket over five stories tall. Yet this vibrating platform can shake the life out of a Saturn V launch vehicle. Some massage!

What the engineers would like to know are the critical vibration frequencies that could destroy a rocket at launch or in flight. Hewlett-Packard has just the instrument to make sense out of all the shakes and rattles.

With this same instrument, electronics engineers can perform more detailed circuit analyses, doctors can look closer at EKG and EEG signals, architects can probe building structures, physicists can dig deeper into nuclear magnetic resonance, and astronomers can minutely scan the noisy universe.

In the case of Saturn, the HP 5450A Fourier Analyzer can perform in seconds a complete vibration analysis, resolving all the component frequencies to display on a scope the power spectrum indicating any dangerous resonance. At the push of a button, it will convert the power spectral density function to the correlation function—using Fourier transforms.

The HP Fourier Analyzer can perform as a Power Spectrum Analyzer, a Correlator, an Averager, a Digital Filter, or you can select from a keyboard any combination of these functions. Using digital techniques and Fast Fourier Transform Algorithm you get the speed and versatility to perform Time Series Analysis up to 25 kHz. Since a straightforward keyboard is used for programming you don't have to be a digital computer expert. However, as a side benefit you do have the full computing power of a standard HP Model 2115A Computer whenever you call for it from the keyboard. System price is approximately $50,000, depending on options.

The full 5450A story, far more intriguing than just massaging Saturn V, is yours for the asking. Simply write for the 5450A Data Sheet and mention your application.

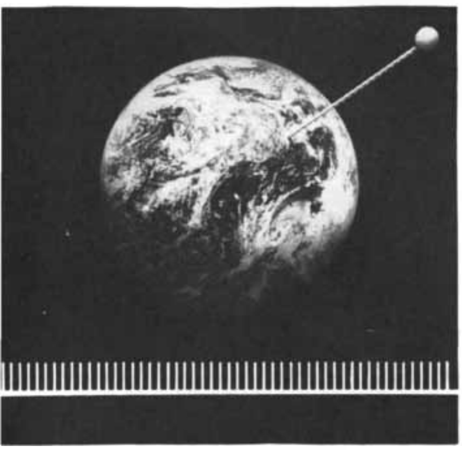
Apollo, journey into time and space—and back.

Apollo re-entry and splashdown precision is no happy accident; it stems from astronaut practice and skill—and, in part, HP dedication to microseconds of time.

Microseconds might seem irrelevant in week-long, million-mile space flights. But such precision timing is critical to mission success. It helps tracking-radars detect minute increments of Doppler shift caused by spacecraft movement—even at lunar distances—so as to determine the vehicle's speed precisely and to plot its position within feet. NASA's worldwide computer network, 15 land stations and 3 ships, depends on meticulously synchronized data exchange necessary for correlating the trajectory calculations. In the event of engine malfunction, behind the Moon or in deep space for example, such information would be vital in getting the astronauts safely back to Earth.

NASA's timing system was completely updated before Apollo 8 and played a vital role in the lunar orbit and subsequent Apollo experiments. Tracking stations in California, Spain and Australia were each equipped with a new primary frequency standard—the HP Precision Frequency Source (E02-5061A), keyed to an HP cesium clock. These primary references and their slaved rubidium and quartz standards were synchronized with a portable HP atomic clock that was flown on a pre-launch round-the-world trip.

If minute details—in time—govern your time- or frequency-dependent studies, write for HP Application Note 52, "Frequency and Time Standards," a 100-page



discussion of the practical aspects of their applications.

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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.

Doctors know arrhythmias can often be successfully prevented by medication, but the usual coronary instrument alerts the doctor only when a serious arrhythmia is in process. Again, doctors know that major arrhythmias—the potentially fatal ones—are almost always preceded by less dangerous ones. The problem is to detect these small irregularities.

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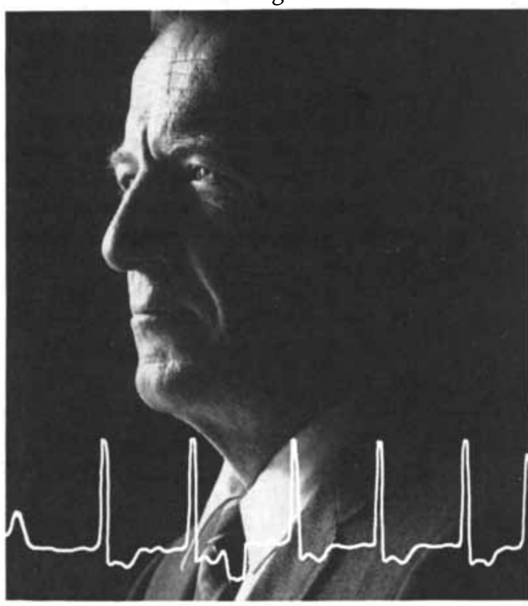
Beats which are abnormal as compared with this stored "normal" are classed as ectopic or out-of-place. The number of these beats occurring in a given time period is numbered and recorded so that the doctor can assess the success of drug treatment. Any excessive ectopic activity will trigger alarms to 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."

If measurement of frequency isn't of personal concern to you, let us know how we can help you—in measurement, analysis or computation. Hewlett-Packard, 1505 Page Mill Road, Palo Alto, Calif. 94304; Europe: 1217 Meyrin-Geneva, Switzerland.

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URBAN MONKEYS

In India rhesus monkeys have shared cities with man for centuries. Has this urban way of life affected their behavior and their ability to solve problems?

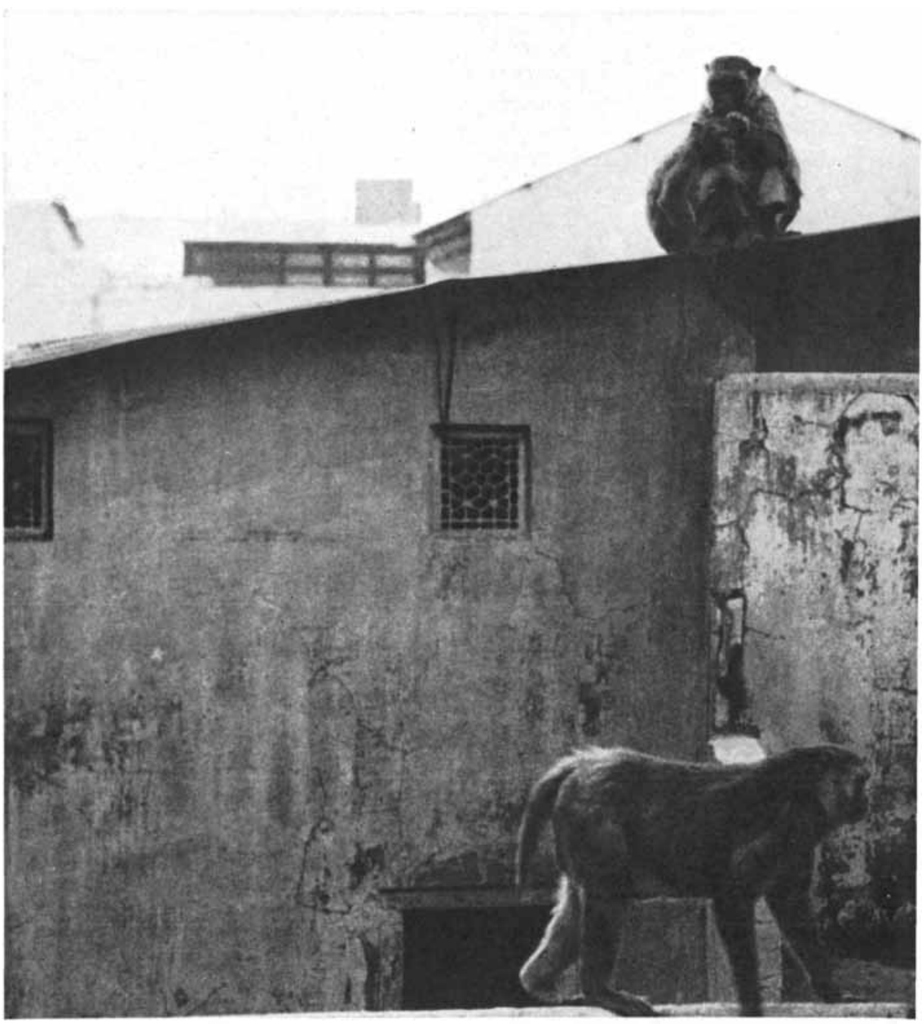
by Sheo Dan Singh

The rhesus monkeys of India mainly comprise two different societies: forest and urban. The urban monkeys inhabit housetops, abandoned buildings and other city niches where they can spend their nights undisturbed by man. They are a common sight in villages, towns and cities in a number of regions in India. Many Hindus regard the monkey, like the cow, as being sacred; it is said that in ancient times a monkey named Hanuman came to the aid of the Hindu god Rama in battles with Ravana, the demon-king of Ceylon. As a result monkeys are still worshiped in many parts of India and freely share the urban habitat with man.

The urban monkeys differ noticeably from their forest-dwelling cousins in temperament and behavior. It occurred to me that from a study of these city-dwelling primates one might learn something about the elementary effects of the urban mode of life on man. My decision to undertake such a study was inspired by a meeting with Harry F. Harlow of the University of Wisconsin, whose investigations of monkey behavior in the laboratory have raised so many suggestive questions about human behavior [see "Love in Infant Monkeys," by Harry F. Harlow, SCIENTIFIC AMERICAN, June, 1959, and "Social Deprivation in Monkeys," by Harry F. and Margaret Kuenne Harlow, November, 1962]. The following is an account of what my colleagues and I have been able to ascertain about the effects of city living on monkeys in India from observation and laboratory tests.

One clear effect has to do with the monkeys' food preferences. Forest-dwelling rhesus monkeys generally live principally on the leaves and fruits of trees such as the banyan, the fig, the mango, the tamarind and the jambos (often known as the rose apple). In contrast, the monkeys that have taken up life in villages and cities have developed a taste not only for fruits and vegetables but also for cooked human food such as *chapatis* (Indian bread), roasted grains, peanuts and even spiced items. In tests in which we offered the urban monkeys choices among various foods the monkeys showed a distinct preference for things that had been cooked, whereas the forest monkeys passed over cooked or roasted items and were distinctly partial to fruits and raw vegetables.

The foraging habits of the urban mon-



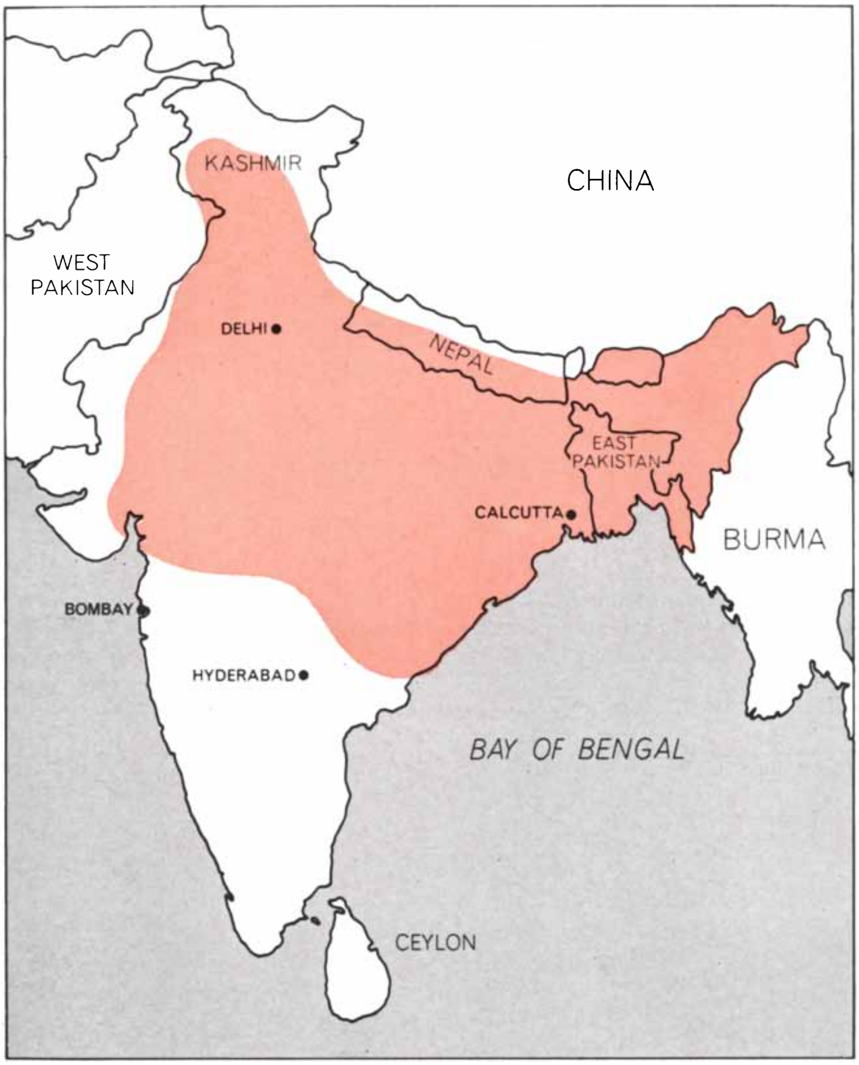
MONKEYS OF JAIPUR, a city in the Indian state of Rajasthan, gather on the rooftops at twilight as the heat of a summer day abates. City-dwelling monkeys in India live in groups keys are of course quite different from those of monkeys in the forest. People occasionally feed urban monkeys willingly (I myself used to do so during my school days), but in the main the monkeys live by pilfering. They raid food shops, kitchens in houses and the stands in open markets, and sometimes they even snatch food from people, particularly children, often injuring the person in the process. As a result monkeys are constantly warring with shopkeepers and are occasionally beaten. In spite of this measure of insecurity the urban monkeys have adjusted to the situation so thoroughly that they greatly prefer life in the city to life in the forest. When they are seized and taken out to the forest, they generally hurry back to town after they are released.

The city monkeys are characterized by comparatively settled housing and sleeping habits. The forest monkeys generally roost for the night in some convenient tree in the area where they have spent the day hunting for food and water; they rarely choose the same tree from one night to the next. The urban monkeys, on the other hand, invariably return to a particular lodging night after night; they move only when they are chased away. Since the places where they can enjoy undisturbed sleep in the city are limited, once they have found such a place they do not readily change their home.

The city monkeys, like their forest cousins and primates in general, live in groups united by strong emotional ties and a sense of mutual dependence. What holds nonhuman primate societies together? Many psychologists and anthropologists believe the primary bond is sexual [see "The Origin of Society," by Marshall D. Sahlins; SCIENTIFIC AMERICAN, September, 1960]. Our observations of the rhesus monkeys in India suggest, however, that sex is not the whole story. The monkeys, both the urban and the forest ones, maintain their group life not only in the breeding season but during the rest of the year as well. Indeed, we have observed that aggressive behavior tending to disrupt the group increases during the breeding season. Further, we can cite a significant and probably characteristic illustration of group concern and involvement that would be very difficult to explain strictly on the basis of sexual motivation. A baby monkey fell into a well; very quickly most of the members of the large group to which it belonged ran to the well in great distress, and they appeared about to jump into it when we arrived and pulled the infant out.

The monkey groups, both urban and nonurban, vary considerably in size; one we came across consisted of about 70 individuals. Among the adult members of a group females greatly outnumber males, probably because the dominant males limit the number of rivals. Charles H. Southwick of Johns Hopkins University found that in the average group of urban monkeys about 20 percent were adult males, 42 percent adult females, 26

of as few as two up to as many as 70 individuals. Not only is their environment completely unlike the forest habitat of their ancestors but also they are unlike their forest kin in group composition, in diet, in group leaders' behavior and in psychological complexity.



RANGE OF RHESUS MONKEYS in India extends generally from the northern barrier of the Himalayas south to between 20 and 17 degrees north longitude on the Deccan plateau.

percent infants and 12 percent juveniles. In forest groups the corresponding proportions were 11 percent adult males, 39 percent adult females, 23 percent infants and 27 percent juveniles. Southwick's censuses indicated that the average urban group consisted of 22 members; the average forest group, about 50 members. Our own count of certain forest groups showed an average membership of about 21 individuals. We have been unable to discern in these counts any significant pattern that would indicate a marked effect of city living per se on the size or composition of the monkey groups. The monkey population does, however, reflect the attitude of the people in the city in which it happens to live; in towns that are devoutly Hindu, and therefore permissive, the size of the monkey groups and the total monkey population are generally larger than elsewhere.

It is well known that societies of primate animals are generally marked by vigorous competition among the males and the establishment of a hierarchy of dominance, which is reflected in priorities in feeding and in sexual and other privileges. All the rhesus monkey groups we observed, in the city as well as in the forest, clearly followed this pattern. To identify the leader of a group one did not need to conduct an opinion poll; all we had to do was watch the group at a feeding place. The leader invariably presided over the food with the other monkeys hovering around him. In forest groups the leader usually monopolized the food. In a test in which we set out a food offering of 10 pounds of grain for the group, the dominant male would take charge; during the nonbreeding season he would not let any other member of the group eat with him, and even in the breeding season (the three fall months) he allowed only one adult female and her infant to share the food with him.

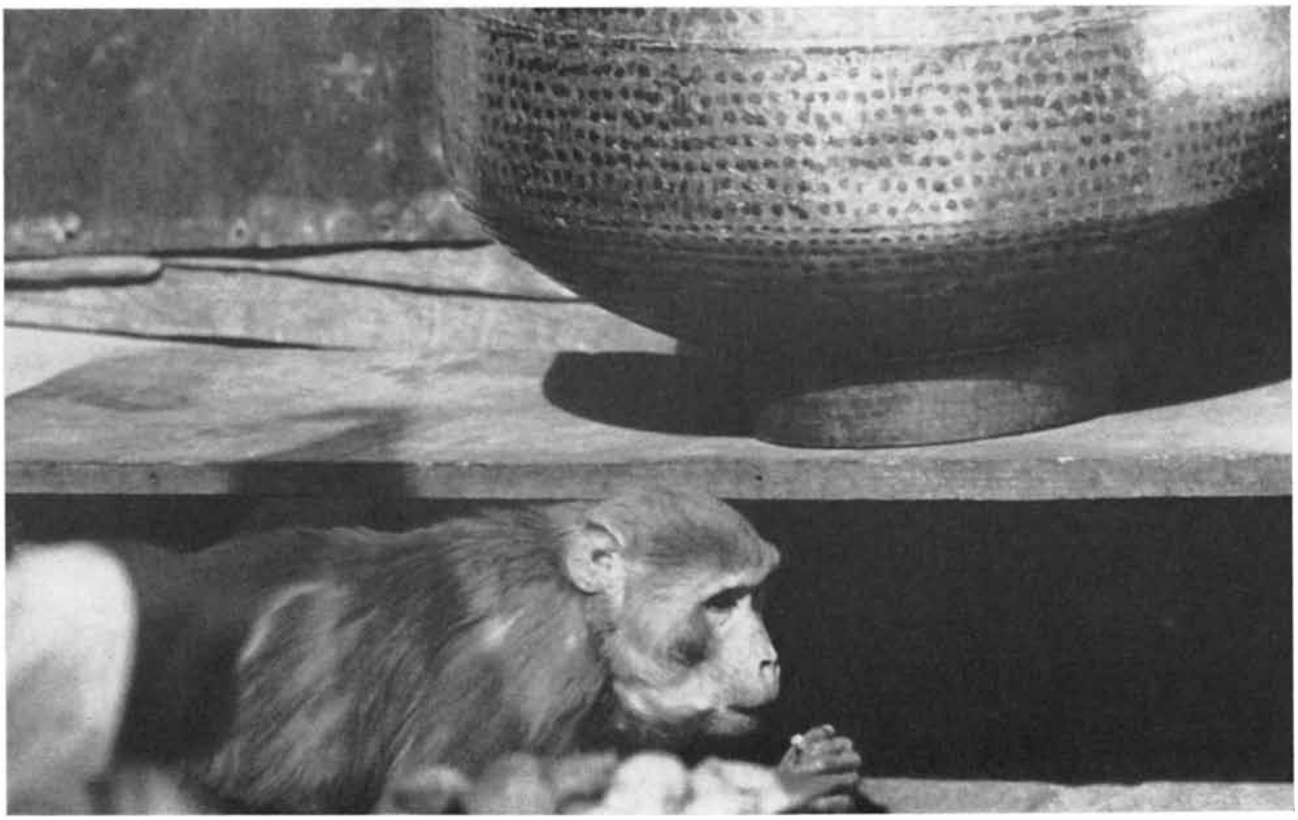
When the same experiment was conducted with an urban group of monkeys, a difference emerged. The dominant male in such a group would allow a number of adult females, infants and juveniles (as many as a fourth of all the group members) to partake of the food with him, regardless of the season. Moreover, there was much less aggressive behavior at the feeding place among the members of the urban group than was displayed by a forest group in the same situation. Presumably the urban monkeys become accustomed to sharing food because the supply available to them is limited.

The relatively unaggressive behavior of the urban monkeys at the feeding place does not mean that they are on the whole less aggressive than forest monkeys. On the contrary, laboratory experiments we conducted showed that they are basically much more aggressive. The experiments consisted in bringing together pairs or groups of previously unacquainted monkeys for the purpose of observing their social interactions. For the tests of pairs we used a six-foot cubic chamber and observed various pairings: two urban monkeys, two forest monkeys or an urban monkey with a forest monkey. Similarly, using a large room (18 by 18 by 18 feet), we put together groups of monkeys (each consisting of four to six members) that were strangers to one another, and these also were tried in various combinations: urban with urban, forest with forest, urban with forest.

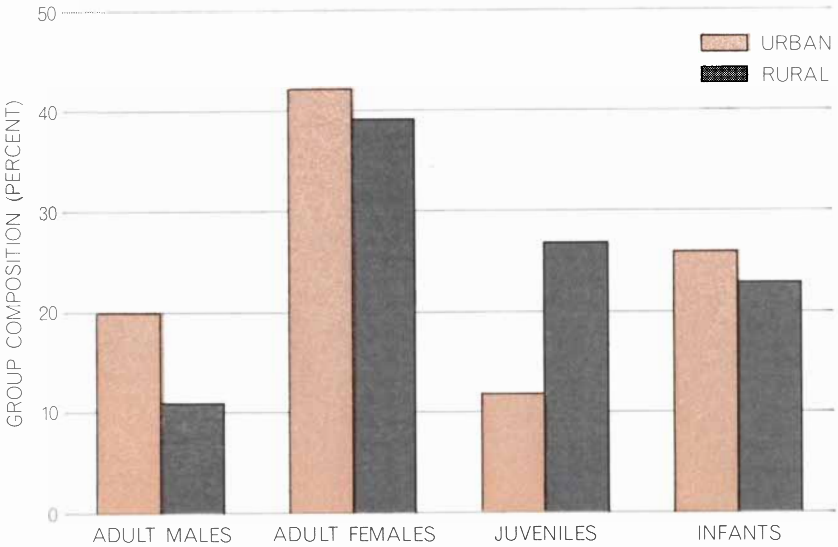
When forest monkeys were placed together, they were relatively relaxed and uncombative. Urban monkeys, however, generally fell to fighting, regardless of whether the strangers to which they were introduced were urban monkeys or forest monkeys. Their battles were violent, usually resulting in severe injuries, and two of the combatants were actually killed. In experiments in which the monkeys competed for food we found that the forest monkeys generally yielded to the urban monkeys. Indeed, although male monkeys are usually dominant over females, in the urban versus forest matchings forest males often gave in to urban females.

Why are the urban monkeys so much more aggressive than the forest dwellers? Various explanations might be offered; I suggest that probably the principal reason is the restrictive urban environment, particularly the limited availability of food, which forces the monkeys to compete among themselves and with human beings for survival. The urban monkeys are highly aggressive toward people as well as toward members of

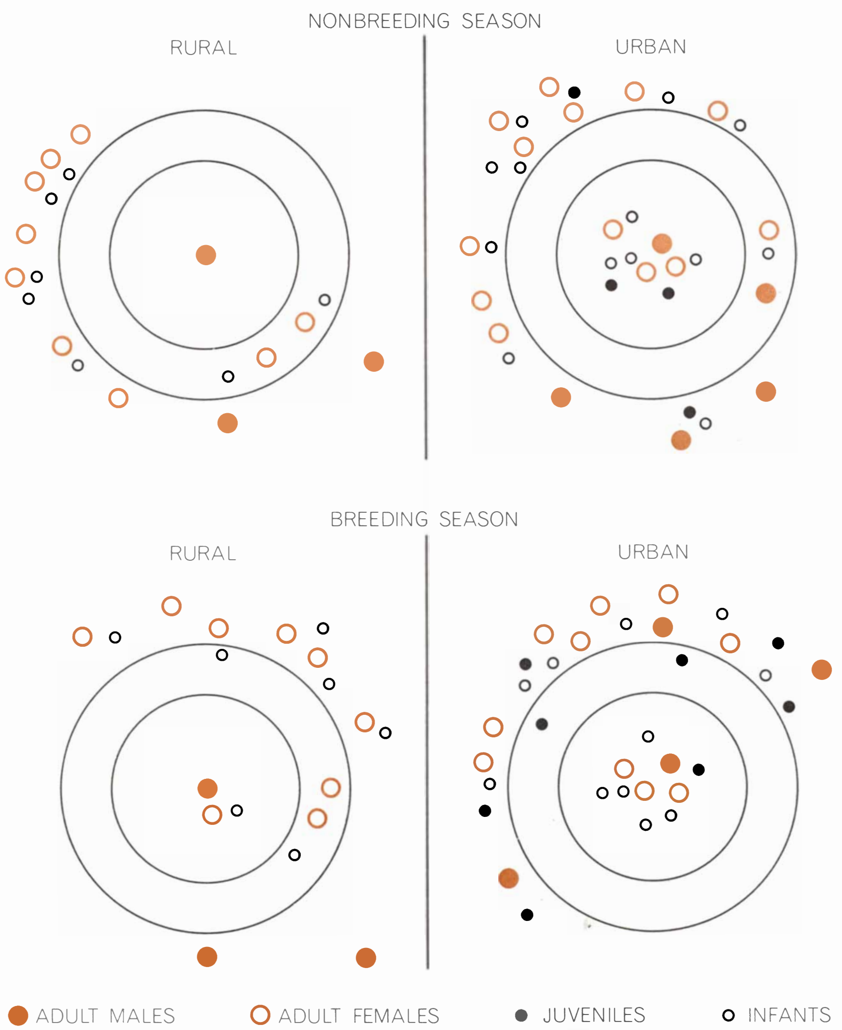
MOTHERS AND INFANTS cluster around a stone basin in the courtyard of a Jaipur house while two of the adults have a drink. Humans and rural monkeys seldom meet, but urban monkeys pilfer food, and they are often chased and even beaten by shopkeepers.



AT EASE IN THE MARKET, an adult Jaipur monkey munches on a peanut. The author's study shows that urban monkeys are more aggressive than rural monkeys and highly responsive and manipulative in dealing with novel or complex environmental features.



FEMALES OUTNUMBER MALES among adults in both urban and rural monkey groups. Urban groups contain more males because their leaders are less hostile to potential rivals.



EXTENT OF DOMINANCE by group leaders is not the same for urban and rural monkeys. Observation of behavior at a forest feeding place (*left*) showed that the dominant male let no other monkeys feed with him in nonbreeding season and let only one adult female and her infant feed with him in breeding season. The urban leader (*right*) was far less strict.

their own species. Cases have been reported of people having been fatally bitten by monkeys in Indian cities. A member of our investigating team suffered a serious attack. An infant monkey he had accidentally touched set up a wail, whereupon several adult males and females jumped on him and bit him so badly that he was hospitalized.

Forest monkeys are shy and afraid of human beings: in the field they flee when approached by a person hundreds of yards away, and even after two years of acclimation in a laboratory they are agitated by the presence of a visitor. In contrast, urban monkeys are not at all afraid of human beings. They will come up close to a person and, as I have mentioned, even snatch food from his hands. In the laboratory they get out of their cages when they can (as a forest monkey will not, even when the door is left open) and boldly explore the surroundings. We have tested the urban monkeys with full-sized human skeletons, stuffed cobras and other novel objects that might be expected to evoke fear; the monkeys show no sign of fright and manipulate these objects with curiosity.

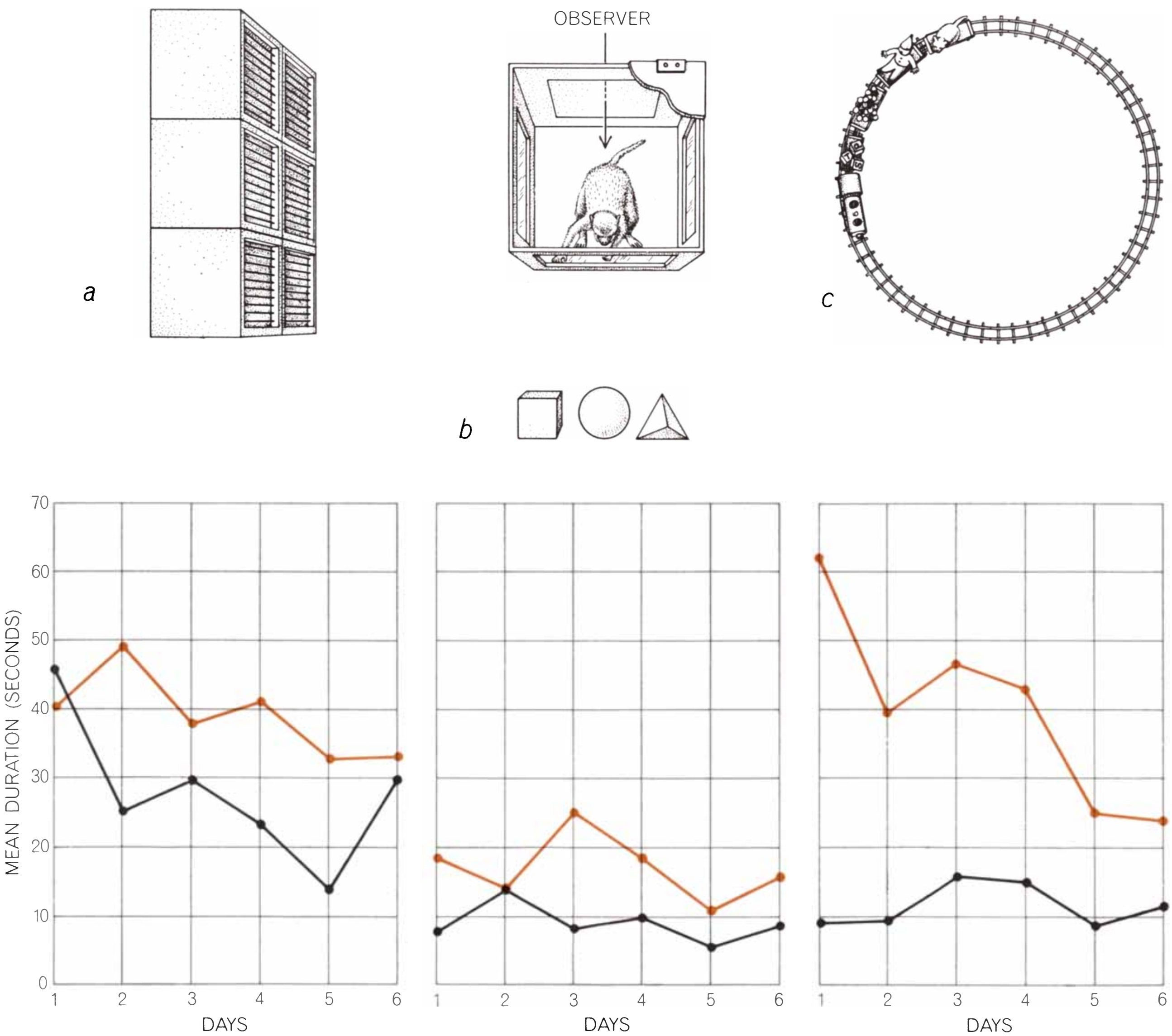
One can conjecture that, because of their experiences with the complexities of city life, the urban monkeys have acquired a well-developed capacity to respond to highly novel or complex situations. In the Regional Primate Research Center at the University of Wisconsin, Robert A. Butler found that monkeys have a rather sophisticated curiosity: they would press a lever to open a window for hours on end if the view outside was sufficiently interesting [see "Curiosity in Monkeys," by Robert A. Butler; SCIENTIFIC AMERICAN, February, 1954]. In current studies in the same laboratory Gene P. Sackett has shown that the level of a primate's curiosity, or exploratory behavior, depends on the extent of the animal's perceptual and motor experiences. Taking a cue from these experiments, we decided to investigate how the exploratory behavior of urban monkeys compares with that of forest monkeys.

Butler's apparatus, a closed box with windows that could be opened by pressing a lever, proved to be unworkable for the forest monkeys: we could not train them to press the lever to open the windows. We therefore used a box with windows that did not need to be opened; there were three windows, each in a different wall, and each showed a different view. One gave a view of a simple setup of some gray blocks; the second showed a battery group of empty rat cages; the third showed a toy train, bearing colored toys, that ran around a circular track. We put each monkey in this box for several days, and through a one-way screen in the fourth wall of the box we watched the animal for an hour and a half each day to observe which window view it favored.

None of the monkeys spent a great deal of time looking through the window at the wooden blocks. All of them, urban and forest, showed more interest in the view of rat cages, with the urban monkeys tending to spend a little more time at this window than the forest monkeys. The view of the moving toy train brought forth a really significant difference between the urban and the forest monkeys: the urban monkeys were highly responsive to this complex display, whereas the forest monkeys showed no more interest in it than they did in the wooden blocks.

Could this difference be taken as an indication of greater intelligence in the urban monkeys? There were reasons to suppose that the city monkeys might indeed develop higher intellectual abilities. For one thing, the urban environment in which they grew up provided them with a richer variety of experiences than was available to monkeys in the forest. Furthermore, the hunters who caught monkeys for our laboratory experiments were convinced that the urban monkeys were more intelligent than those in the forest; although we offered the equivalent of $7 for each urban monkey, as against only $2 for a forest monkey, the catchers preferred to hunt in the forest, believing the city monkeys were too smart to be trapped easily.

We conducted a series of elaborate tests to probe the relative intelligence of the urban and forest monkeys. Some of the problems presented to them were at a rather high level of difficulty—so taxing that they were not easy even for human youngsters. For example, in one case we used as test objects pieces of wood that varied in size (being either 10 square centimeters or 22 square centimeters in surface area), in shape (a square or a triangle) and in color (red or green). In each case three objects were set out before the monkey and it was required to select the one that differed from the



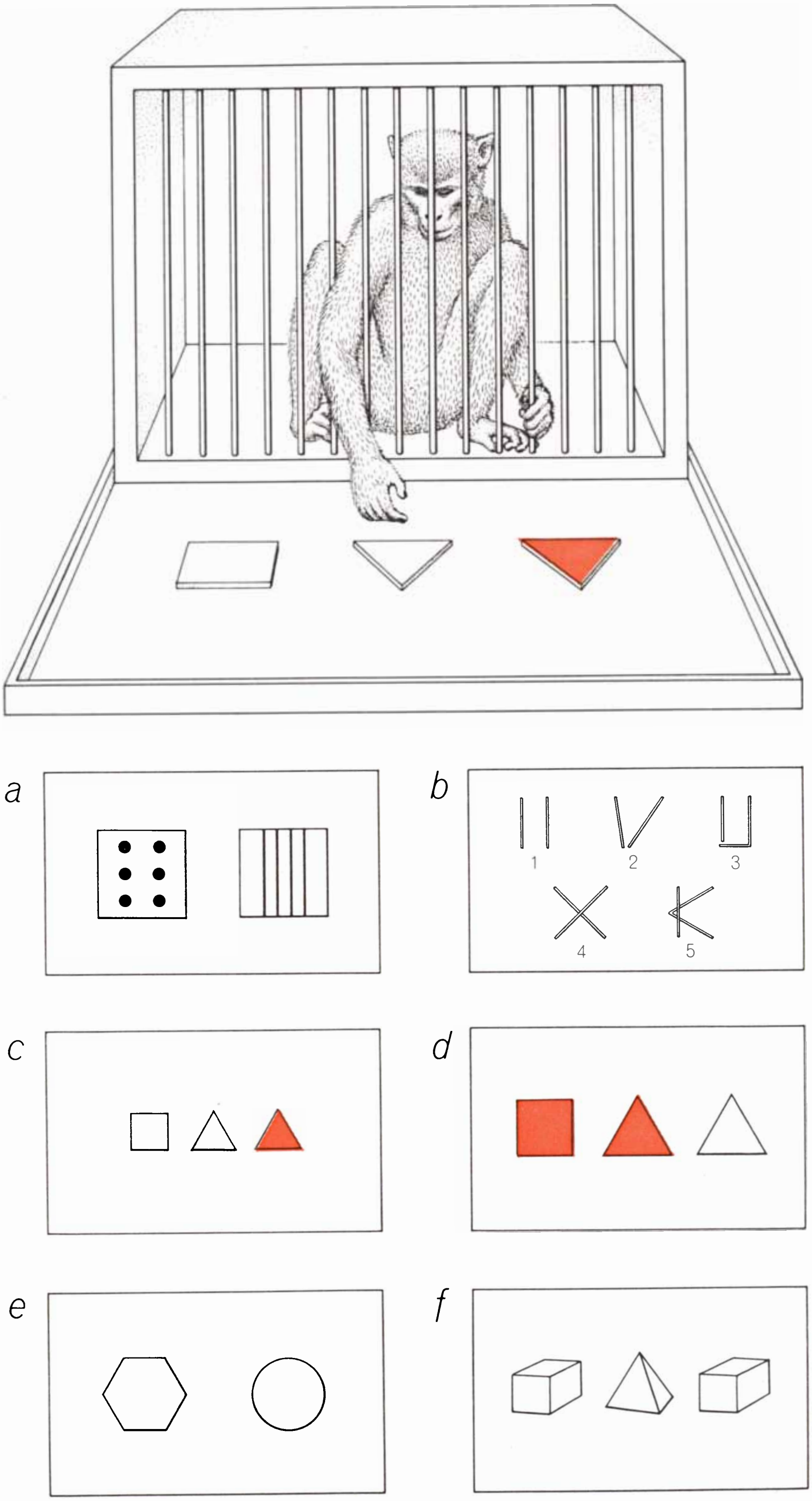
COMPARATIVE CURIOSITY of urban and rural monkeys was assessed by confining members of each group to a box with windows that offered a view of a battery of cages (*a*), of wooden blocks (*b*) and of a toy train, bearing colored toys, that ran on a circular track (*c*). The blocks held little interest for either group; more time was spent by both looking at the empty cages. The urban monkeys, however, were far more interested in the train than were the rural monkeys, who spent much more time looking at empty cages.

other two in a particular respect, depending on the context. For instance, the three objects might be a green square, a green triangle and a red triangle. If the three were of the small size, the monkey was rewarded for picking up the object that was odd in color (the red triangle); if, on the other hand, these objects were presented in the larger versions, the correct choice was the object that was odd in form (the green square). In order to solve such a problem the monkey had to learn that the shape or color of the object was important only in relation to another factor, in this case the size of the three objects. We complicated the problems for the monkeys by presenting the possible groupings of objects in random order from trial to trial.

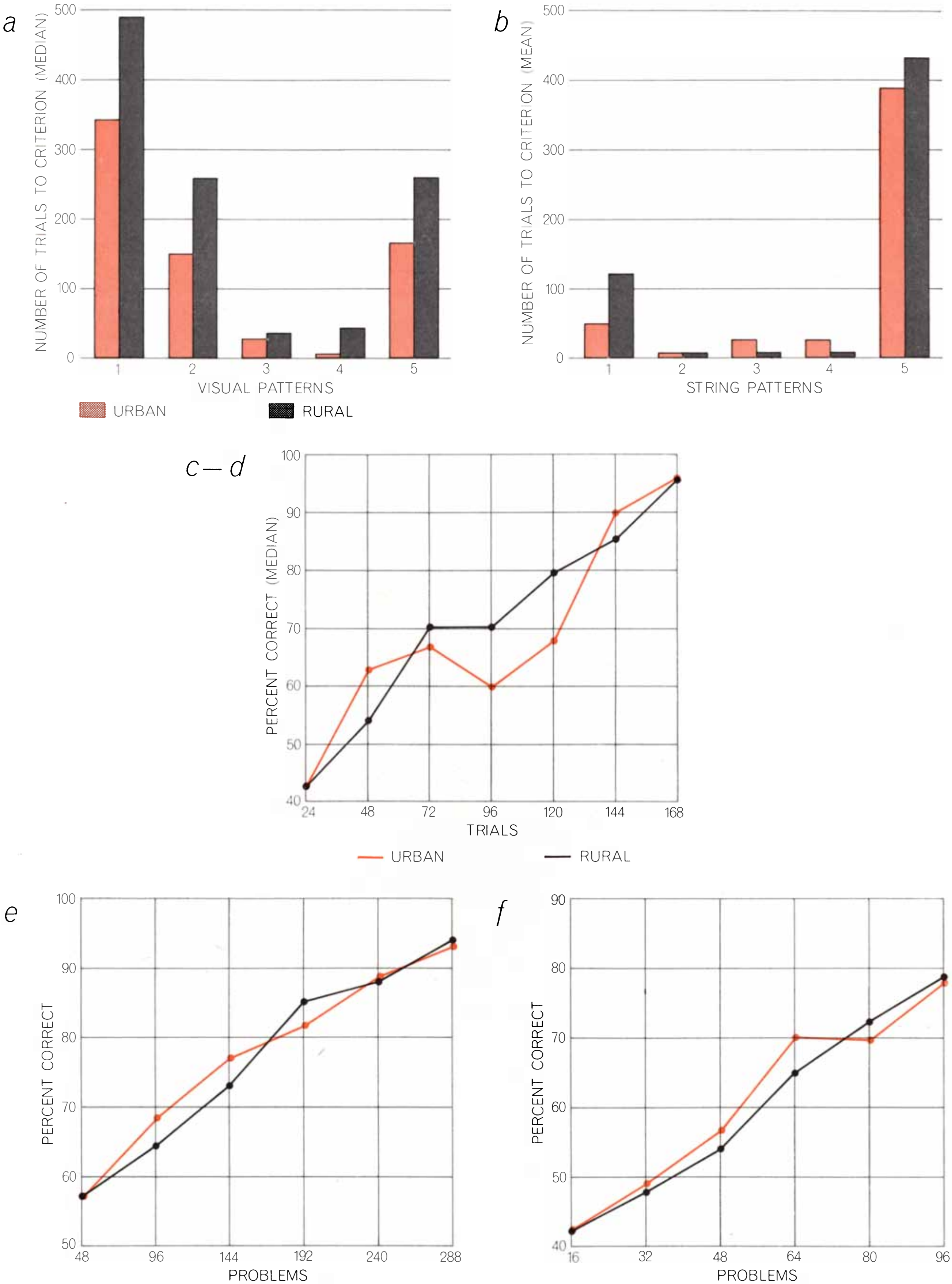
To our surprise we found that the forest monkeys did about as well as the urban monkeys on these difficult problems. They performed poorly in an initial test calling for discrimination among various visual patterns, but that result can reasonably be attributed to the forest monkeys' shyness or fearfulness. Once they became used to the test situation they learned the solutions to all the test problems, simple or complex, as efficiently as the urban monkeys.

It appears that, whatever other effects urban living may produce in monkeys, it does not significantly promote their intelligence. This finding is in accord with what Harlow has learned from laboratory studies of monkeys; in experimental situations of quite a different kind he has also found that intellectual capability is not much affected by the environmental conditions. Monkeys that he raised in social isolation (that is, kept out of contact with other monkeys from birth) showed no significant impairment of their intelligence in later tests, although there were profound effects on their social, emotional and perceptual behavior.

To sum up our findings, we have observed that the urban way of life causes monkeys to change their feeding and sleeping habits, alters their behavior toward one another, increases their aggressiveness, makes them highly responsive and manipulative in their approach to novel or complex features of the environment and in general enhances their psychological complexity, but it does not advance their intelligence, although their behavior may appear to exhibit a high degree of shrewdness. I leave it to the reader to speculate on what implications these findings may have for understanding the impact of urban life on the behavior of man.



BATTERY OF TESTS was used to determine whether urban monkeys, raised in an enriched environment, had developed higher intellectual abilities than their forest-dwelling cousins. Members of each group could choose among various objects presented to them. The monkeys were rewarded if their choice was correct. The first test (*a*) required distinguishing among various visual patterns (only two are shown). The next (*b*) required the monkeys to pull the correct one of two strings in each pair. A third rewarded selection of the object "odd" in color when all three objects were small (*c*) and the object "odd" in shape when the three were larger (*d*). Other tests rewarded discrimination between two shapes (*e*) and selection of "odd" object among three (*f*). Scores are given on opposite page.



ESSENTIAL EQUALITY in the intelligence of rural and urban monkeys was demonstrated in all six tests, with the exception of poorer performance by rural monkeys on some problems in the first test (*a*). The author attributes this to the rural monkeys' initial fear of the test situation. He concludes that the urban monkeys' shrewdness reflects psychological complexity rather than intellect.

MATHEMATICAL GAMES

Tricks, games and puzzles that employ matches as counters and line segments

by Martin Gardner

Paper or wooden matches have two properties that lend themselves to mathematical amusements: they can be used as "counters" and they are handy models of unit line segments. A full compilation of mathematical recreations using matches would fill a large volume. This month we consider a few representative samples of tricks, games and puzzles with matches.

The old trick known to magicians as the "piano trick" (because of the spectator's hand positions) can be presented as a miraculous exchange of odd and even parity. Ask someone to place his hands on the table, palms down. Insert two paper matches between each pair of adjacent fingers except for the ring finger and little finger of one hand, which get only a single match [*see top illustration on opposite page*]. Remove the pairs of matches one at a time. Separate the matches of each pair and place them on the table, one match in front of each of the spectator's hands. Each time you do this say "Two matches." Continue in this way, forming a small pile of matches in front of each hand, until only the single match remains. Take this match from his hand, hold it in the air and say: "We have here two piles of matches, each formed with pairs. To which pile shall I add the single odd match?" Place the match on the pile he designates.

MATCHES LEFT	SPECTATORS 1	2	3
1	S	M	L
2	M	S	L
3	S	L	M
5	M	L	S
6	L	S	M
7	L	M	S

Key for the three-object trick

Point to the pile on which you dropped the match and say, "This is now a pile containing an extra match." Point to the other pile and say, "This remains a pile made up of pairs." Wave your hands over both piles and announce that you have caused the odd match to travel invisibly over to the other pile. To prove that this has indeed occurred, "count" the matches in the pile on which you dropped the single match by taking the matches by pairs and sliding them to one side. "Count" is in quotes because you do not actually count them. Instead, merely repeat "Two matches" each time you move a pair to one side. The pile will consist entirely of pairs, with no extra match left over. "Count" the other pile in the same way. After the last pair has been slid aside a single match will remain. With convincing patter the trick will puzzle most people. Actually it is self-working, and the reader who tries it should easily figure out why.

A trick that goes back to medieval times and can be found in the first compilation ever made of recreational mathematical material, *Problèmes plaisans et délectables*, by Claude Gaspar Bachet, published in France in 1612, is still performed by magicians in numerous variants. The classical version is as follows.

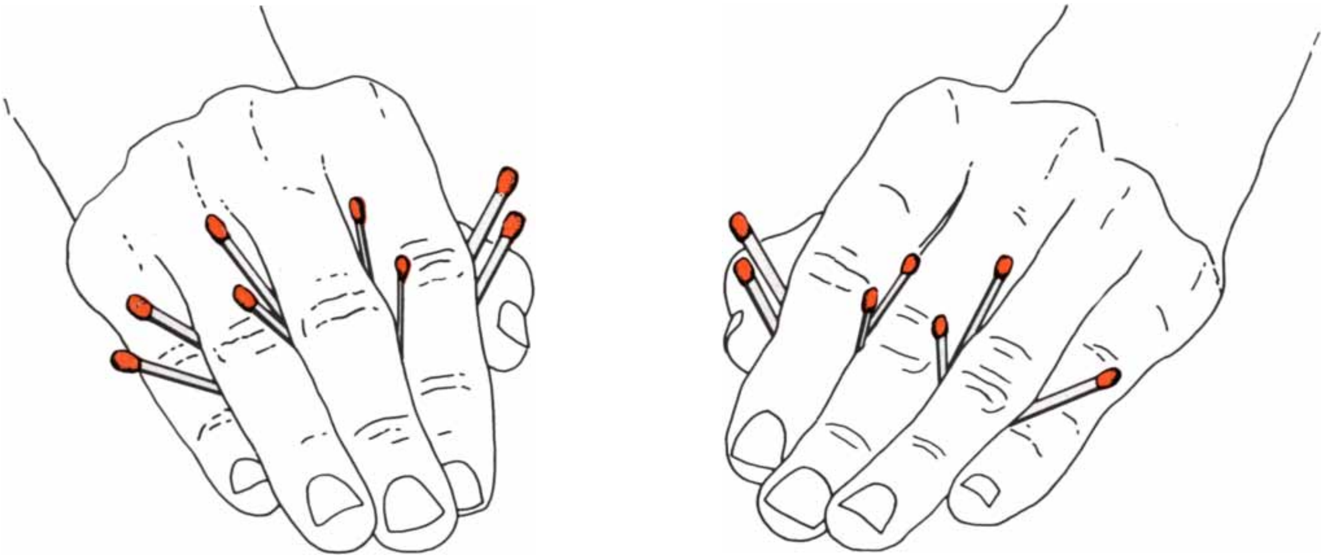
Twenty-four matches are placed on a table, together with any three small objects—say a dime, a finger ring and a house key. Three spectators are chosen to assist. Designate them 1, 2 and 3. To make sure that this order is remembered (you say), give one match to spectator 1, two matches to spectator 2 and three to spectator 3. These matches are taken from the 24 on the table, leaving a pile of 18. Ask each spectator to put his matches in his pocket.

Turn your back so that you cannot see what happens and ask that spectator 1 take any one of the three objects and put it in his pocket. Spectator 2 picks either of the two remaining objects. The third spectator pockets the last object. Now ask the person who took the dime to remove from the table as many matches as you originally gave him and hold them in a closed fist. (You have no way of knowing who it is because your back is still turned.) Ask the person who took the ring to remove twice as many matches as you originally gave him and hold them in his fist. Ask the one who took the key to take four times the number of matches he was given and hold them.

You turn around and, after a few moments of feigned extrasensory concentration, tell each person which object he took. The clue is provided by the number of matches remaining on the table. There are six possible permutations of the three objects in the pockets of the three spectators. Each permutation leaves a different number of matches on the table. If we designate the objects *S*, *M* and *L* for small, medium and large, the chart at the left on this page shows the permutation that corresponds to each possible remaining number of matches. (Note that it is impossible for four matches to remain. If you see four matches on the table, someone goofed and the trick has to be repeated.)

Dozens of mnemonic sentences have been devised so that a performer can determine quickly how the three objects are distributed. Bachet labeled the objects *a, e, i,* the first three vowels, and used this French sentence: (1) *Par fer* (2) *César* (3) *jadis* (5) *devint* (6) *si grand* (7) *prince*. The two vowels in each word or phrase provide the needed information. For example, if the magician sees five matches on the table, the fifth word, "*devint*," tells him that object *e* was taken by the first spectator (who had been given one match) and object *i* by the second spectator (who had two matches); the remaining object, *a*, must be in the pocket of the remaining spectator, who had been given three matches at the start of the trick. Other 17th-century European tricksters, also using the first three vowels for the objects, remembered the six permutations by the first two vowels of each word in the Latin line: *Salve certa animae semita vita quies.*

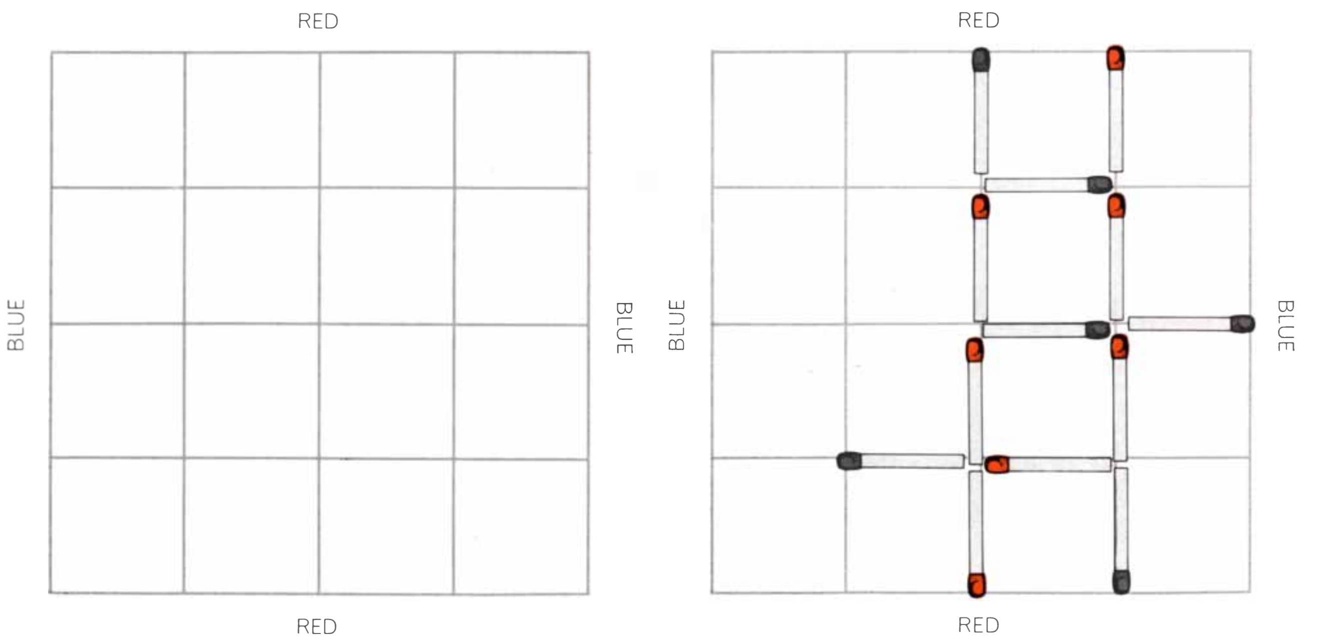
For the version given here, with objects designated S, *M*, *L*, a good English mnemonic sentence was invented by



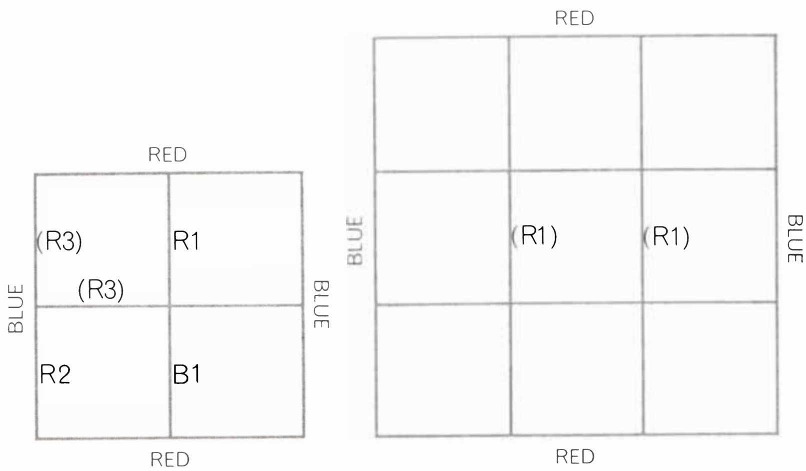
The "piano trick"

Oscar Weigle, an amateur magician: (1) *Sam* (2) *moves* (3) *sl*owly [(4) since] (5) *mule* (6) *lost* (7) *lim*b. The first two appearances of the key letters, shown in italics, give the objects taken by the first and second spectators respectively, leaving the third object to be paired with the third spectator. Many other mnemonic sentences for the trick have been published in English and other languages. The reader may enjoy making up one of his own. The objects can be designated by other letters, such as *A, B, C* or *L, M, H* (for light, medium, heavy), or by the initial letters of whatever three objects are used, and so on. It is convenient to introduce a dummy fourth word, as in Weigle's sentence, where it is shown bracketed, even though four remaining matches are not possible. This enables the performer to count the matches quickly by repeating the words of the sentence without having to worry about skipping number 4 if there are more than three matches. An interesting extension of the trick, dating from 1893, to *n* players and *n* objects using an *n*-based number system, is given in W. W. Rouse Ball's *Mathematical Recreations and Essays* (page 30 in the revised 1960 edition).

Some elementary number theory and the fact that a new folder of paper matches contains 20 matches lie behind a more recent mind-reading stunt. While your back is turned ask someone to tear from a full folder any number of matches from one through 10 and pocket them. Then have him count the remaining matches, add the two digits in this number and tear from the folder the number of matches equal to the sum. (For instance, if 16 matches remain, he adds 1 and 6 and tears out seven more matches.) These matches he also puts in his pocket. Finally, he tears out a few more matches—as many as he wishes—and holds them in his closed fist. You turn around and take the folder from him, mentally counting the remaining matches as you put the folder in your pocket. You can



Hit-and-Run board (left) *and a completed game* (right)



First-player win on order-2* (left) *and order-3* (right) *boards

now tell him the number of matches in his fist. The first two operations always leave nine matches in the folder. (Can you prove that this must be the case?) Therefore you have only to subtract from 9 the number of matches still in the folder to learn the number concealed in his hand.

A variety of "take away" games, such as nim, can be played with matches, and there are various betting games in which matches are used as counters and concealed in a fist. The following game is one in which paper matches are particularly appropriate because of their shape and the fact that they can be obtained with differently colored heads. The game was invented recently by Jurg Nievergelt, a computer mathematician at the University of Illinois, who calls the game "Hit-and-Run." It is ordinarily played on an order-4 square matrix [*see bottom illustration on preceding page*].

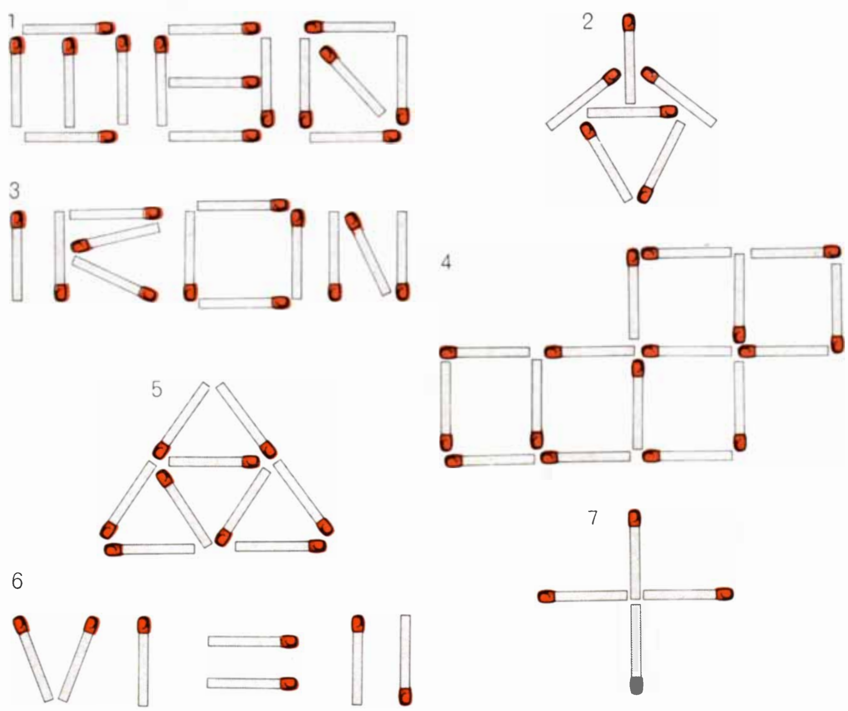
One player starts with a full folder of red-tipped matches, the other with a full folder of blue-tipped matches [*gray-tipped in the illustration*]. It is a pleasant coincidence that 40 matches are just enough. Players take turns placing a single match on any line segment of the matrix. Red's object is to construct a path connecting the two red sides of the board, Blue's is to construct a path connecting the other two sides. (Opposing paths may cross each other at a right angle.) The first player to build his path wins. The game is called Hit-and-Run because a move can block an opponent's path (a hit) and at the same time extend the player's own path (a run).

The game bears a superficial resemblance to Piet Hein's game of Hex and later variants such as Bridg-it and Twixt, both currently on sale in this country, but the mathematical structure behind it is quite different. In Hex, Bridg-it and Twixt no draw is possible—a fact that underlies an elegant proof by game theorist John F. Nash (see *The Scientific American Book of Mathematical Puzzles & Diversions*) that the first player has a sure win if he plays correctly, although Nash's proof does not provide even a hint of a winning strategy. A winning strategy has not yet been found for the general game of Hex, although it is known for small-sized Hex boards. A general strategy *has* been discovered for Bridg-it (see *New Mathematical Diversions from Scientific American*), but not (to my knowledge) for Twixt, a game similar to Bridg-it except that the "bridges" join points by knight moves instead of one-square rook moves. Nievergelt's game, in contrast to these three, can be drawn, and so the Nash proof of a first-player win does not apply.

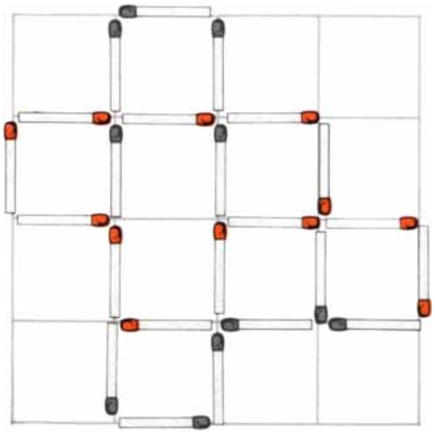
On an order-2 square Hit-and-Run is easily seen to be a win for the first player [*at left in top illustration on this page*]. Red's first move (R1) forces Blue to reply B1. R2 puts Red in position to complete a path by one move in either of two ways (marked R3), and so there is no way Blue can stop Red from winning on his next move. The first player can win in a similar way by playing first on any of the six vertical line segments.

Readers can try to prove that on the order-3 square the game can also always be won by the first player (Red) if he plays first on either line marked R1 [*at right in top illustration on this page*]. Nievergelt obtained such a proof by exhausting all possibilities; because it is long and tedious it will not be given. To my knowledge it is not yet known whether Hit-and-Run on the order-4 board, or any square board of a higher order, is a win for the first or the second player or a draw, if both sides play their best.

Red and blue matches can also be used for playing Connecto, a game devised by David L. Silverman for his forthcoming McGraw-Hill puzzle book, *Your Move*. Here too the players alternate in placing matches on a square matrix of any size, but the object now is to



Seven match puzzles



Completed game of Connecto

be the first to enclose a region of any shape within a boundary of one's own matches. In the illustration above Red has won the game. Can you discover Silverman's simple strategy, before it is disclosed next month, by which the second player can always prevent the first player from winning, even on an infinite matrix?

Finally, here are seven entertaining match puzzles, all to be answered next month [*see bottom illustration on opposite page*]:

1. Remove six matches, leaving ten.

2. The six matches are shown forming a map requiring three colors, assuming that no two regions sharing part of a border can have the same color. Rearrange the six to form a planar map requiring four colors. Confining the map to the plane rules out the three-dimensional solution of forming a tetrahedral skeleton.

3. Rearrange the 12 matches to spell what matches are made of.

4. Change the positions of two matches to reduce the number of unit squares from five to four. "Loose ends"—matches not used as sides of unit squares—are not allowed. An amusing feature of this classic is that, even if someone solves it, you can set up the pattern again in mirror-reflected form or upside down (or both) and he often will have as much difficulty solving it as he did before.

5. It is easy to see how to remove four matches and leave two equilateral triangles, or to remove three matches and leave two equilateral triangles, but can you remove just *two* matches and leave two equilateral triangles? There must be no "loose ends."

6. Move one match to produce a valid equation. Crossing the equality sign with a match to make it a not-equal sign is ruled out.

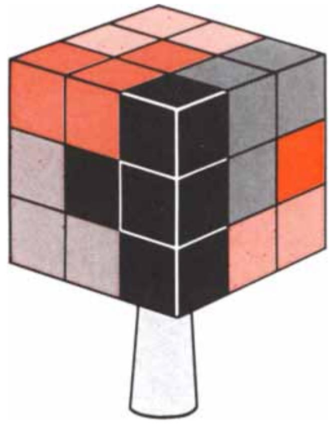
7. Move one match to make a square.

The old joke solution of sliding the top match up a trifle to form a square hole at the center is not permitted; here the solution is a different kind of joke.

Piet Hein's Soma cube, first introduced to American readers in this department for September, 1958, has been made commercially available this summer by Parker Brothers with an attractive 56-page booklet written by Piet Hein, the Copenhagen poet and inventor. If we define a "polycube" as a polyhedron formed by joining unit cubes, the seven Soma pieces include all the different nonconvex polycubes that can be made by joining one through four unit cubes. As Piet Hein points out in his booklet, many computer programs have now verified that there are exactly 240 ways the seven Soma pieces can be put together to form a 3-by-3-by-3 cube, not counting rotations and reflections as being different. The figure was first established in 1962 by John Horton Conway and M. J. T. Guy, mathematicians at the University of Cambridge. Conway discovered the curious fact that only one of the 240 solutions allows the Soma cube to be balanced on a pedestal that touches only the central square of the cube's 3-by-3 base [*see illustration at right above*]. This unique solution is diagrammed in the illustration below, in which each square with the same letter indicates that the unit cube it represents belongs to the same Soma piece. The central square on the bottom layer is the one that rests on the pedestal.

Last month's two problems having to do with random walks are answered as follows:

1. Two men start at the same spot on the plane. One makes a random walk of 70 unit steps, the other a random walk of 30 steps. What is the expected (average) distance between them at the finish? If you imagine one man reversing the direction of his walk until he returns to where he started and then continuing along the other man's path, you will see

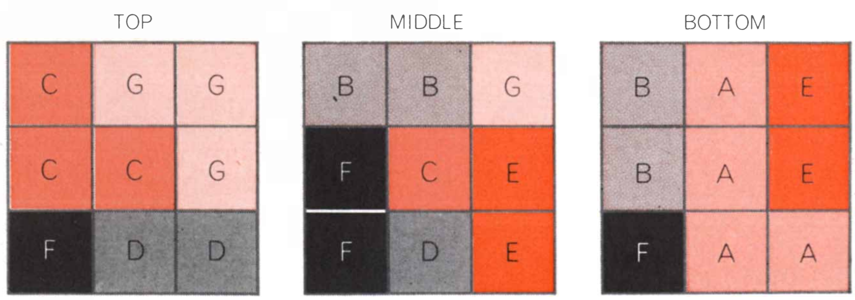


Balancing a Soma cube

that the question is the same as asking for the expected distance from the starting spot of a single random walk of 100 steps. We were told last month that this expected distance is the average length of a step times the square root of the number of steps, and therefore the answer is 10 units.

2. Because of the cube's symmetry any first step of the drunken fly is sure to take it toward the cube's most distant corner, where the drunken spider has begun its simultaneous walk. It does not matter, therefore, what first step the fly takes. The spider, however, can reach a corner adjacent to the fly only by taking two of its three equally probable first steps. Therefore the probability that, after their first steps, the creatures will be at adjacent corners is 2/3. At every possible pair of adjacent corners they can then occupy, the probability that the fly will move toward the spider is 2/5 and the probability that the spider will move toward the fly is 1/4. The product of these three probabilities, 2/3, 2/5 and 1/4, is 1/15. This is the probability that the spider and the fly will meet in the middle of an edge after each has traveled 1½ edges.

Next month I shall comment on the many letters I received concerning the answers to April's short problems.



Layer-by-layer diagram of Soma-cube solution

THE AMATEUR SCIENTIST

The metabolic rate of small animals is measured in homemade apparatus

Conducted by C. L. Stong

A man lives far longer than a mouse, but in one sense they come out about even, as can be verified with a homemade instrument for measuring metabolism. The average man weighs more than 500 times as much as the average mouse, and of course the man needs more food, but pound for pound they process food and expend energy at about the same rate. Jean K. Lauber, who is assistant professor of zoology at the University of Alberta, refers to metabolic rate as a measure of the "aliveness" of animals. She has designed an easily constructed apparatus for measuring metabolic rate and suggests a series of experiments that can disclose some interesting facts about the chemistry of animals.

"Metabolism," she writes, "is essentially an oxidation process. The animal uses oxygen in direct proportion to the rate at which it burns foodstuffs for releasing energy to run its internal machinery—energy for growth, for keeping the organism warm, for movement and for running the myriad chemical reactions that constitute the life process. For this reason the amount of oxygen consumed by an organism per unit of time can be used as a measure of its metabolic rate.

"Oxygen consumed by an organism can be monitored in a number of ways. Most hospitals, for example, determine metabolism with a spirometer, an instrument that responds to the volume of oxygen consumed by the patient. Exhaled carbon dioxide, the principal waste product of the metabolic process, is removed chemically. The apparatus includes a pen recorder that automatically draws a graph of the rate at which oxygen is supplied to the patient through a face mask.

"A number of simpler devices have been made for determining the metabolism of small animals. Most of the instruments embody the same basic principles. Oxygen is measured in terms of volume consumed per unit of time. Carbon dioxide is removed, sometimes being measured. Certain variables must be taken into account. For example, the animal must be fed normally so that the results of the experiment are not influenced by a diet that is deficient or excessive.

"The rate at which oxygen is consumed reflects the physiological state of the whole animal, the sum total of its chemical reactions. For this reason the experiment can disclose the influence of drugs on a selected chemical reaction within the metabolic scheme. The more significant variables are temperature and barometric pressure. The entire experiment must be run under conditions of controlled temperature and pressure, or these variables must be taken into account mathematically when the data are reduced. The environmental conditions may change substantially during an experiment. For example, marked changes in both temperature and barometric pressure may occur with the approach of a storm. Variables of this kind can be measured by including a thermobarometer in the experiment. It is an apparatus exactly like the one that measures metabolism, but it contains no organisms. Any changes of volume that occur in the thermobarometer system are entered as corrections in the data from parallel runs in which organisms are used.

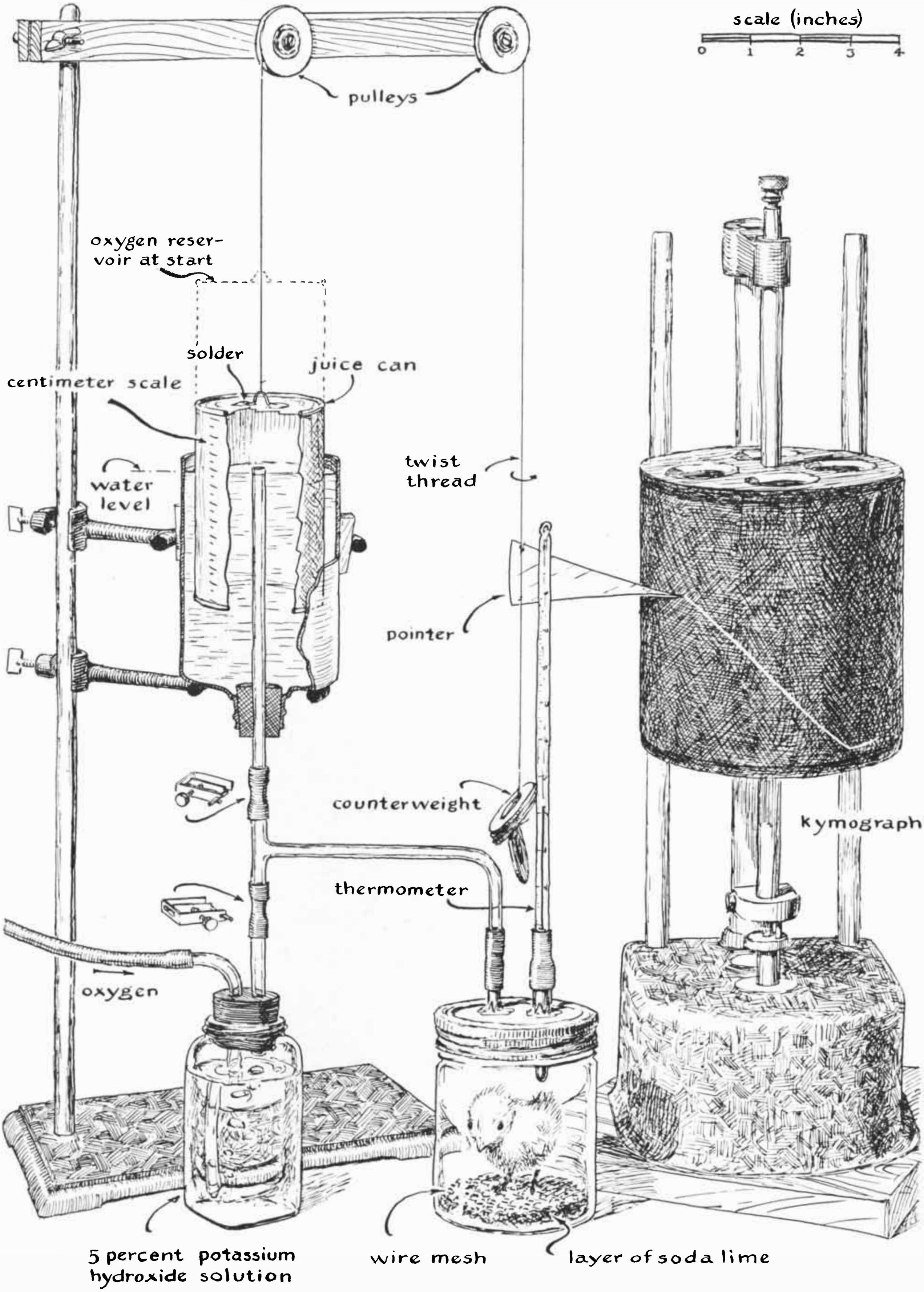
"One of the most accurate and widely used devices for monitoring oxygen consumption was devised by the German physiologist Otto Warburg. As I have modified it for amateur construction it consists of a sealed animal chamber fitted with a slender glass tube that is open at the outer end [*see illustration on page 124*]. As oxygen is consumed by the animal more air flows into the chamber through the manometer tube, carrying with it a droplet of colored water or a strong film of bubble solution to serve as a visual indicator of the gas flow. Carbon dioxide exhaled by the animal is absorbed by a solution of potassium hydroxide on a small wad of cotton. I attach the cotton to the inner end of the tube with a rubber band and then moisten the wad with solution by means of a medicine dropper.

"The potassium hydroxide, which represents 5 percent (by weight) of the solution, is a form of lye that is both toxic and corrosive. Handle it accordingly. If the solution comes in contact with the skin, wash the affected part immediately with lots of water and rinse with vinegar. The chemical will also burn animals on contact. If the animals can crawl up the sides of the bottle or can fly, I enclose the chemical in a protective cage of wire screening.

"I have used this simple apparatus to measure the oxygen consumption of a large variety of small animals, including houseflies, honeybees, fruit flies, earthworms, grasshoppers, crayfish, clams and even fish. Almost any animal can be studied if it is small enough to fit into a widemouthed bottle that has a capacity of one or two ounces. Usually I do several experiments simultaneously, using a separate chamber for each animal or group of animals.

"Each bottle is closed with a rubber stopper that is perforated to make a snug fit with a glass tube one to three millimeters in inside diameter. The manometer tube should be about 50 centimeters long, bent to a right angle two centimeters from the stopper so that the long segment extends horizontally when the bottle stands upright. The side of the stopper is coated lightly with Vaseline. After one or more animals have been put in each bottle the stoppers are inserted and held in place with a wrapping of waterproof adhesive tape. The bottles are placed in a wire rack that is immersed in a water bath so that the necks of the bottles are just at the waterline. The water has been previously heated or cooled to the desired temperature. If necessary, support the outer ends of the tubes so that they are approximately horizontal.

"After 15 minutes, when the tempera-



Jean K. Lauber's scaled-down spirometer ture of the air in the bottles has reached the temperature of the surrounding water, I start the experiment by placing a drop of indicator solution (water tinted with food coloring) in the open end of each tube. (A more sensitive indicator that is easier to measure can be made by substituting for the colored drop a film of durable bubble solution [see "The Amateur Scientist," May]. The film is less massive than the drop and hence responds to smaller differences in gas pressure.)

"As the animal continues to respire, oxygen is drawn into the bottle. The volume represented by each one-centimeter length of the tube, multiplied by the distance traveled by the indicator drop as the experiment proceeds, gives the volume of oxygen used. To find the volume of the tube per centimeter of its length, measure the inner diameter of the tube as accurately as possible in centimeters, divide by two and multiply the quotient by itself and by 3.1416. Expressed algebraically, the formula for the volume is $V = \pi r^2 h$, in which V is the volume per centimeter of tube length, π is 3.1416, r is the radius of the tube and h is its height (in this case one centimeter).

"Include in the rack of immersed animal chambers one empty chamber of identical construction to serve as the thermobarometer. Place the indicator drop inside the thermobarometer tube a few centimeters from the outer end of the tube so that it can move in either direction. Mark the position of the indicator on the glass with a grease pencil. With the apparatus and animals thus prepared, record on a sheet of paper the time when the indicators are placed in the manometer tubes; on the same line enter a zero at the head of a separate column for each bottle in the rack, including the thermobarometer. At 10-minute intervals for one hour record for each tube the distance in centimeters that the indicator has moved from its initial position.

"Measure and record the temperature of the water bath in degrees Kelvin. To get degrees Kelvin add 273 to degrees Celsius. If your thermometer is calibrated in degrees Fahrenheit, subtract 32 from the reading, divide the remainder by 9, multiply the quotient by 5 and add 273 to get degrees Kelvin.

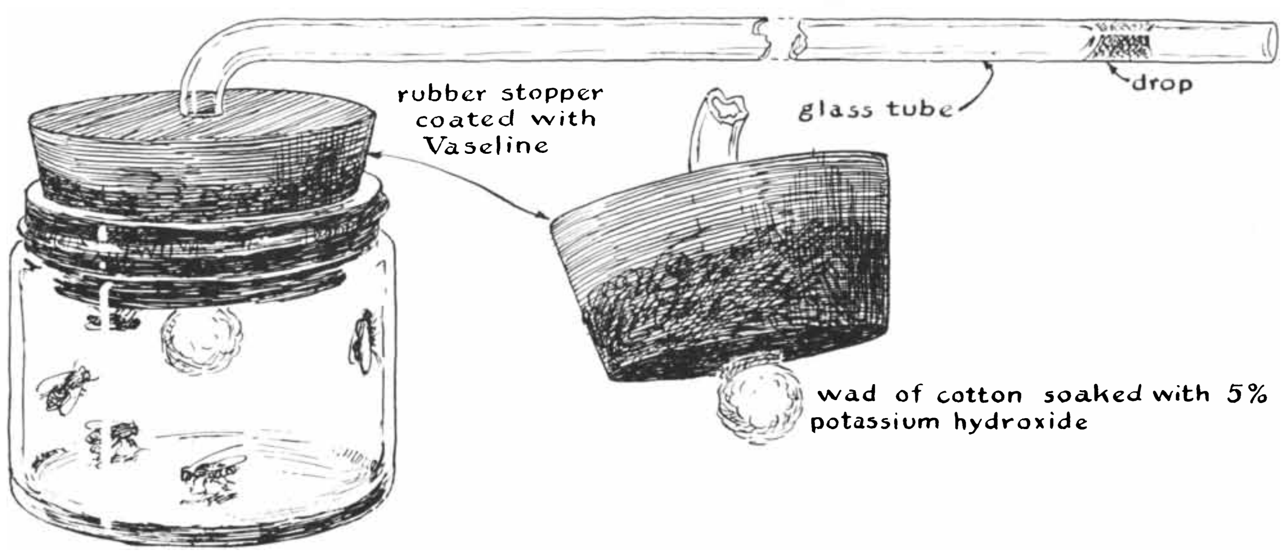
"Measure and record the barometric pressure in torr. If your barometer is calibrated in millimeters of mercury, simply record the reading. (One torr is equal to the pressure exerted by a column of mercury one millimeter in height.) If the instrument is calibrated in inches of mercury, multiply the reading by 25.4 to get the pressure in torr.

"From these data you can find by a few simple calculations the amount of oxygen each animal consumes. The actual consumption may vary with the pressure of the atmosphere and with the temperature. It is useful for comparing experimental results observed at various times and under various conditions to adjust the data to a standard barometric pressure and temperature. By agreement biologists use as standards a barometric pressure of 760 torr and a temperature of 273 degrees K.

"First find the apparent volume of oxygen consumed by the animal or animals in each bottle during each of the six 10-minute intervals. To find the apparent oxygen consumption in cubic centimeters multiply the distance in centimeters that the indicator moved during each 10-minute interval by the previously determined volume per centimeter of the length of the tube. Determine for each interval of time the change in volume of the air that took place in the thermobarometer. The volume of air in the thermobarometer may have increased (indicated by the outward movement of the colored drop or the bubble film), decreased (indicated by the movement of the indicator toward the bottle) or both.

"Correct the apparent oxygen consumption to the actual consumption by adding or subtracting from each figure the change that occurred simultaneously in the volume of air in the thermobarometer. Record the actual consumption of oxygen for each bottle during each of the six time intervals. Finally, adjust the actual consumption to standard pressure and temperature.

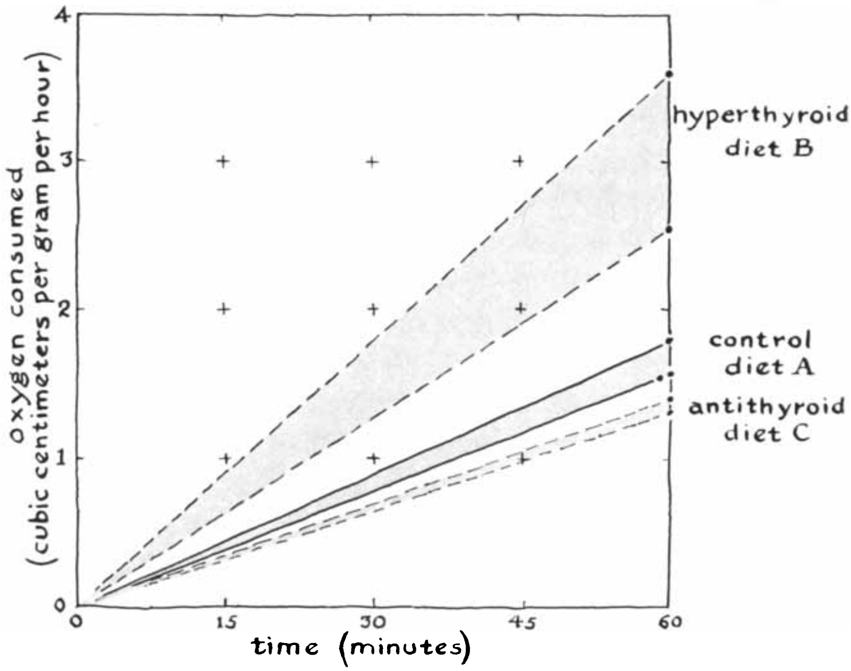
"For each bottle and time interval multiply the actual consumption of oxygen in cubic centimeters by .36 and by the barometric pressure in torr and divide the product by the recorded temperature in degrees Kelvin. Expressed algebraically, the conversion formula is $V' = .36VP/T$, in which V' is the volume of oxygen consumed at standard pressure and temperature, V is the actual volume as measured by the experiment, P is the barometric pressure indicated by the barometer and T is the observed temperature of the water bath in degrees Kelvin. Record the oxygen consumption as corrected for standard pressure and temperature.



Elements of an apparatus for measuring oxygen consumption

"As the final step weigh the animal in grams. Add the corrected volumes of oxygen consumed during the six intervals to get the total consumption for one hour and divide the total consumption in cubic centimeters by the weight of the animal in grams to determine the consumption of oxygen per hour per gram of the animal's weight at standard pressure and temperature. A graph can be drawn to show the oxygen consumption of each experimental animal during the experiment by plotting the oxygen consumption, in cubic centimeters, against time in minutes.

"Many variations of the above experiment suggest themselves. One can compare the performance of a single large animal with that of several smaller animals of the same total weight. Similarly, the effects of increased or reduced amounts of light can be measured, but in this experiment take care to maintain the water bath at constant temperature. One animal of a pair can be restrained in a cheesecloth bag while its companion remains free in a separate bottle, thus demonstrating the effects of reduced activity on metabolism.



Metabolic results of three diets for rats

"Most invertebrates exhibit a decrease in metabolic rate with reduced temperature. To lower the animal's temperature immerse one bottle in an ice bath. If aquatic animals are used, each animal chamber and the thermobarometer should contain a standard amount of the water in which the animal normally lives. The chambers should not be more than half filled with water, however, because the air above the water must contain enough oxygen to supply the animal normally during the experimental run.

"For animals as large as a mouse the equipment that has been described works nicely if the experiment is limited to about 10 minutes. The animal chamber and the manometer tube must be of appropriate size or the mouse will use up all the oxygen and suffocate. Watch the movement of the soap film carefully during the experiment. If the movement of the film slows appreciably, the animal may be running out of oxygen. In this event remove the bottle from the water bath and open it immediately. Then substitute a manometer tube of about twice the diameter of the first one and try again.

"It is also easy to construct a scaled-down version of the spirometer, the instrument used for determining the metabolic rate of humans and other large mammals. The scaled-down instrument [*see illustration on page 123*] consists essentially of an airtight animal chamber connected by tubing to a reservoir that is in turn linked mechanically to the stylus of a kymograph, which automatically draws a graph displaying oxygen consumption against time. Apparatuses of this type can be designed for accommodating animals weighing from 50 to 1,000 grams simply by varying the size of the animal chamber and the oxygen reservoir.

"For approximating the dimensions of the oxygen reservoir a good rule of thumb is to assume that each hour an animal at rest will require about one cubic centimeter of oxygen per gram of body weight. For example, a spirometer that contains 250 cubic centimeters of oxygen would be adequate for a one-hour test of a 250-gram animal. The accuracy of the measurements will suffer if the apparatus is made excessively large, because the animal will then consume only a small fraction of the available oxygen, thus reducing the change in volume of the spirometer and the resulting excursion of the stylus.

"The apparatus has been used for rats, mice and baby chicks. The animal chamber is a widemouthed, one-pint Mason jar fitted with a self-sealing lid and screw band. Two 1/4-inch holes were drilled in the metal lid, and a one-inch length of 3/8-inch copper tubing was soldered in place over each hole. One copper nipple is connected by rubber tubing to the oxygen supply; the other one is the exhaust and is fitted with a short sleeve of rubber tubing so that this opening can be sealed by inserting a thermometer. It is extremely important that the system be leak-free. Grease the top of the jar and all rubber-tubing connections lightly with Vaseline, clamp off the oxygen-supply tube and check the apparatus for leaks by immersing it in a tub of water.

"Circles of 1/4-inch-mesh hardware cloth were cut to fit the inside of the animal chamber. During the experiment they rest on top of a layer of soda lime ($NaOH + Ca(OH)_2$), which acts as the absorbent of the carbon dioxide. The stack of wire disks protects the animal from contact with the corrosive chemical; the mesh must be fine enough so that the animal's feet will not slip through the stack and touch the soda lime. For the oxygen supply I have used a tank or lecture bottle; if such a supply is not at hand, one can have a balloon or an inner tube filled with oxygen at a local chemistry laboratory, hospital or welding shop.

"The oxygen supply is connected to the apparatus by flexible tubing and a *T* fitting, with the animal chamber on the lower arm and the spirometer on the upper arm. The spirometer is made from two telescoping tin cans, one slightly smaller than the other. The outer can of my apparatus is a liquid-soap container of the type that has a plastic neck and screw cap. The bottom of the can was cut out with a can opener. If one uses a different kind of container, one end is cut out and a 10-millimeter hole is drilled in the other end. This hole, or the neck of the soap can, is fitted with a one-hole rubber stopper. A glass tube extends through the stopper to a point 10 millimeters below the open end of the can. The can is mounted securely by a large clamp attached to a ring stand and is filled with water to approximately 20 millimeters from what is now the top. On the outside of the smaller can (I used a frozen-juice can, which clears the soap can by about three millimeters on all sides) a loop of wire is soldered in place exactly in the center of the bottom. The can is inverted inside the larger one and is suspended from the loop by a thread.

"The thread runs up over two pulleys. The first one is about 25 centimeters above the top of the outer can; the second pulley is at the same level but about 15 centimeters to one side. The thread runs around this pulley and down to a counterbalance equivalent in weight to the inner can. A centimeter scale marked on the side of the inner can is convenient. The thread on the counterbalance side carries a pointer that is cut from a piece of photographic film and is held in position between two knots in the thread. The pointer is brought in contact with the smoked surface of a kymograph drum, the thread having been twisted in such a way that its tendency to untwist will keep the pointer in constant but delicate contact with the drum.

"At the beginning of a run the inside can is moved to its lower position and a pinch clamp is placed between the spirometer and the upper arm of the *T* fitting. The chamber is charged with fresh soda lime and the animal is sealed inside. With the exhaust tube open, oxygen is first bubbled through water, a step that saturates the gas and also serves to indicate rate of flow, and then is delivered to the chamber. After a five-minute equilibration period the clamp below the spirometer is removed and the spirometer is charged with oxygen by briefly closing the exhaust tube. The inner can should now be in its upper position, but its lower rim must extend into the water so that no room air can leak in to dilute the oxygen. The experimental run is started by simultaneously sealing the exhaust tube and clamping the oxygen-supply tube.

"As the animal uses oxygen the inner can of the spirometer moves down and the pointer writes a rising curve on the kymograph drum [see "The Amateur Scientist," April, 1960]. Pressure in the animal chamber and the spirometer remains at atmospheric level since the inner can of the spirometer is freely movable. If the animal seems easily disturbed by activities in the room, drape a black cloth around the chamber. On a day that is warm but not humid, cooling of the chamber can be effected by dampening the cloth occasionally. It may also be necessary to submerge the entire chamber in a constant-temperature water bath; a sink or a plastic dishpan will serve for this purpose. Temperature fluctuations take place much more slowly in water than in air.

"It is necessary to know the volume of oxygen contained in the spirometer can. The volume can be determined by calculating the volume of a cylinder, as in the previous experiment. An even easier way is to fill the inner can with water and determine the depth in centimeters of a given volume of water. For instance, in my setup 325 cubic centimeters of water filled the can to the 10-centimeter mark. Thus each centimeter on the side of the spirometer can, or each centimeter in the vertical rise of the recording stylus, represents a volume of 32.5 cubic centimeters. This is the spirometer-calibration factor. It is also necessary to know how fast the kymograph is turning, that is, how much time is represented by one centimeter of the base line of the graph. An easy way to get this figure is to mark the exact starting point with an arrow on the kymograph tracing; mark the finish point one hour (or fraction thereof) later.

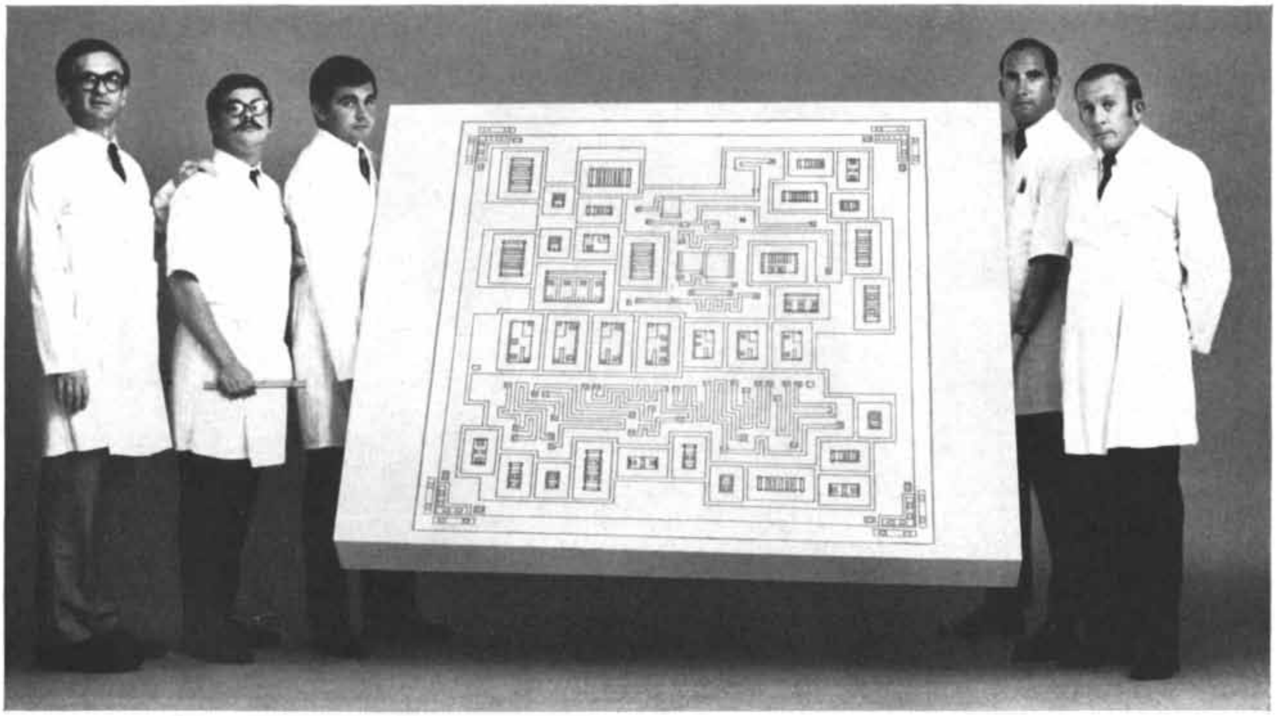
"In a typical experiment I used weanling male rats divided into three groups of two rats each. The animals always had access to food and water. They were weighed daily, at which time the cages were cleaned. The control group, *A*, received a standard diet (I used a turkey-brooder ration that was available as a finely ground mash). To the diet of group *B* thyroid hormone was added at a rate of one crushed five-grain tablet of U.S.P. thyroid per 40 grams of feed. Adequate mixing was assured by placing the diet plus ground thyroid hormone in a large paper bag and shaking it well. Group *C* rats received standard feed to which was added one crushed 50-milligram tablet of propylthiouracil, an antithyroid drug, per 700 grams of feed. (These drugs are prescription items, available only from a licensed pharmacist. I have checked with several pharmacists in my area and have been assured that an amateur biologist could probably obtain enough pills for such an experiment by explaining his need to his physician.)

"After one week on these diets weight differences became apparent. Differences in behavior were also beginning to appear: rats receiving the hyperthyroid diet *B* were definitely more active and 'jumpy,' whereas rats on diet *C* seemed sluggish. After two weeks on the experimental diets food was withheld overnight, and the following morning oxygen consumption was determined for each animal. Each rat was allowed a five-minute equilibration period in the animal chamber, and then oxygen consumption was monitored for 20 minutes. The chamber was washed, dried and charged with fresh soda lime after each run.

"Barometric pressure on the day of the experiment was 701 torr. Other raw data were recorded in a table that showed in its first four columns the diet given the rat, the number of the rat, the rat's weight in grams and the temperature of the animal chamber in degrees Celsius. There followed for each rat four columns. Column 1 gave the measurement from base line to finish point on the kymograph tracing. Column 2 was obtained by multiplying the figures in column 1 by 32.5, the spirometer-calibration factor. Column 3 was obtained by multiplying these figures in turn by 3 (20-minute run times 3 is 60 minutes). Column 4 was derived by dividing by the body weight. To reduce these figures to standard pressure and temperature (column 5) we used the same formula that was employed in the earlier experiment. The plotted data yielded the accompanying graph [*preceding page*].

"The hyperthyroid diet *B* markedly affected metabolic rate; the loss of weight on this diet arises because the rats run off food reserves instead of storing them. The antithyroid diet *C* did not have such a dramatic effect on weight, but it depressed oxygen consumption. At the conclusion of the experiment all the rats were given a standard diet, and within a week they had returned to normal weight and behavior.

"In retrospect it would have been preferable to conduct all runs at exactly the same temperature. The conversion to standard pressure and temperature corrects for the expansion of oxygen in the spirometer that accompanies a rise in temperature, but it does not take account of another variable: all warm-blooded animals must expend energy, hence oxygen, in order to maintain a constant internal temperature in spite of varying external temperature. To this extent such determinations of basal metabolic rate are not quite basal, and the results should always be stated as cubic centimeters of oxygen consumed per gram per hour at a stated temperature."



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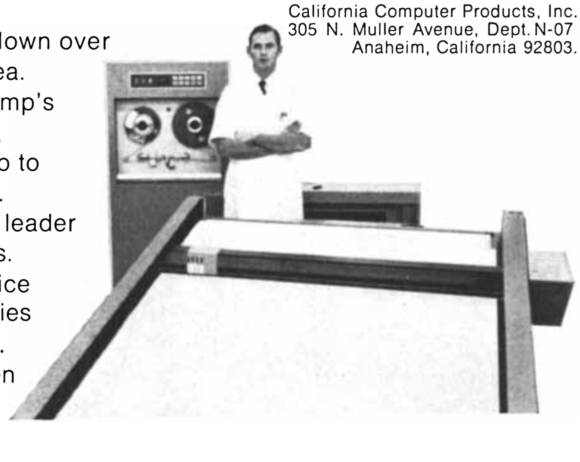


BOOKS

Gunnar Myrdal's survey of the problem of economic development in South Asia

by P. C. Mahalanobis

ASIAN DRAMA: AN INQUIRY INTO THE POVERTY OF NATIONS, by Gunnar Myrdal. Pantheon ($8.50).

The Asian drama visualized by Gunnar Myrdal turns on the question: Can the underdeveloped countries of South Asia bring about their industrial revolution under political democracy? History does not know of such a transformation. In the industrial revolutions of the West the democratic principle was always compromised to permit the coercive measures necessary for the adequate accumulation of capital from its principal source: involuntary saving by the population. Coercion supplied by one-party governments has been serving the same essential function in the industrial revolutions now proceeding under Communism. In the "great awakening" that came with independence the nations of South Asia were determined to find another way. They are attempting to achieve economic development through democratic planning.

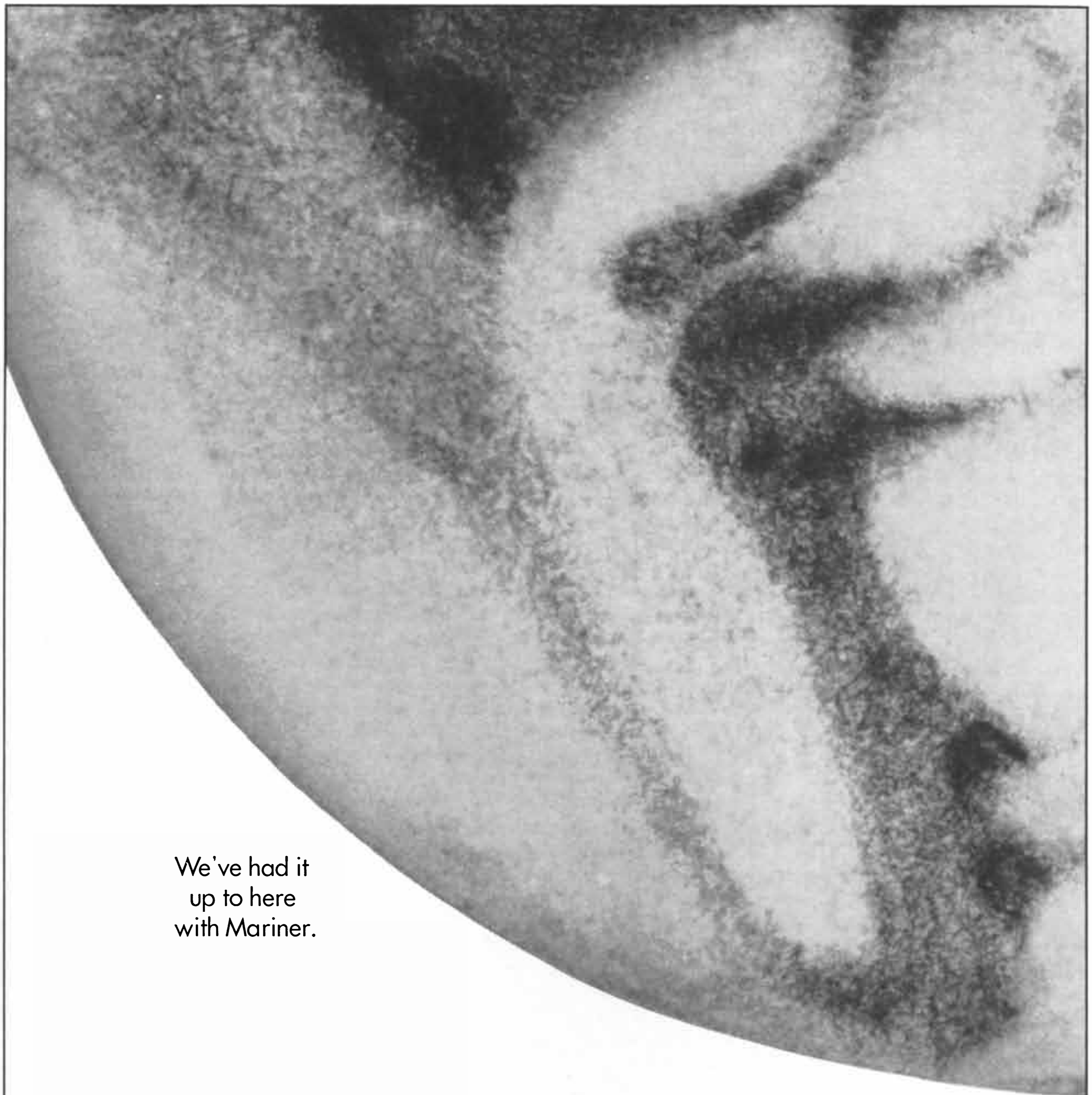
Myrdal points out that the national liberation movements embraced planning as an idea long before they had won the power to plan. Democratic planning implies acceptance of a matrix of interlocking value premises: national independence; rationality, particularly in the utilization of science and technology for increasing productivity; equity in the sharing of improvements in the level of living in terms of nutrition, housing, health, education and cultural amenities; equality in political status; the civil liberties and the dignity of the individual. The aim, in sum, is industrial revolution without coercion. Myrdal rightly characterizes the popular demand for economic development in South Asia (and, even more, the popular charge to governments to promote development by planning) as "a new event in history."

This drama involves the lives of some 800 million of the poorest people on earth. Until the present generation most of the people of South Asia lived in the changeless village world of preindustrial agriculture. The vision of democratic planning is urged by a small group of political and intellectual leaders of the new nations. "The lofty aspirations of the leading actors," says Myrdal, "are separated by a wide gap from the abysmal reality—including the unreadiness of leaders, followers, and the more inert masses to accept the consequences of attempting to attain these aspirations. And that gap is widening. The movement of the drama is intensified as, through time, aspirations are inflated further by almost everything that is printed and preached and demonstrated, be it planned or not, while positive achievements lag. Meanwhile populations are increasing at an ever faster pace, making the realization of aspirations still more difficult."

At the outset of this work Myrdal squarely faces his own involvement in the struggle of South Asia, saying "all of us are participants." He declares that it is necessary "to raise the question of objectivity in research as a problem in logic." Moreover, he insists: "A 'disinterested' social science has never existed and never will exist. For logical reasons, it is impossible. A view presupposes a viewpoint. Research, like every other rationally pursued activity, must have a direction. The viewpoint and the direction are determined by our interest in a matter. Valuations enter into the choice of approach, the selection of problems, the definition of concepts, and the gathering of data, and are by no means confined to the practical or political inferences drawn from theoretical findings."

Accordingly Myrdal makes his premises explicit in his introduction. They are the value premises of democratic planning, which he sets down in a careful inventory of the "modernization ideals" that have become the official creed of the new nationalism of South Asia. He is thus obliged at the outset to confront a philosophical issue familiar to natural scientists: the uncertainty that arises from the interaction of the observer with the observed. He finds its resolution in a restatement of the principle of indeterminacy for application to the study of human affairs: "In the classic conception of drama—as in the theoretical phase of a scientific study—the will of the actors was confined in the shackles of determinism. The outcome at the final curtain was predetermined by the opening up of the drama in the first act, accounting for all the conditions and causes of later development.... In life, while the drama is still unfolding—as in the practical phase of a study, when policy inferences are drawn from value premises as well as from premises based on empirical evidence—the will is instead assumed to be free, within limits, to choose between alternative courses of action. History, then, is not taken to be predetermined, but within the power of man to shape. And the drama thus conceived is not necessarily tragedy."

The subtitle of the book—*An Inquiry into the Poverty of Nations*—is an evocation of Adam Smith's title *An Inquiry into the Nature and Causes of the Wealth of Nations,* and it draws the contrast between the expanding horizons of 18th-century Europe and the darkly clouded future of 20th-century South Asia. Coming from Myrdal, the subtitle may also be taken as claiming for this work a place beside the original classic of economics. There can be no doubt that *Asian Drama* is a major work—in three volumes, 2,284 pages, 16 appendixes, a large number of statistical tables and running to more than a million words. It has the flavor of an epic at a high level of tension when the master himself is zestfully speaking in a torrential outflow of words, ideas and images. The level is somewhat uneven when the associates and apprentices in the school of Myrdal are dealing with particular problems, reporting useful surveys based on painstaking assembly of information from primary sources or detailing technical criticisms of planning policies that are sometimes irrelevant and not uniformly convincing. In this connection I must confess to a personal involvement in the book, as one



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who has been associated with the economic planning of India.

Apparently Myrdal did not set out to write a classic. He started the project in 1957, shortly after a new strategy for industrialization had been adopted in the Second Five-Year Plan of India (1956–1961), a plan that aroused a good deal of hope at the time. Myrdal made India his headquarters in a mood of optimism. His original intention was to complete the work in two and a half years, as a contribution to current policy-making in the South Asia region. The labor was extended to 10 years. Developments in South Asia were not encouraging. Myrdal became profoundly distressed at the absence of any sign of self-sustaining economic growth in any country in the region, including India, the country that has the strongest base for planning. In order to identify the factors responsible for stagnation he was obliged to address his great energy and ability to a deeper analysis of the problem. His book is worthy of its title and its subtitle.

Readers will be grateful for Myrdal's comprehensive and empirically balanced statement of his own "institutional" economics and for his decisive rejection of the "modern approach" of the post-Keynesian economists of the West, who have so recently discovered "development" as an object of study. His first task was to destroy the abstract concept of man as an economic automaton. *Homo oeconomicus*, if the metaphor may be mixed, is the *deus ex machina* of the determinism—the inexplicit teleology—that pervades the mainstream of classical economics and the rival interpretation of Marxism alike.

In his masterly Appendix 2 ("The Mechanism of Underdevelopment and Development and a Sketch of an Elementary Theory of Planning for Development") Myrdal disposes of the notion that any compulsive mechanism brings economic relations to the "equilibrium of harmony" posited by laissez faire economics or to the "realm of liberty" imagined by doctrinaire Marxists. On the contrary, what Myrdal calls "back-setting" effects tend to overwhelm "spread" effects in the real world. In the absence of intervention from sources of power external to the economic process the rich become richer and the poor become poorer. Instead of leading to growth by automatic progression from "takeoff" to "high mass consumption," as propounded by "stage-builders" such as W. W. Rostow, the impulses to growth in South Asia tend to damp out in stagnation. As for growth under Communism in the U.S.S.R. and in China, "they have used the government to reshape society, instead of letting society, changed by the modes of production, determine the government." Myrdal cites, supplying the italics, Lenin's famous assertion: "Communism is *Soviet power* plus electricity."

Myrdal's institutional approach goes beyond "output and incomes," "conditions of production" and "levels of living," the headings under which the economic aspects of society are usually abstracted from the rest. The social system for which one would undertake to plan must be understood to involve also such noneconomic conditions as "attitudes toward life and work," "institutions" and "policies," including the policies of the plan itself. In South Asia "the interdependence of 'economic' and 'non-economic' factors is much more intensive and consequential" than in Western countries. "Obstacles to rapid economic expansion are formidable and... rooted in the inefficiency, rigidity, and inequality of the established institutions and attitudes, and in the [existing] economic and social power relations." A plan is "fundamentally a political program."

Not only the economy but also the entire social system must be moved forward as a whole. This requires planning. If the planning is to be democratic, then it must proceed, with rationality and humanity, from the value premises announced by the leadership of South Asia and embraced by Myrdal. These affirm, as he observes, the highest aspirations of Western civilization.

India, as the largest country in South Asia and the one best able to claim designation as a parliamentary democracy, engages Myrdal's principal attention. The situation there brings him close to the despairing conclusion that Indian "democracy is not really a vehicle for economic and social change but, for the time being at least, a protection for the *status quo*." The country, he says, "is ruled by a select group of upper-class citizens who use their political power to secure their privileged position" over the masses, who "are very poor, inarticulate, and split by caste and community allegiances." In particular, the upper classes have appropriated to their own limited number most of the fruits of national economic planning. To this Myrdal adds a perceptive observation: "The explanation of the gulf between ideals and reality is, however, far more complex than simple hypocrisy." The upper classes generally believe in the egalitarian ideals of modernization. In spite of intellectual dishonesty and even plain cheating, the appeal to the masses on the basis of these ideals must have a long-range impact on the attitudes of the population as a whole and on the country's political institutions.

The fallibility of conventional economic analysis is clearly exposed by Myrdal's examination of the question of whether the egalitarian ideal of planning in South Asia helps or hinders development. He recalls J. M. Keynes's vivid words to the effect that "it was precisely the *inequality* of the distribution of wealth which made possible those vast accumulations of fixed wealth and of capital" that financed the industrial growth of 19th-century Europe. "Under the spell of the Western practice of treating development as a function of savings, physical investment, and output," a conflict between the two goals of development and egalitarianism is often assumed by South Asian planners under the influence of their counselors from the West. Yet in South Asia, particularly in India, where a large part of the population suffers from malnutrition and a lack of elementary health and education facilities, it is plain that "measures that encouraged essential consumption in the lower strata would raise productivity." Planning at a subsistence level in these countries must thus reckon with a turnabout of the ordinary chain of economic cause and effect; increase in consumption can bring about increase in production! On the other hand, in superficial imitation of the Western countries, labor and welfare measures are sometimes introduced at a cost that the country can ill afford at an early stage.

Myrdal lays great stress on the dictum that "all effective planning is physical planning." By this he means to downgrade the purely fiscal and financial considerations that govern priorities in an advanced economy. He encourages the planners of the developing countries to set aside the criteria of comparative efficiency that rationalize the international division of labor and have served in the past to limit these countries to the supplying of raw commodities to the industrial nations. If appropriate to the total plan, they should not hesitate to build inefficient industries and to protect them by mercantilist measures. Higher costs and inefficiencies are tolerable in such enterprises when they are designed and operated to set off repercussions leading to further growth.

Because I so warmly endorse this approach I find it difficult to accept the criticism of Indian planners, made elsewhere in *Asian Drama,* for not keeping the time factor in mind and for failing to maintain adequate balances of outputs and inputs in their industrialization scheme. "Physical planning" was the deliberate starting point of the Second Five-Year Plan. The strategy was to establish heavy industries based on energy and steel from India's own resources. These industries were to produce the inputs of machinery, fertilizer, insecticides and the like necessary to increase the productivity of Indian agriculture. It was understood and openly declared that lead times of 10 or 15 years would have to be accepted before the plan brought results; food grains, fertilizer and machinery to set up fertilizer plants would meanwhile have to be imported. With the watchword "perspective planning," the plan asserted the claims of the country's long-term interests, as against its short-run needs, in the allocation of scarce foreign exchange. Hindsight may indeed reveal many imbalances and, above all, a serious shortfall in the execution of the plan. Nonetheless, the Indian landscape also shows the highly tangible *physical* presence of new steel and heavy-engineering establishments.

The wider question of "emphasis on agriculture" in preference to industry that haunts the pages of this book may reflect Myrdal's increasing disappointment over the decade of his labor. Fear of hunger has forced human beings to give all possible emphasis to agriculture at all times all over the world; until the very present men faced the specter of periodic shortages of food and outright famine. Even in the U.S. it was fear of hunger that led to the creation of the land-grant colleges about 100 years ago. The yield per acre of wheat, barley and maize began to rise significantly in America only as recently as the mid-1930's. Similar improvements came even later in Europe. In Japan agriculture contributed only about 1 percent per year to economic growth between 1875 and 1925.

The reason is easy to discover. The yield per acre or per man-hour can increase only with an increase in the quantity and variety of inputs that become available with the progress of industrialization. In India, as elsewhere, improved implements, fencing, pesticides, fertilizers, tractors, electricity and irrigation facilities must be brought to the villages; the agricultural surplus must be preserved, processed, transported and marketed; credit facilities must be extended for both production and distribution, and so on. Finally, and most important, for effective utilization of industrial inputs, village habits and psychology must be transformed; the outlook of industrial technology must inculcate interest in tools, gadgetry and new innovations and the desire for skill in using them.

To bring about full industrialization of agriculture in an underdeveloped country will take possibly two generations, or a period of 40 or 50 years. It will, in other words, require a much longer period of time than that required for the establishment of the basic supporting industries. An agricultural surplus is indispensable for industrial progress. An increase of industrial inputs, however, is equally indispensable for agricultural growth. It is simply not possible, in theory or in practice, to give more emphasis to agriculture than to industry. We thus return to Myrdal's essential point: rational planning must move the social system forward as a whole.

I am distressed to find myself in serious disagreement with Myrdal on a narrower, yet crucial, issue in agricultural policy. Myrdal agrees that a radical redistribution of land to agricultural labor would help to advance the dual objective of equity and development. Yet, "as neither the political will nor the administrative resources for... any fairly effective land reform are present," he advocates, almost in despair, the promotion of "capitalist farming." This would supply preferentially to the larger and more successful cultivators such facilities as credit, improved seed, fertilizers, pesticides, electricity, tractors and other machinery. Just such a preferential supply of industrial inputs in packaged form has been undertaken in several districts in India on a demonstration basis and with some success under sponsorship by the Ford Foundation. In these districts the top 10 percent of the households have become richer during the past 10 or 12 years. The poorer households may not have become poorer in absolute terms, but disparities have increased within the villages. Increase in the marketable surplus has been bought at the price of increased inequality.

If this were the end of the story, it might be said that the experiment had worked and had set the stage for a new line of policy. There is a serious hazard, however, in encouraging selective growth of capitalist agriculture in India. Rich cultivators in a country that is not self-sufficient in food grains tend to hoard their grain in years of good harvest and try at all times to maintain and increase prices by restricting production. To offer higher and higher prices for food grains as an incentive to the richer growers is to invite a spiral of inflation. As a result the agricultural surplus may be reduced in years of good harvest and may vanish in years of shortfall. This has in fact been the experience of India, which already suffers from more than enough inequity in the distribution of land and other agricultural resources.

How to increase agricultural production without increasing the price of food grains is perhaps the most difficult problem in Indian planning. One solution, which I put forward some years ago, is for the government to maintain a buffer stock of food grains in order to control prices by open-market operations or through physical rationing in years of scarcity. No more than 5 percent of the annual consumption of food grains would be required to lever the price of the entire supply. This policy was adopted by the government in 1953, but it has not yet been adequately implemented, owing to social and political obstacles as well as to shortfalls in harvests.

In common with other students of development, Myrdal looks for a retardation in the increase of population to speed economic growth. He speaks with approval of the family-planning programs of India. There is no escape from arithmetic: out of the total increase in national product attained during the first two five-year plans, from 1950 to 1961, half went to give new additions to the population the same per capita consumption as the population had had at the beginning of the period, and only half of the gain was available to increase the per capita income of the larger 1960–1961 population. It is necessary, however, to recognize that there is no evidence of any scientific value to show that the effort to promote birth control in India has any short-term effect in either increasing the use of contraceptives or reducing the birthrate. In any population the birthrate is the resultant of the interplay of complex social, economic, political and psychological factors. There is some evidence to show that in India improvements in the level of living have a retarding effect on the birthrate. Rapid industrialization, with the increase of income and urbanization, may in the long run be the most effective means of reducing the rate of growth of population.

I venture now an elaboration of Myrdal's institutional approach to development. To the "noneconomic" conditions that must be reckoned with in planning I would add "science and technology." Reference is made, of course, to science and technology throughout the book; they enter Myrdal's institutional scheme as elements in "conditions of production" and in "attitudes toward life and work." In South Asia, however, one sees the world as it was 400 years ago, and so one can sense more vividly the difference that science and technology make in the nature of human existence.

Before the emergence of science there were only two domains of decision in organized society. There was first, as there always will be, individual choice—of food, clothing, habitation, recreation, art, literature, values—within the limits of social constraint and the availability of supplies. There was second the domain of authority, in which the nature and the force of sanctions depend on the level of authority in a hierarchy determined by custom, law or religion. With the emergence of science the human mind became aware of "nature" as an objective reality amenable to human understanding by observation and experiment. The crucial point is that such observation and the inferences drawn therefrom by one person—and so, in one sense, subjective to that person's experience—may be repeated and verified by others. Such interpersonal (or intersubjective) agreement requires the acceptance, in principle, of interpersonal parity. Science thus introduces into human affairs a new third domain of objective reality, which cannot be changed by any authority, however high its status, nor by personal choice or preference. This was the nature of the turning point reached by the history of civilization 400 years ago.

The transformation of the advanced, and still rapidly advancing, countries has been brought about by the acceptance of the scientific and rational view of life and nature. In these countries the scientific view has permeated in large measure the administrative organization, tempering the outlook of individual administrators and executives and increasing their ability to make responsible decisions, particularly at the lower levels of the hierarchy of authority. This is the foundation of the modern age. C. E. Ayres, in his *Theory of Economic Progress*, makes the point sharply: "The power which ideas exert by virtue of being correct is a function not of mind over matter but of technology over institutions in the long-run process of social change."

Myrdal makes an observation that deserves consideration in the present context: "The Western experience of scientific, technological, and economic advance may well be unique: a series of extraordinary circumstances seems to account for the cumulative process of development in Western history." It is scarcely possible to accept this suggestion. Japan has reached a high level of scientific and technological achievement and is developing very fast. In China also, distinguished Western scientists agree, there has been steady progress in scientific research and technology. What is more, China seems already to have reached the stage of self-sustaining growth. Scientists from India, Pakistan and other underdeveloped countries have made significant contributions to science and technology. Inborn talent is not lacking in these countries, and Myrdal surely intended no such inference. What is lacking for the present, at least, is institutional support and the ability to recognize talent.

The position of science and technology in India illustrates the situation. On the foundations established during British rule independence brought a rapid expansion of higher education and technical training. India now has a large stock of scientific and technical personnel; expenditure on research and development is increasing possibly at the rate of 20 percent or more per year at current prices. Yet science and technology remain in India the captives of an outmoded governmental administration whose main task continues to be the collection of taxes and the maintenance of law and order in much the same way that this system served the British raj. The authoritarian principle remains strong in the Indian bureaucracy; decisions continue to be made on the basis of rules, precedents and authority instead of on the rational test of objective validity.

The progress of industrialization in India—and in other countries in South Asia—is likely to be retarded until a radical transformation of the social structure allows and encourages the growth of science. This is plainly the conclusion indicated by Myrdal's institutional approach to economic development, amended here to give full recognition to science and technology as essential preconditions of development.

Nonetheless, I find evidence that India is moving forward. Indian planning has started the process of industrialization in a way that cannot be reversed. Industries are expanding. Heavy-machine-building complexes have made slow progress but will soon be turning out machinery for the production of steel, electricity, fertilizers and other inputs to promote industrial and agricultural development. It should then be possible to put up new plants built to a large extent around machinery produced in India.

The benefits of industrialization have started reaching rural areas. New industrial towns are being established and are changing the character of the surrounding countryside. The supply of technical inputs to agriculture is increasing. The interlocking and reciprocal feedback between agriculture and industry, once it reaches the critical level, will carry the country a long step toward self-sustaining growth.

Conditions in India, I believe, are ripe for modernization. The infrastructure is ready for the "big push." Myrdal, along with other students of development, concludes that "underdeveloped countries cannot rely on a 'gradualist' approach.... [The] very idea that planning is needed to start development, and that market forces by themselves cannot do it, implies the thesis of the big push." To generate and sustain this crisis in the growth process requires "not only that the efforts have to be larger than a critical minimum, but also that they must be directed simultaneously at a great number of conditions, concentrated within a short period of time, and applied in a rationally coordinated way."

As one of the somber conclusions of this book Myrdal confesses his doubt that the indigenous governments of South Asia, much as they fall short in implementation of the democratic ideal, are equal to the task of generating the big push. Those governments, he says, are "soft" for lack of sufficient social discipline, particularly among the ruling classes. Their fate and the destiny of the entire region may hang on external forces generated by the recurrent competition of the two superpowers, to be joined soon, perhaps, by China. If political democracy must fail in India, Myrdal thinks there is a greater chance of takeover by a coalition of military officers, higher civil servants and businessmen than of one by Communists, at least in the near future.

From within the country I would judge that such a development would bring no necessary improvement in India's prospects for economic growth. Pakistan did not approach any closer to the big push under Ayub Khan. In India it would be even more difficult to set up a military dictatorship; such a regime would not be viable because the armed forces are not homogeneous with respect to language, religion and community, and also because of the political maturity of the people. I still feel that Indian development may enter the big-push phase under parliamentary democracy. If there is a failure of top leadership, owing to betrayal by the intellectual elite who form the ruling classes, the country may have to go through a period of dissension, increasing frustration, disorder or violence until a strong government is firmly established with a progressive modernization program. The time has not yet come, however, to despair of

India's continued effort to set a new example in world affairs: the achievement of an industrial revolution without violence or coercion.

I have expressed my views frankly. This is the best way I can think of to pay homage to a great man who has written a great book with the highest intellectual integrity and with intense sympathy and anguish for the fate of the one-fourth of the world's people who live in South Asia.

Shorter Reviews

by Philip Morrison

POLDERLANDS, by Paul Wagret. Methuen & Co Ltd ($10). ARID LANDS: A GEOGRAPHICAL APPRAISAL, edited by E. S. Hills. Methuen & Co Ltd ($15). By hard work agricultural man can reclaim a piece of land "from sea or inland water, and constantly defend it thereafter." Such land is called a polder, from the tongue of the Dutch people, more than half of whose patrimony is dike-guarded land won over the millenniums. Polders are both ancient and worldwide. The delta below Hanoi is much polderized—dikes, sluice gates, pumping and all. It was the Sumerians who first made polders in the lower reaches of their two famed rivers, where Ur once rose on an island in the marshes. Yet a sixth of the land of our world has too little water for crops, and an equal area is semiarid, like the coast of southern California. A really arid climate—say the climate of the Norte Grande, the big northern desert of Chile—goes many years without any rainfall at all. A quarter-inch of rain in August, 1959, did considerable damage to houses in the town of Arica; some even collapsed.

These two books are recent treatments of the two extremes in the abundance of water, the most important of variable mineral resources. The wetter book is a rather personal account by a French geographer—lively, not very technical and filled with anecdote from history. It is sometimes a bit less logical than one might wish: nowhere is there a crisp sequence of maps of Holland over the centuries, although the maps are scattered here and there. The desert book is not dry, but it is a more technical and detailed treatment by a set of international experts, 17 of them, the whole sponsored by UNESCO as an entry into the field for students. (That it lacks an index is hard to believe but sadly true.)

Today the polders of Friesland are beautiful, the golden grain waving, in that clear light so mastered by the Dutch landscape painters, across the flat land. The neater portions are geometrically partitioned by the network of drainage ditches and roads, somewhat irregularly divided in the less planned work of older times. They began as ugly silt flats built up by natural sedimentation. Once they had risen high enough to flood only at extreme high tide, man entered. They were diked and defended by the Frisians with "five arms: sword and buckler... spade, fork and spear." In the golden age of the Dutch the great dike-masters rose and formed the simple and patient but insistent and powerful technology that they spread to all Europe, from Malvern on the Irish Sea to Tilsit on the Baltic. "To work surely means to work slowly," wrote Andries Vierlingh, *dijkmeester* to William the Silent. The natural marsh that precedes the dike-building is already partly clear of salt; once diked from the tides, a year or two of washing by the rain often suffices to see the salt-loving vegetation give way to daisies and thistles. If the soil is good (silt alone repays reclamation, not sand, and much effort has been wasted by overlooking this rule), the farmer can move in. But the successors to the dike-masters, men like Jan Leeghwater, were more active and less subtle. He was not dubbed "Jan Wind" idly. Where older windmills ground grain, his mills pumped out the water and made inland lakes and marshes into new Dutch soil. Mills were built by the thousands, and once again the Dutch spread their Chinese prime movers over two continents. Hilltop mills still ground grain, but the new mills were set low on the canal bank.

The prototype of modern polder-building is the Zuider Zee, which is still far from complete. Here pumps powered by diesels are used, not on mere inland lakes but on arms of the sea itself. In 1932 the main dike was closed, cutting the North Sea off from the South Sea. The impounding of the fresh waters of the Ijssel River is an essential part of the project, and the salt is slowly giving way. Scale and rate mark the era of the machine; in this century the Dutch lands will gain an area equal to half the total won since the 13th century. The gain is not unchallenged: the sea also reclaims. Land slowly subsides, and the sea level seems to be rising; high tides and severe low-pressure storms can swamp the defenses.

The desert too has its human artifices. You can read of the sip wells of the Bushmen, who dig to arm's reach into the soil at the roots of the right plant, and sucking for hours on a reed tube can draw water into a bunch of grass matted around the lower end of it. There is the air well, used in ancient times and being studied today. A pile of large, smooth stones gathers water by condensation in its cool interior as the air temperature rises outside. A pyramid of broken stones on a 10-foot concrete base can collect a couple of quarts of pure water each summer day in the dry south of France. In Australia they seed clouds for rain. The desert counterpart of the Dutch dikes is the marvelous *qanat,* the artificial spring made by digging a gently sloping tunnel from the ground-water level deep below the broken gravelly stuff at the edge of the mountains to the valley far below. In Teheran, "where a qanat passes beneath a residential area, some houses have a summer living room alongside the flowing stream, several tens of feet underground." This technique is known from the Atlantic shores of Morocco to the hinterland of Peking, and it works today in the Chilean desert to which the Spanish brought it.

The fauna and flora of the salt marsh and of the arid lands are both described, the arid examples much more fully. Man still has a great deal to learn about the management of the desert. Both the polder and the desert lands reclaimed by irrigation seem to share a single limiting effect: the gradual salination of the soil, by evaporation, sea-water leakage and the invasion of brackish ground water. In the Netherlands the level of such water is rising, as it is in the long-irrigated valley of the Indus, and perhaps in the Nile delta too. Only a policy of drainage carefully matched to irrigation can alleviate this terrible threat in the desert, and great fresh-water supplies such as the Ijsselmeer are essential for the polders bordering the salt sea.

The pictures in both books are excellent. Naming three or four will carry the impression: a few tugs and dredges nuzzling the long dike in triumph at the point where they had first closed off the Zuider Zee; an aerial view of the line of manholes along a desert *qanat;* the camp of oil-seekers, their long gasoline and water trucks flanked by the tents of their Saudi Arabian escort in the desolate dunes of the Empty Quarter; the orchards of the oasis town of Palmyra safe inside their mud windbreaks. These two books sum up the work and the hope and the errors of millenniums; they belong to the geography of challenge.

THE ZOOLOGY OF TROPICAL AFRICA, by J. L. Cloudsley-Thompson. W. W. Norton & Company, Inc. ($12.50). Professor Cloudsley-Thompson, a zoologist now in Khartoum, has written numerous books for the general scientific reader, on a variety of topics drawn from his own experience in the ecology of the desert and the rain forest and from the biological literature. This one perhaps appeals to the widest range of interests. Its subject is the animal life of all Africa, except for the northern coasts and the southern tip, and it does not overlook the interaction of other species with man. The book is meant less for a single reading than for browsing. It is a source of connected exposition on many subjects, each in a spacious but explicit context.

The first chapters amount to a simple survey of the geology and geography of the continent. Then we find a chapter each on life in the rain forest, the savanna, the desert, the mountains, the fresh waters and finally the coastal swamps and the reefs. Migrations and rhythms are treated, and special chapters on the adaptations of animals to dry and to humid heat follow. The last chapter considers man in Africa as an ecological factor. There are black-and-white photographs of the coconut palms of Zanzibar and the arid Nubian Desert, with wallowing hippopotami and grazing elephants in their place. Many drawings by the author present animals clearly, although with distressing regularity they lack any statement of scale.

The rain forest comes clear: dim and usually still except for the buzz of insects and the occasional echoless calls of birds. At dawn and dusk, however, "the forest resounds with innumerable strange cries." Vision is limited; even smell is little carried in the windless groves. Most of the color and life are far overhead in the canopy. At ground level there are few flowers or animals, except the ubiquitous ants and termites and "long, fine, dancing legs on the tree stumps"—the Tipulid flies in constant trembling so that their bodies are "invisible in the gloom." The swarm of animal and plant species is real, but most of the biomass is hidden in the humus and below it: the mites and bugs and worms of the damp cool soil. The savanna is always sunny and open, varying from dense but sun-dappled forest edge to an almost treeless subdesert. This is the kingdom of grasses, and with it come the mammals, feeding on the open grassy ground and also with great efficiency on the higher levels: the thornbush, the acacia and the shoots and leaves of even bigger trees. The biomass of hoofed animals in the forest-edge savanna, mostly elephant and hippopotamus, weighs in at 300 times more per acre than the large animals in the West African rain forest, mainly tiny antelopes, chimpanzees and monkeys. The rich invertebrate life in the soil can help to redress this imbalance but cannot fully overturn it.

The savanna breeds the locust plague. Three species of these creatures suddenly strike at the livelihood of man, often after many years of total absence. A swarm can weigh up to 50,000 flying tons and eat its own weight each day, defoliating entire areas. There have been four major plagues since 1910. Nowadays the migratory locust and the red locust, whose breeding grounds seem to be in small, well-defined areas in the Niger and the Rift valleys, are under at least precarious control. These areas are patrolled, and swarms are attacked before they can escape; no new plagues have erupted since the regional control organizations have been at work. The desert locust has a less clear breeding pattern, but it too is under a close and gradually more effective watch.

The author holds that the marvelous herds of the East African savanna are human artifacts, responses to the long burning of the plains by man. It is not man, however, but the baboon, his mainly terrestrial cousin, who seems the traditional ruling primate there. Man hunts over a much wider range than baboons gather from; not until very recently did man begin to outnumber the baboon! In Sierra Leone the forest chimpanzees have been drawn to feed in farms and gardens by the clearing of the high bush. They live longer now, but they have much tooth decay.

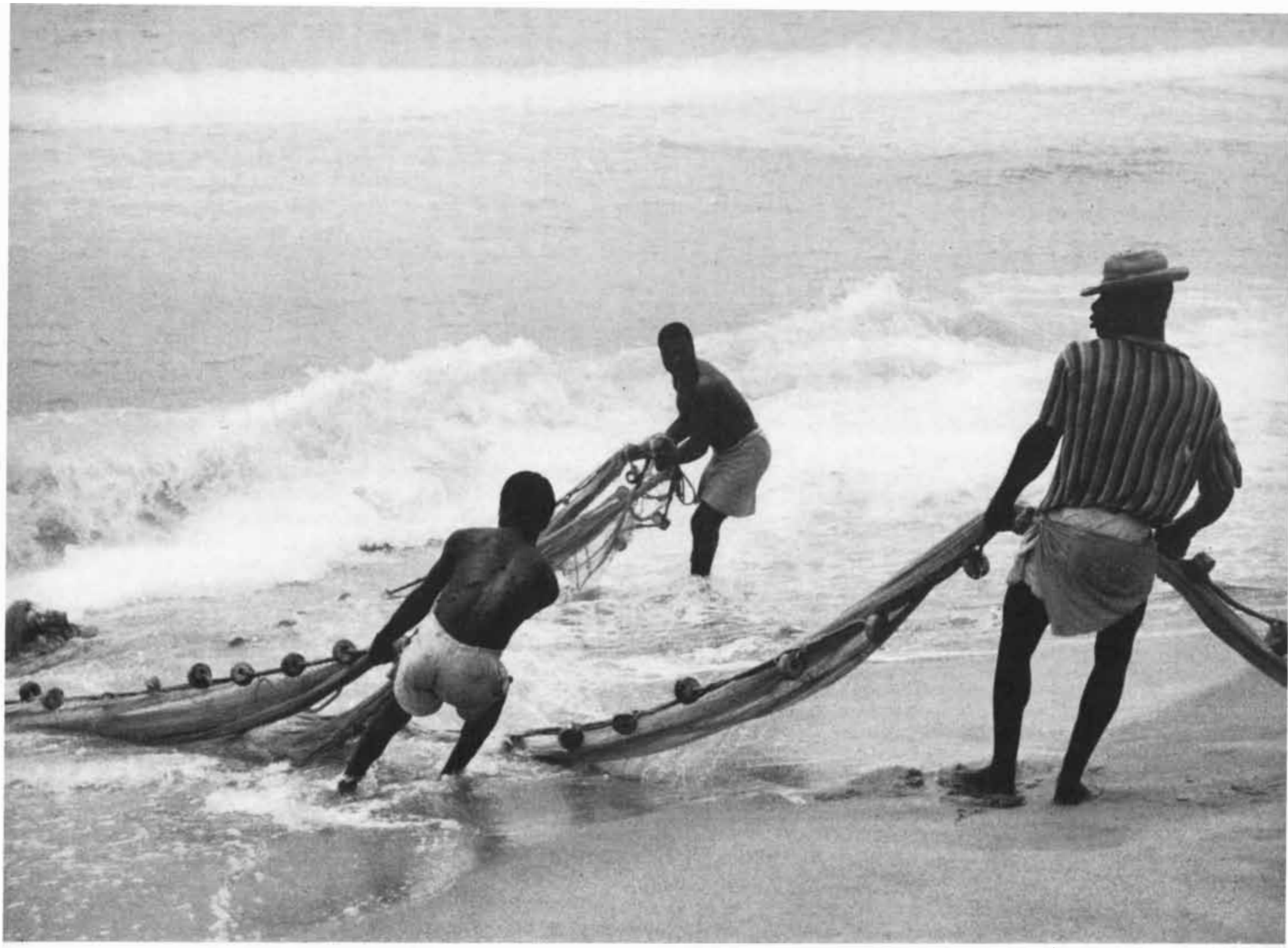
The references are excellent but are mainly in English, a limitation enforced by the libraries of Khartoum. Much South African literature is cited that is not as familiar elsewhere as it ought to be. The book ends with an engaging plea for many more biologists to enter this intellectually exciting domain; the book will help the recruiting effort.

Bird Navigation, by G. V. T. Matthews. Cambridge University Press ($2.45). In its second edition this "slim volume" remains the careful, reasoned but exciting book the famous first one was 15 years ago. Most of the references come from the years between, but the matter is not yet closed, although there are strong hints of success. The book is no less useful as a model of experimental design than it is as a study of the intriguing topic it addresses.

There is no doubt that birds migrate by both night and day. The famous arctic tern summers in the deep Canadian arctic, and it migrates by way of the west coast of Africa to the Antarctic pack ice. Year after year such migrants breed in the same nest site. Certain albatrosses returned thousands of miles to their tiny Midway Island home from all directions across the sea, with 80 percent returns and speeds of as much as 300 miles per day. Acoustic and radar data have demonstrated that navigation is not purely seasonal, that it is related to clear skies and favoring winds, that it works well when landmarks are clouded over but less well when the sky is hidden. "The basic . . . information . . . is most likely derived from astronomical clues." Both the motions of confined birds—scrambling with inky feet out of a paper cone toward the wall of a circular cage, for example—and the free flight of birds marked with a radio beacon and followed by light aircraft bearing directional receivers have been studied, and many another ingenious method has been used. Neither ESP, strange radiations, radio waves, inertial navigation or the sensing of magnetic fields or of the Coriolis force remain plausible after severe field tests plus theoretical considerations of aptness and sensitivity. Even the celestial navigation effects first observed in the planetarium (which are not yet excluded) have shown equivocal results, in spite of a first flush of enthusiasm. The pattern of the stars does enable birds to orient themselves, but no more than that is clear.

What remains is just what was conjectured in the first edition of this book by the author himself, now far better sketched in. Birds navigate by day (not merely finding their correct compass direction but learning what amounts to two coordinates) mainly by clues from the moving sun. This implies knowledge both of angle and of time: if the sun reaches its full height early, fly west for home; if its full height is low, fly south for home, and so on. Such rules, which have been generalized to include a scheme of extrapolation to the noon point by observation at any hour of the rate of the sun's change in altitude, would explain most of the data. One must allow other systems as well, most certainly landmark recognition once the bird is within some 50 miles of the home base. The eight-foot error in nest site measured year by year for shearwaters flying from Japan to New Zealand does not refer to their long-range navigational skills any more than an airline pilot drives to his home in Queens by the same means he used to direct his landfall over Boston from London.

A bird needs a good eye for angles; an experienced homing pigeon can discriminate angles and judge the vertical to somewhere between half a degree and one degree—good enough for navigation



TOGO FISHERMEN—United Nations

up to a few tens of miles. The need for good timekeeping is met by many species of animals; not much direct evidence yet comes from birds. A biological clock accurate to within a couple of minutes a day would suffice for the observed performance.

It would have been pleasing to read Matthews' opinion on the ingenious solar-altitude location scheme developed by the GHOST project for its round-the-world weather balloons, a scheme that sounds very much like a bird's navigation system. There is in this book, however, almost everything else in the field, honestly and insightfully set out.

DISTRIBUTION-FREE STATISTICAL TESTS, by James V. Bradley. Prentice-Hall, Inc. ($12.95). This is a book of an unusual kind on mathematical statistics. It does not draw on any resources of training beyond simple algebra, in particular making no important use of calculus. It is nonetheless a book that derives just about all the results it states—the "antithesis of a cookbook." This claim is possible because of the subject matter. The tests for statistical hypotheses described here, aimed at practical use with small samples, neither make the assumptions nor entail the elaborate mathematics of classical statistics, founded so trustingly on the Gaussian, or normal, distribution. That law leads naturally to a pretty deep use of analysis—the calculus—and too often therefore to the cookbook approach for nonmathematical users. Bradley has two aims: to free his readers from the burden of the often wholly unreal assumptions of normality (he quotes approvingly, "There never was, and never will be, a normal distribution") and to give them a chance to understand the tables their results so often depend on. He succeeds well, but be warned: his book is by no means easy or nonmathematical; it is tight, carefully argued, has few graphs and makes heavy demands on the logical resources of the reader, even though not at all on their study of *dx*'s and *dy*'s.

The point of the new statistics, now about a generation old in self-conscious existence, is to use the distribution of the observed characteristic of the sample and not the distribution of the population imagined behind it. A third distribution is involved, the distribution of the test statistic actually used. The rank of the magnitude of a single observation, the frequency of that magnitude or its position in the sequence of observations—all are properties of one or a few samples. The sample belongs to a finite and typically discrete distribution, manageable by algebraic methods. The text treats dozens of tests, grouping them by logical families, and includes a 66-page appendix of necessary tables for the use of the tests.

The first use of these "modern" methods was actually made by John Arbuthnot in 1710. He saw that in every year from 1629 to 1710 more males than females were born in London. If male and female births were equally likely, the binomial distribution implies that the probability that the same result would occur 82 or more years in a row is less than one in 10^{25}! He drew the correct conclusion: the null hypothesis is wrong.

IL MUSEO DI STORIA DELLA SCIENZA A FIRENZE, A CURA DI MARIA LUISA RIGHINI BONELLI. Cassa di Risparmio di Firenze. Electa Editrice (free). Of all the treasures of Florence readers of SCIENTIFIC AMERICAN will not count as least the lens with which Galileo first saw the moons of Jupiter—later broken accidentally by Galileo himself. It is there, with many other marvels, in the collections of the Museum of the History of Science just behind the Uffizi gallery. That museum has a history of some 40 years of bringing together the rich materials that exhibit the growth of science in its first modern homeland. Threatened physically twice, once by the explosives with which the Germans wrecked the bridges across the Arno as they abandoned Florence and again in 1966 by the floodwaters that inundated its ground floor, the collection is better displayed and ordered now than ever, thanks to the support of friends at home and abroad and above all to the devotion and scholarship of its present curator, Maria Luisa Bonelli. This is a valuable annotated catalogue of its holdings, beautifully illustrated with nearly 150 photographs, and with an introductory history and assessment by its curator. The first edition is generously distributed by the Cassa di Risparmio di Firenze, the well-known bank of Florence; no doubt the publishing firm Electa Editrice will place the work on the market in due time. Authenticated Galilean relics include his lodestone, astrolabe, telescopes, geometrical compasses and—very Italian—right middle finger! (No picture of the finger is included.)

THE POCKET ENCYCLOPAEDIA OF PLANT GALLS IN COLOUR, by Arnold Darlington, with illustrations by M. J. D. Hirons. Philosophical Library ($7.50). Here and there from the twig of an oak grows a strange leaf-brown apple-like fruit—not an acorn—or from an oak-leaf vein springs a cherry-sized sphere of leafy stuff. Those are plant galls, familiar and enigmatic to every walker in the woods. They are a kind of orderly tumor, a growth response of the host plant, specific and structured yet not functioning for the plant itself. The host has been galled, the oaks most often by a specific set of wasps. The wasp may insert a single fertile egg into the leaf vein, and the larva grows and pupates inside the sphere of hard leaf material, neatly centered within it by a fluffy bed of fiber, all somehow made by the oak in response to this affront. This handsomely illustrated little pocket guide displays a couple of hundred such galls, in plants from the turnip and the bramble to the oak. It is a guide to identification, a clear outline of the intricate life cycles and circumstances of this highly evolved form of parasitism and a set of suggestions for real research on the living materials, from rearing the little invaders to the study of the entire complex of secondary visitors that sometimes live in the gall. The book was made possible by student aid in collecting the materials; it is credibly claimed that no such guide has been published for more than 50 years. The book is, as one might have guessed, British; how far it will be of use to American students and amateurs they must decide. Perhaps it will at least gall us to emulation.

THE TRUMPET SHALL SOUND: A STUDY OF "CARGO" CULTS IN MELANESIA, by Peter Worsley. Schocken Books ($2.45). This touching account of the century of "millenarian" movements among the New Guinea people was first published a decade ago, and it is now presented in a paperbacked second edition. It is a story of men whose disinheritment from the modern world expresses itself in wildly expanding cults, led by seers of omen and wit who promise a cargo of enriching and liberating goods, delivered in the latest version by space rocket. The new edition appears with a very good bibliography, an excellent set of maps and a long new analytic introduction explicitly taking up the critical reviews of the first edition and amounting to a thoughtful essay on the recent trends of sociological theory. The essay is aimed at students and specialists rather than at the general reader, but the events and the implications of the book retain their appeal. A man named Yali was able, a footnote says, to explain zoos, pets, evolutionary evidence and other European phenomena within his own totemistic theoretical structure. Perhaps he was "a Melanesian Levi-Strauss."

The author is at his best in such gentle iconoclasm, as when he observes that the informants relied on for a study of the beliefs of a culture are often the counterparts of professors of theology.

CANNABIS: REPORT BY THE ADVISORY COMMITTEE ON DRUG DEPENDENCE. Her Majesty's Stationery Office ($1.50 in the U.S.). This carefully prepared brochure is the result of a study made by two dozen men and women, experts and laymen, since the spring of 1967 and published late last year with much attention from the British press. The use of drugs from cannabis, the plant source of marijuana, is rising swiftly in Britain, particularly among the native-born. The drug most frequently taken is not marijuana, which is from the leafy portions of the plant, but the more powerful substance known as hashish, or charras, which is from the resin scraped from the flowering parts. According to the brochure, "the verdict is clear, if tentative: all in all, it is impossible to make out a firm case against cannabis as being potentially a greater personal or social danger than alcohol.... Alcohol, with all its problems, is the 'devil we know'; cannabis, in Western society, is still an unknown quantity." In India and Egypt and in some other North African states the devil is better known and is regarded with some fear when subject to heavy abuse. The habit is growing fast in Nigeria among "long-distance lorry drivers ...enabling them to take daredevil risks." The wrecks on the road there and the big diesels barreling down the center of the narrow pavement are anecdotal evidence. The committee concludes that, whatever defenses may be offered for the habit in general, grass and gas don't mix. This report, particularly in that its call for controlled experiment is beginning to be met, is useful reading for many people. Its main tendency is a cautious effort to make sure that neither unduly severe punishment nor any other control measures act to shift cannabis from the economic status it now holds, with the supply dominated by amateur smugglers, into the terrifying regime occupied by the harder drugs, whose supply is controlled by corporate crime, cynically holding the shield of a fiercely punitive law.

THE DICTIONARY OF EXCEPTIONS TO RULES OF RUSSIAN GRAMMAR, by Sigrid Schacht. American Elsevier Publishing Company, Inc. ($9.50). Seven thousand three hundred entries, all frequently encountered exceptions to the rules of inflection!

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